The effects of (aminooxy)acetic acid on the growth and development of *Petunia* x *hybrida* Vilm. 'White Flash'

by

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ABSTRACT

(Aminooxy)acetic acid (AOA) was applied to Petunia x hybrida Vilm. 'White Flash' seedlings at three different stages of development in order to determine its feasibility as a commercial growth regulator. Stage 1 seedlings were too small for treatment because fewer than 4 plants per cell pack survived many of the treatments, and, therefore, Stage 2 and Stage 3 were analyzed.

Results showed that the height of 'White Flash' petunias treated with AOA was shorter than that of untreated plants from eight weeks after sowing until the plants were in full flower. The greatest difference in height occurred at 12 weeks, which was the onset of flowering.

Analysis at 12 weeks showed a stage by concentration interaction for plant height and diameter. The height of Stage 2 plants was less than that of Stage 3 plants, and the greatest difference was observed at concentrations of 8, 12, and 16 mM AOA. Plant height decreased as concentration increased. The difference in height was important commercially. The difference in diameter, though significant, was not great enough for commercial importance.

Application was also significant at week 12 for height and diameter. As the number of applications increased, plant height decreased linearly, and plant diameter increased linearly. The differences, however, were not important commercially.

Analysis at the time of harvest (full flower) showed a main effect of stage, application, and concentration for plant height. Plant height of

Stage 2 was greater than that of Stage 3, and the height of both stages decreased as the number of applications and AOA concentration increased. The differences were not commercially important.

A stage by concentration interaction was observed for diameter, days to flower, fresh weight, and dry weight. The means of diameter, days to flower, fresh weight, and dry weight of Stage 2 plants were greater than those of Stage 3 plants, and they increased as concentration increased. The differences were not commercially important.

At harvest, as the number of applications increased, plant height decreased, and plant diameter, days to flower, and dry weight increased linearly, though the differences were not commercially important.

The mean of Stage 2 plants at the time of harvest exceeded that of Stage 3 for all variables measured. This could be related to the fact that Stage 2 plants flowered later than Stage 3 plants and thus had a longer growing period before harvest.

To determine the relationship of untreated plants to plants treated with AOA, an interval of a predicted mean and a mean for a lower concentration of AOA were estimated based on the linear effect of AOA concentration. The true mean for most variables fell within the predicted interval and, therefore, was related linearly to AOA.

As the number of applications and concentration of AOA increased, the amount of visual phytotoxicity also increased. Phytotoxicity symptoms included chlorosis, turgor loss, restriction of root development, chemical spotting, and desiccation. Seedlings showing desiccation usually did not survive. Because of the potential for phytotoxicity, inhibition

of root development, and lack of growth control great enough for commercial significance, AOA does not seem to be feasible for use as a commercial chemical growth retardant at this time. Investigation is needed of the effects of AOA on other species and cultivars, and of interactions between AOA and the environment.

INTRODUCTION

The bedding plant industry has been increasing at an annual growth rate of approximately 10 percent for the past 20 years. The total value of the bedding plant industry in the United States was less than $10 million in the days prior to World War II. By the early eighties, the value had reached nearly $300 million. Future expansion of the bedding plant industry will depend on new varieties of plants, innovative marketing programs, and new technology accomplished by the technical advancements made in single-cell-plant production, or plug production. Plug production is a highly technical advancement in growing bedding plants. Seedlings are grown at a high density in individual compartments of specialized trays. Procedures that are typically labor intensive, such as seeding, watering, and transplanting, are mechanized. Seedlings are germinated and grown in an optimal environment that provides uniform temperature, moisture, nutrition, and light.

Competition within the industry has forced production to become more efficient. Commercial bedding plant growers strive to produce quality plant material in as short a time as possible and to maximize the number of plants grown in a given area. The traditional method of maintaining the quality of plants grown in cell packs has been through environmental and chemical regulation. Growth retardants are applied mainly to control the height of young seedlings and older plants. Chemical growth retardants are especially important in controlling the height of plug seedlings because they are grown at high densities and may remain in the

plug trays for up to eight weeks before transplanting.

B-Nine is the most common growth retardant used on bedding plants, but it is limited in its effectiveness by temperature, crop species, and cultivar. The future availability of B-Nine is questionable and may force growers to choose other chemicals. A-Rest is used on certain bedding plants, but it is costly. Cycocel and Florel also may be applied to bedding plants, but their use is limited to only a few species. A new chemical growth retardant, therefore, is needed that may be used on numerous crops, is not affected by the environment, and is inexpensive.

The chemical, (aminooxy)acetic acid, AOA, has been shown to increase the vase life of cut carnations (12). Interest in the feasibility of AOA as a commercial plant growth retardant was raised from research that showed that the antiethylene properties of AOA significantly increased the vase life of cut carnations, and increased the vase life quality of cut roses (12). At Iowa State University, trial applications of AOA to transplanted petunias controlled the growth of the plants. This research examined the effects of different AOA applications and concentrations on three different stages of development of one cultivar of transplanted petunias in order to further assess the potential of AOA as a commercial growth regulator.

REVIEW OF LITERATURE

Controlling plant height is a major concern of commercial bedding plant growers. Short, compact bedding plants with axillary shoots are preferred (36). Low light and high humidity, plus high-density growing conditions encourages stem elongation rather than horizontal branch development (7). Temperature also affects growth. In northern growing regions, the cooler temperatures in February through April control plant height and retard plant growth, but in southern regions, and in northern regions during late April and May, the warm temperatures promote rapid, succulent plant growth.

Chemical plant growth retardants can be used to control plant growth under these conditions. They have been developed to supplement environmental control of plant height, especially when light, water, and temperature cannot be controlled. Cathey defined chemical growth retardants as "...new types of organic chemicals which retard stem elongation, increase the green color of leaves, and indirectly affect flowering without causing malformation of the plant" (5). Chemicals should not cause adverse effects on growth, such as stunting or complete stoppage of growth, delay in flowering, or malformity of leaves. The rate of plant development and vigor should not be affected (6). The effectiveness of chemical growth regulators is dependent on environmental factors such as temperature, light, moisture, and time of year (28). Other factors that influence the activity of chemicals include chemical concentration, solution pH, method of application, wettability of the

plant foliage, plant age, and stage of plant development (28).

B-Nine (SADH) is a chemical plant growth retardant effective on many bedding annual species (9, 33) and is the retardant most commonly used by commercial growers on petunias (32, 33). Foliar applications of B-Nine to petunia and other species effectively produce plants having shorter internodes and a more compact growth habit (8, 9, 31, 32), thicker stems (32), darker green leaves (9, 32), and thicker, smaller leaves (9). B-Nine improves tolerance of petunia and other bedding annual species to moisture stress (8, 27) and allows easier handling and shipping of the plant material (33).

The response of petunias and other species to B-Nine is dependent on temperature (8, 36), photoperiod (8), relative humidity (9), frequency of application (8), concentration (8), cultivar (32, 33), and stage of development (8, 9, 27). Temperatures above 10.5°C have been reported to reduce the growth retarding effects of B-Nine (36). Petunia 'Comanche Improved' seedlings growing under 16 to 18°C night temperature were treated with one application of 5000 mg per liter B-Nine at 42 days when the stem was beginning to elongate rapidly (8). Height control lasted four to six weeks and the plants flowered sooner. Petunia cultivars 'Ensign' and 'Recoverer White' were treated at the first true leaf stage, 15 days after transplant, with one application of 5000 mg per liter B-Nine. B-Nine retarded the height of 'Recoverer White' but did not control the height of 'Ensign', indicating a cultivar difference (32).

B-Nine is reported not to affect the flowering of petunias (31); however, 5000 mg per liter B-Nine delayed flowering when applied to

petunia 'Comanche Improved' grown under eight-hour days in comparison to treated and untreated plants grown under the natural days of February 28 through June 1 (8).

Optimum height control of petunia transplants was achieved when B-Nine was applied to well-established (31), rapidly elongating seedlings six to eight weeks old (8), before flowers were initiated (8, 9). Tayama and Brooks reported that petunias should be sprayed with 5000 mg per liter B-Nine when four to five cm in diameter and every four weeks thereafter to insure that plants remain short even during long-day and warm temperature conditions (29). Supraoptimal concentrations of B-Nine are reported to have little detrimental effect on responsive species (8, 9).

B-Nine may control plant growth for only a short duration of time, depending on the prevailing environmental conditions (32). It can lose effectiveness rapidly as temperature increases, requiring frequent repeated applications (32). For maximum uptake, B-Nine (SADH) must be applied to dry foliage of fully turgid plants and allowed to remain dry at least 24 hours (9).

Ethephon was applied to petunias to control plant height and diameter. Different cultivars varied in response to the ethephon treatments depending on the time of application and concentration, and flowering was delayed by ethephon (2, 3, 32, 33). Foliar chlorosis appeared within three days after treatment of seedlings having three pairs of leaves, and it disappeared after 14 days (32). New growth was not chlorotic.

Cathey reported chlormequat (cycocel) to be ineffective on petunias (9). Low concentrations of a slow release formulation of chlormequat stimulated growth and higher concentrations retarded the growth of tomatoes, petunias, snapdragons, and marigolds without causing chlorosis typical of drench and foliar sprays (29). Foliage was greener than that of untreated plants. Tomatoes treated with slow-release cycocel flowered earlier, had more blossoms, and had an increased stem diameter. Cycocel drench reduced height, and hastened flowering of seed geraniums while the foliar spray did not (2).

Certain herbicides can be applied to control plant growth in a way that is beneficial to the plant, such as enhancing yield or aiding in harvest, according to Nickell (27). The potential for use of herbicides as growth regulators is based on the response of plants to sublethal rates of the herbicide. Cultivar differences, optimum environmental conditions, geographical restrictions, seasonal effects, and residual problems must be determined, however, (11).

Herbicides inhibit growth by affecting two aspects of plant growth: cell enlargement and cell division (16). Increased cell wall turgidity, decreased cell turgor pressure, or a decrease in the production or activity of cell wall loosening compounds can inhibit cell enlargement (16). Cell division can be disrupted by compounds that affect plant metabolism, mitotic activities, or protein synthesis (16). The effectiveness of chemical growth regulators usually is measured by growth parameters; however, growth inhibition may be a secondary result of herbicide interference with cell division and/or cell enlargement (16).

Cell permeability, extensibility, osmotic concentration, and turgor pressure also can be affected by the herbicide (16). Similar to growth retardants, herbicide effectiveness is dependent on plant cultivar, stage of development, plant age, temperature, light, humidity, plant nutrition, and amount of chemical absorbed (11, 17, 21, 22, 27).

The auxin-type herbicide 2,4-dichlorophenoxyacetic acid (2,4-D) disrupts cell enlargement by loosening cell walls (16). The effectiveness of 2,4-D is dependent on the amount of chemical absorbed by the plant, the amount of chemical translocated within the plant, and the responsiveness of the plant to the chemical (25). Absence of light (30), decreased temperature (30), or a pH of 9 (34) independently can reduce the absorption of 2,4-D. In contrast, the absence of light (30), high temperature (30), turgid foliage (30), wetting agents (1, 30), or low pH (34) increase the absorption of 2,4-D by plants.

Conditions favorable for carbohydrate or photosynthate synthesis and translocation also are favorable for 2,4-D translocation (24, 30). Cell elongation often is accelerated by 2,4-D, which is translocated from the point of application to roots (1), and terminal buds where it inhibits growth (25). Plant response to 2,4-D is dependent on cultivar, part treated, stage of development, and amount of chemical absorbed (25).

Glyphosate is a nonselective, water-soluble, post-emergent herbicide (17). Glyphosate acts on actively growing meristematic tissues (4, 21) to inhibit root and rhizome growth and survival (4, 22, 26), and cause abnormal morphology and wilting of leaves (4). Phytotoxicity symptoms usually appear in two to ten days after glyphosate is applied to the

plant foliage (4, 21, 26). Chlorosis is the first visible symptom and usually is followed by necrosis (4, 26).

The activity and toxicity of glyphosate is dependent on temperature (4, 19, 21, 23, 35), humidity (10, 13, 19, 21, 23, 35), light intensity (4, 26), and maturity of the plant part treated (21, 35). As the temperature increases, the amount of ^{14}C-glyphosate absorbed and translocated increases in Johnsongrass (23) and bermudagrass (19). Higher temperatures reduce glyphosate activity and lower temperatures increased toxicity on quackgrass (4), soybeans (23), and cotton (35). High humidity increases the amount of glyphosate absorbed and translocated in Canada thistle (13), leafy spurge (13), cotton (35), quackgrass (4), purple nutsedge (10), soybean (23), Johnsongrass (23), and bermudagrass (19). Chlorosis occurs more rapidly in unshaded plants, but toxicity, though delayed in expression, is more extensive in shaded plants (4, 26). Mature stems and leaves are more sensitive to glyphosate than immature stems and leaves of cotton (35) and soybeans (23).

Similar to glyphosate (4, 17), AOA, an analog of 2,4-D, strongly inhibits root elongation and secondary root production (18). AOA at 50 μM also inhibits fresh weight gain of soybean axes under both light and dark conditions (18). AOA inhibits ethylene production in many higher plants, and this may result from its inhibition of several pyridoxal-phosphate dependent enzymes (15, 18).

In 1964, AOA was patented for use as a herbicide in controlling unwanted seed germination and many broadleaf and grass species (20). A spray application of 1.20 g per liter (18.20 mM) to 120.00 g per liter

(1820.40 mM) AOA was reported to control plant growth. The exact concentration of AOA depended of the type and stage of development of the plants and on temperature (20). Modifications for different conditions were not discussed. Complete kill was achieved in 10 days for many broadleaf and grass species five cm to 13 cm tall treated with a spray solution of 0.5 percent by weight AOA (5 g per liter=75.89 mM) applied at a rate of 94.63 liters per ha to 567.80 liters per ha (1.2 ml to 7.25 ml per 0.15 m sq=approximately 0.0168 ml to 0.1007 ml per plant in a 1206 tray). Tomato seedlings were killed completely by a 0.4 percent by weight (4 g per liter=60.68 mM) AOA solution in a similar experiment (20). Any seedlings that survived the experiments were stunted and chlorotic, and the phytotoxicity symptoms were not discussed (20).

DEVELOPMENT OF THE PROBLEM

Technical advancement, specialization, and competition have forced the bedding plant industry to modify and improve its growing and marketing programs. Commercial growers strive to produce more quality plant material in a shorter period of time. To accomplish this, bedding plant crops must be grown at warmer temperatures and in more crowded conditions. Single-cell-plant production, plug production, has been introduced to mechanize the production of seedlings in high density, specialized trays. These single-cell-plants are germinated and grown under optimal and uniform environmental conditions of temperature, moisture, nutrition, and light.

Chemical growth retardants are applied to bedding plants by commercial growers to maintain the quality of plant growth. Control of plant height is a major concern of growers, in addition to increased branching, and flowering.

Chemicals currently used to control plant growth are limited in effectiveness because of prevailing environmental conditions, or crop cultivar. B-Nine is the most commonly used growth regulator for bedding plants; however, B-Nine loses effectiveness at temperatures above 10.5°C (29). Also, the future availability of B-Nine is questionable. A-Rest is costly, and Cycocel and Florel are effective on only a few species.

Experimentation using AOA as a plant growth retardant began after the discovery that AOA will extend the vase life of cut carnations (12). Preliminary applications of AOA to petunias at Iowa State University

resulted in a visual control of plant growth relative to the number of applications and concentration of AOA.

This research was designed to examine the commercial feasibility of the effect of different AOA applications and concentrations on three different stages of plant growth of Petunia x hybrida Vilm. 'White Flash'. The first experiment was begun November 2, 1983. Because of a severe fungus gnat larvae and nutrition problem, shoot proliferation, phytotoxicity, and low percent of plant survival, the data was not reported. The second experiment was begun November 9, 1984. Because of similar phytotoxicity and percentage of plant survival as with the first experiment, analysis of these data was postponed until after the analysis of the third experiment which began January 29, 1985. The delay in analysis was made to inspect the experimental procedures for any cultural error. The third experiment, which replicated the previous cultural techniques, produced a similar type of plant response, though less severe. The difference in the extent of phytotoxicity and plant survival between the three experiments is attributed to the prevailing seasonal conditions during the time the experiments were conducted. The results of the third experiment only are presented in this thesis.

MATERIALS AND METHODS

Seeds of Petunia x hybrida Vilm. 'White Flash' were sown January 29, 1985, and germinated in 406-cell plug trays that contained a medium of 35% Hypnum, 35% Sphagnum, and 30% fine, sand-finish perlite, plus 2.96 kg per cu meter $CaSO_4$ and 1.78 kg per cu meter 0-20-0. The trays were placed under mist to insure uniform germination. A soil temperature of 27 $\pm 2^{o}C$ was maintained by mats constructed of heating cables insulated with vulkene. After 3 days, when the radicals were just emerged, the seedlings were transferred to a controlled environment chamber equipped with cool white fluorescent lights. The average irradiance was 40 microeinsteins $s^{-1}m^{-2}$. The soil temperature was 26 $\pm 2^{o}C$. After 10 days, the seedlings were transferred to a greenhouse. The soil temperature in the greenhouse was maintained at 21 $\pm 2^{o}C$.

When the seedlings were 1 cm dia. (17 days from sowing) they were transplanted into 1206 cell packs containing a medium of 60% Sphagnum, 25% coarse perlite, and 15% #3 vermiculite. Additives per cu meter of medium included 0.59 kg iron sulfate, 2.96 kg calcium sulfate, 2.96 kg superphosphate (0-20-0), 0.89 kg magnesium sulfate, 4.74 kg calcium carbonate, and 1.78 kg Esmigran. Seedling growth was continued in a greenhouse that provided a soil temperature of 22 $\pm 2^{o}C$ day and 18 $\pm 2^{o}C$ night. The average langleys of light was measured to be 330 ± 100. The relative humidity was 44 ± 10 percent.

Seedlings were selected for uniformity according to leaf canopy diameter and divided into three groups. Chemical treatments were

initiated as each group obtained a certain stage of development: Stage I (1 to 2 cm dia., 24 days from sowing), Stage II (2 to 3 cm dia., 28 days from sowing), and Stage III (3 to 4 cm dia., 33 days from sowing). The cell packs were arranged on a bench at 10 cm spacing in three randomized complete blocks, one replication per block. The seedlings were foliar treated to runoff (approximately 0.30 ml per plant) using a hand-held atomizer. Treatments consisted of factorial combinations of 4, 8, 12, 16, 20, or 24 mM AOA in 1, 2, 3, or 4 applications. Tween 20 was added to make a final concentration of 0.01 percent. The AOA solutions were applied in seven-day intervals between 5 and 6 p.m. Standard Daylight Time. Plants were irrigated no sooner than 12 hours after treatment.

In preliminary experiments, the application of fertilizer during the period of chemical treatments caused a visual increase in phytotoxicity of the plants. Therefore, 75 mg per liter of a 15-16-17 commercially prepared fertilizer was applied once per week, beginning five weeks after sowing. Fertilizer was applied once per week beginning seven weeks after sowing with 125 mg per liter from a 15-16-17 commercial preparation. At 10 weeks, the fertilizer was increased to 250 mg per liter, plus 3.58 g per liter Sequestrene 330, with each irrigation. Soil samples were analyzed weekly to monitor nutritional levels.

Plant height and diameter were recorded weekly. When all six plants per cell pack reached full bloom, determined by a 2 cm diameter flower, each cell pack was harvested and the days to flower, height, diameter, and fresh weight were recorded. Each harvested petunia plant was placed in a paper bag, oven-dried at 21 $\pm 2^{\circ}$C, and the dry weight recorded.

Analysis of variance was performed on the randomized complete block design using SAS to determine any significant effects of stage, number of applications, AOA concentration, and interactions at 12 weeks from sowing, and at the time all six plants per cell pack were harvested. The Least Significant Difference (LSD) was obtained when the F-test was significant at the 5 percent level. An interval estimate of the predicted mean of untreated check plants was made to determine the relationship of untreated plants to plants treated with AOA.

RESULTS AND DISCUSSION

Plant growth over time

Results from this experiment showed that the height of plants treated with AOA was shorter when compared with untreated control plants from eight weeks after sowing until the plants were harvested in full flower (Figure 1). Figure 1 illustrates a typical response of plants treated with AOA. The difference in height between the treated plants and the controls was proportional to the size of the plants and was of interest scientifically and commercially.

Eight weeks after sowing, or two weeks after the third chemical application, the height of Stage 2 plants treated with 12 mM AOA in 3 applications was 2 mm less than the height of untreated control plants (Figure 1). By week 10, the height of AOA-treated plants was 4 mm less than untreated plants. The height of AOA-treated plants was 28 mm and 46 mm less than that of untreated plants at weeks 11 and 12, respectively. These differences at weeks 11 and 12 indicated that AOA may have potential for use as a commercial growth retardant. However, when the plants were harvested at full flower, the height of the untreated check plants was only 12 mm greater than that of the AOA-treated plants and not significantly different commercially. Petunias receiving other treatments exhibited a similar growth curve; however, the duration of the retardation of growth was increased as the number of applications or AOA concentration increased.

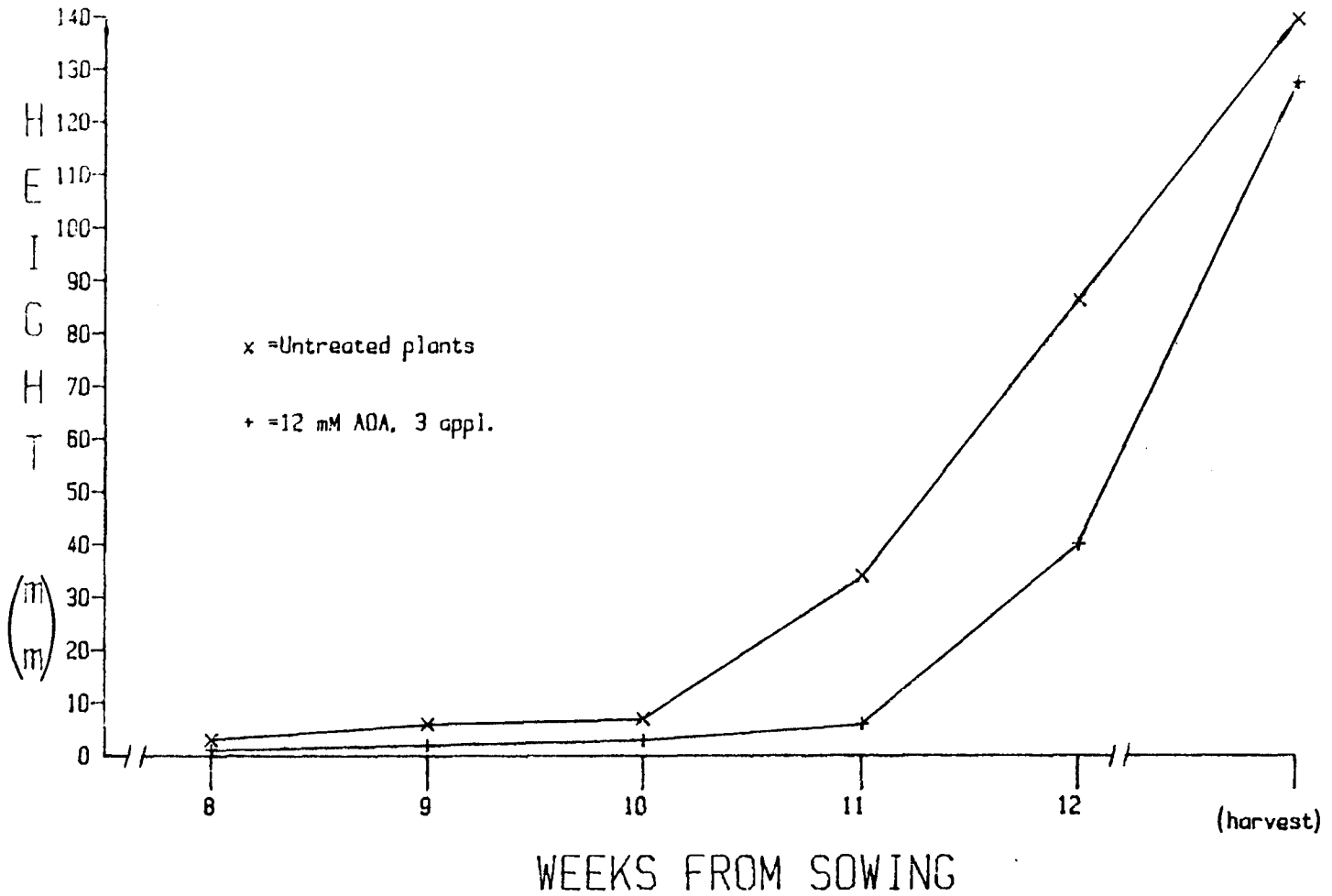

Figure 1. Height of Petunia x hybrida 'White Flash' treated at Stage 2 with three applications of 12 mM AOA. Height is plotted, beginning two weeks after the third application of AOA, to the time of harvest

The effect of AOA on the rate of survival of Stages 1, 2, and 3

The importance of stage of development was examined in this experiment by treating transplanted petunias at three different stages of development. The subsequent rate of survival of the different stages determined the manner in which the data were analyzed. Table 1 shows the mean number of plants out of six possible that survived each treatment for Stages 1, 2, and 3. Survival rates of less than four plants per cell pack were not considered feasible for commercial use. Because of the low rate of survival, Stage 1 was determined too immature for treatment with AOA. This possibly may have been caused by a lack of a well-established root system. Stage 1 was excluded from the analysis because of the large amount of missing data, which would bias the analysis. Stages 2 and 3 had more extensive root systems at the time of treatment, had a higher survival rate, and were included in the analysis.

Analysis at the onset of flowering

At week 12, eight weeks after the first chemical application, analysis of variance revealed a 2-factor, or first-order, interaction between stage and AOA concentration (Table 2). The interaction was significant for plant height and diameter. Figure 2 shows that the difference in height between Stage 2 and Stage 3 was greater at the concentrations of 8, 12, and 16 mM AOA than at 4, 20, and 24 mM AOA. When the stage by concentration interaction was subdivided, no significant linear or quadratic response was observed (Table 2); however, the response was visualized best as quadratic. The height of Stage 2 plants was less than that of Stage 3 plants for all concentrations, and

Table 1. The number of plants remaining out of six possible at the time of harvest of *Petunia hybrida* 'White Flash'

Stage	Number of applic.	Mean of Plants Remaining at Harvest[a] AOA concentration (mM) 4	8	12	16	20	24
1	1	6.00	6.00	5.33	3.67	5.33	-[b]
	2	6.00	6.00	5.00	3.00	2.00	-
	3	6.00	5.67	3.33	3.33	4.00	-
	4	6.00	6.00	4.67	1.33	2.33	-
2	1	6.00	5.67	6.00	6.00	5.33	5.67
	2	6.00	6.00	6.00	5.67	5.67	4.33
	3	5.67	6.00	6.00	5.00	5.67	3.67
	4	6.00	6.00	6.00	5.33	4.33	4.67
3	1	6.00	6.00	6.00	6.00	5.67	6.00
	2	6.00	6.00	6.00	6.00	5.83	5.00
	3	6.00	5.67	6.00	5.33	4.33	5.00
	4	6.00	6.00	6.00	5.67	3.67	4.00

[a]Mean of plants remaining out of six possible per cell pack, replicated three times.

[b]Treatments of the plants were not conducted because of results from previous experiments where complete kill was observed.

Table 2. The effect of stage of development, number of chemical applications, and AOA concentration on the height, and diameter at the onset of flowering at week 12 of Petunia hybrida 'White Flash' treated with AOA

Source	df	Mean Squares: Plant ht (mm)	Mean Squares: Plant diam (mm)
Replication	2	842.51**	414.60**
Stage[a]	1	9646.19**	8.27
Application[b]	3	423.06*	782.67**
Linear	(1)	1090.99**	2323.59**
Remainder	(2)	89.10	12.21
Concentration[c]	5	1310.59**	428.31**
Linear	(1)	5410.70**	1870.39**
Remainder	(4)	285.56	67.80
A*C	15	175.96	37.45
S*A	3	181.74**	92.71*
S*C	5	483.48**	102.87*
S*C Linear	(1)	27.25	0.28
S*C Quadr.	(1)	0.58	1.28**
Remainder	(3)	796.53**	170.94**
S*C*A	15	151.89	36.49
Error	94	130.85	41.78

[a]Stage (S).
[b]Application (A).
[c]Concentration (C).
**Significant at the 1 percent level.
* Significant at the 5 percent level.

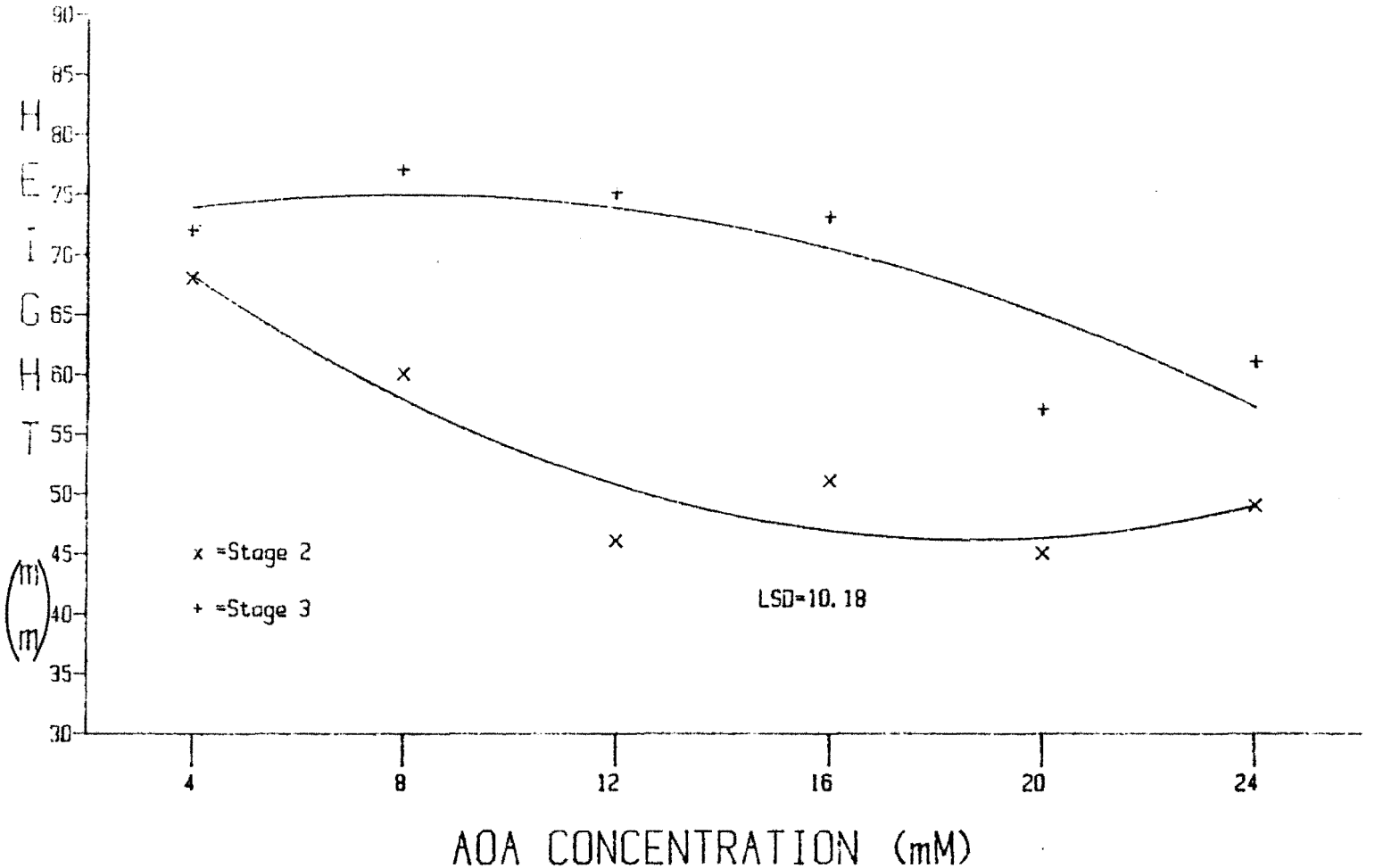

Figure 2. The effect of AOA concentration and stage on the height of Petunia x hybrida 'White Flash' at the onset of flowering at week 12

plant height decreased as the concentration of AOA increased (Table 3). The greatest difference of 30 mm in height between Stage 2 and Stage 3 at 12 mM AOA, and the greatest difference of 15 mm in height between concentrations 4 and 20 mM AOA, Stage 3, was significant and commercially important (Table 3). According to Figure 2, the best control in height was achieved by treating Stage 2 seedlings with 12, 16, 20, or 24 mM AOA.

Plant diameter increased linearly as the concentration of AOA increased for Stage 2 and Stage 3 (Tables 2, 3). The rate of increase in diameter for Stage 2 and Stage 3 was parallel. The greatest difference in diameter of 5 mm between Stage 2 and Stage 3 at 12 mM AOA, and 13 mm between concentrations 8 and 20 mM AOA, Stage 3, was not great enough to be of commercial importance.

Number of applications did not interact with any other factor, but did cause a simple linear effect on plant height and diameter (Table 2). As the number of applications increased, plant height decreased, and plant diameter increased (Table 3). However, the 7 mm difference in height and 11 mm difference in diameter between the number of applications was not great enough to be important commercially.

Analysis at full flower and harvest

Table 4 shows the analysis of variance for plant height, diameter, days to flower, fresh weight, and dry weight at the time each cell pack came into full flower and was harvested. The first cell pack was harvested April 25, 1985, and the daily harvest continued until the last cell pack was harvested May 7, 1985.

A first-order stage by concentration interaction was observed for

Table 3. The significant means of Stage 2 and Stage 3 plant height, diameter, days to flower, fresh weight, and dry weight for Petunia hybrida 'White Flash' treated with AOA

	Means						
	Height (mm)		Diameter (mm)		Days to flower	Fresh wt (g)	Dry wt (g)
	Week 12	Harvest	Week 12	Harvest			
Stage:							
2	NA[a]	130.08	NA	NA	NA	NA	NA
3	NA	125.73	NA	NA	NA	NA	NA
LSD		4.17					
Application:							
1	64.07	132.25	110.00	NA	88.09	NS[b]	0.88
2	64.25	128.22	113.78	NA	88.24	NS	0.85
3	58.99	127.28	116.44	NA	89.62	NS	0.91
4	57.61	123.86	121.09	NA	90.17	NS	0.95
LSD	5.47	6.01	3.09		1.17		0.09
AOA concentration (mM)							
4	NA	134.45	NA	NA	NA	NA	NA
8	NA	132.21	NA	NA	NA	NA	NA
12	NA	127.67	NA	NA	NA	NA	NA
16	NA	128.33	NA	NA	NA	NA	NA
20	NA	125.30	NA	NA	NA	NA	NA
24	NA	119.47	NA	NA	NA	NA	NA
Stage x AOA conc. (mM):							
2 4	67.99	NS	111.13	120.87	88.00	10.05	0.81
2 8	59.67	NS	111.45	123.33	88.43	10.71	0.90
2 12	45.89	NS	115.71	135.85	91.37	10.48	0.90
2 16	50.81	NS	115.35	129.14	89.44	11.03	0.93
2 20	45.08	NS	117.80	131.95	91.19	11.14	0.93
2 24	48.84	NS	121.98	141.44	91.58	12.41	1.12
3 4	72.15	NS	112.08	120.20	87.82	10.23	0.86
3 8	77.02	NS	108.82	117.45	86.23	9.80	0.89
3 12	75.42	NS	110.70	118.82	85.73	10.05	0.80
3 16	73.78	NS	119.78	130.62	88.56	10.58	0.86
3 20	56.97	NS	121.65	139.23	90.88	11.53	1.01
3 24	61.17	NS	117.52	131.27	89.13	10.81	0.89
LSD	21.13		5.75	7.24	2.17	1.01	0.13

[a]Not applicable.
[b]Not significant at the 5 percent level.

Table 4. The effect of stage of development, number of chemical applications, and AOA concentration on the height, diameter, days to flower, fresh weight, and dry weight at the time of harvest of Petunia hybrida 'White Flash' treated with AOA

		Mean Squares				
Source	df	Plant ht (mm)	Plant diam (mm)	Days to flower	Fresh wt (g)	Dry wt (g)
Replication	2	652.85*	160.74	16.49	0.36	0.00
Stage[a]	1	682.90*	625.00**	136.45**	7.91*	0.14**
Application[b]	3	429.38*	1569.31**	37.68**	2.57	0.07*
Linear	(1)	1229.21**	4611.68**	104.07**	4.89	0.13*
Remainder	(2)	29.46	48.13	4.49	1.41	0.04
Concentration[c]	5	669.91**	1172.72**	48.65**	9.27**	0.13**
Linear	(1)	3092.64**	5551.73**	193.80**	42.37**	0.56**
Remainder	(4)	64.22	77.96	12.36	0.99	0.01
A*C	15	154.90	88.24	7.84	0.80	0.02
S*A	3	121.70	157.31**	9.55**	1.18*	0.01**
S*C	5	138.60	455.73**	25.18**	3.17*	0.07**
S*C Linear	(1)	130.60	9.39	0.08	2.17	0.06
S*C Quadr.	(1)	70.90	0.02	17.23**	0.65*	0.00**
Remainder	(3)	163.43	756.42**	36.19**	4.34*	0.10**
S*C*A	15	81.79	120.41	5.28	1.10	0.02
Error	94	157.70	66.17	5.93	1.29	0.02

[a]Stage (S).
[b]Application (A).
[c]Concentration (C).
**Significant at the 1 percent level.
* Significant at the 5 percent level.

plant diameter, days to flower, fresh weight, and dry weight (Table 4). The mean of Stage 2 plants was greater than the mean for Stage 3 plants; however, the difference between stages at each concentration was not great enough for any of the variables to be of commercial importance (Table 3). The effect of increased concentration was a linear decrease in height, and a linear increase in the measurement of diameter, days to flower, fresh weight, and dry weight (Table 3).

It should be noted that the ranking of Stage 2 and Stage 3 plants reversed from week 12 to the time of harvest (Table 3). In general, at week 12, the height and diameter of Stage 3 plants exceeded that of Stage 2 plants. At the time the plants were harvested, Stage 2 plants had a greater mean height, diameter, fresh weight, and dry weight (Table 3). This can be related to the time to flower of Stage 2 and Stage 3 plants (Table 3). The Stage 2 plants flowered later than Stage 3 plants, and had a longer period of growth. Therefore, the longer growth period resulted in larger Stage 2 plants at the time of harvest.

The number of applications affected plant height, diameter, days to flower, and dry weight at the time of harvest (Table 3). As the number of applications increased, plant height decreased, and plant diameter, days to flower, and dry weight increased linearly (Table 4). The difference at the time of harvest was not commercially significant.

The relationship of untreated plants to plants treated with AOA

In order to determine the relationship between plants treated with AOA and untreated control plants, an untreated control measurement was predicted with an equation that estimates the interval of the mean of a

future (untreated) observation (14). The equation is:

$$\hat{Y} \pm t(S^2_{\hat{Y}} + \frac{S^2}{k})^{1/2},$$

where $\hat{Y}$ is a predicted value, t is the Student's t value, S^2 is the mean square error, k is the number of observations contributing to the check mean, and $S^2_{\hat{Y}}$ equals the square of the standard error of the predicted value. Table 5 shows the interval within which the predicted mean should lie, the predicted mean, and the true mean. The true means for measured variables of the untreated control plants fell within, or very close to the predicted intervals. The relationship of untreated check plants to those plants treated with AOA, therefore, can be considered linear.

Visual responses

'White Flash' petunias treated with AOA exhibited a visual response to the treatments within three days. Compared with untreated controls, the foliage of plants treated with AOA became very soft and succulent, and assumed a slight brownish-green color (Figure 3). Turgor loss and wilting was common even though sufficient moisture was available. The wilted condition coincided with a visible restriction of root development (Figure 4). Visible, active root growth resumed approximately one week after the last chemical application. Color, turgor, and root growth seemed to recover fully within two weeks.

Desiccation, the most severe of the symptoms, was visible on the tips of the foliage, especially on Stage 1 plants (Figure 5). The degree

Table 5. Interval estimate of the predicted mean, the predicted mean, and the actual mean of untreated control petunias

Variable	Week	Stage	Interval of the predicted mean	Predicted mean	True mean
Height (mm)	8	2	(57.99, 91.62)	74.81	86.17
		3	(66.44, 103.73)	85.09	85.78
	9	2	(132.99, 165.21)	149.10	138.89
		3	(121.13, 156.47)	138.80	128.89
Diameter (mm)	8	2	(89.53, 104.66)	97.10	96.68
		3	(89.43, 112.17)	100.80	111.90
	9	2	(90.43, 116.57)	103.50	97.95
		3	(89.21, 115.79)	102.50	118.97
Days to flower	9	2	(81.12, 88.46)	84.79	86.44
		3	(81.07, 88.36)	84.72	85.94
Fresh weight (g)	9	2	(7.61, 10.49)	9.05	10.54
		3	(7.74, 11.01)	9.37	10.12
Dry weight (g)	9	2	(0.482, 0.888)	0.685	0.834
		3	(0.516, 0.923)	0.720	0.811

Figure 3. Chlorosis on foliage treated with AOA. The foliage of plants treated with AOA became soft and off-colored within three days after application

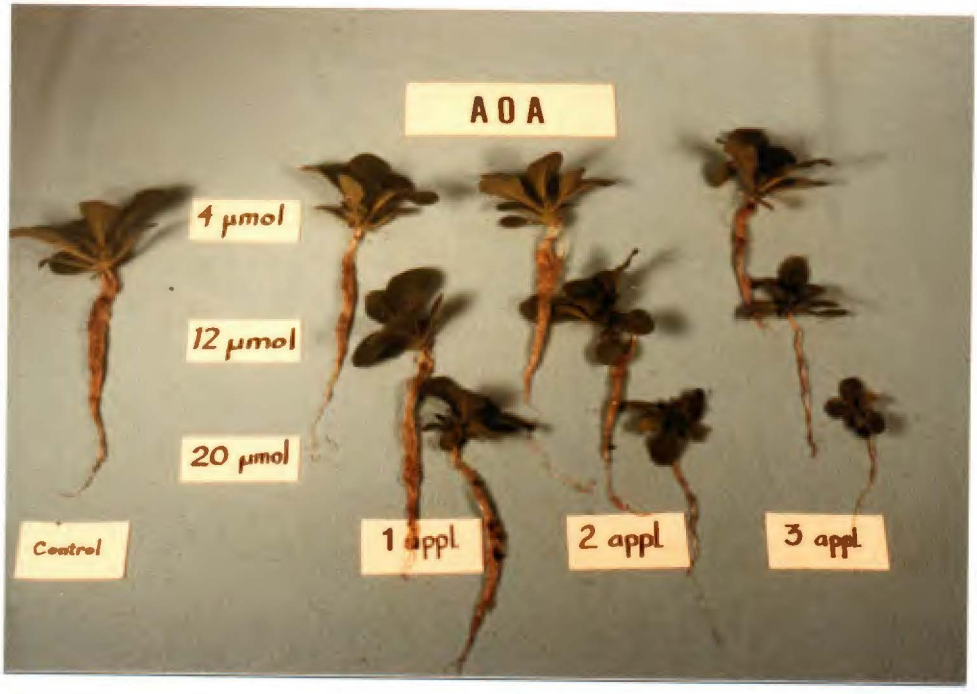

Figure 4. Effect of AOA on root growth of Petunia x hybrida 'White Flash'

Figure 5. Desiccation on foliage treated with AOA. The symptom was observed initially on the leaf tips

of desiccation increased with increased AOA concentrations and additional applications. Plants having desiccated leaf tips usually did not survive because the deterioration spread rapidly over the leaf and petiole (Figure 6). The greater sensitivity of the Stage 1 petunias to the inhibiting effects of AOA probably was caused by a lack of adequate establishment and lack of active growth before treatment, compared with Stage 2 and Stage 3. Therefore, Stage 1 plants were considered too small for treatment with AOA because of their low rate of plant survival.

Chemical spotting or necrosis was observed on the foliage of larger petunia seedlings, especially Stage 3 seedlings treated with AOA (Figure 7). This probably was the result of the droplets of solution coalescing into larger droplets on the leaf blades before evaporating or running off. Chemical spotting did not prove fatal to the seedlings.

The growth-inhibiting effects of AOA are very similar to the effects of the herbicide glyphosate (18). Three-day-old soybean seedlings were treated with 50 μM AOA or 0.5 mM glyphosate via their roots. The rate of seedling growth decreased with most of the effects observed in the inhibition of root elongation and secondary root production. Root inhibition also was observed in this experiment (Figure 4). Because the effects of AOA application occur in locations other than the place of application, AOA probably is translocated within the plant in the xylem and phloem cells. Like glyphosate, AOA has been shown to reduce anthocyanin and chlorophyll levels in soybean hypocotyls grown in light (18). This evidence, combined with the knowledge that AOA is an *in vitro* inhibitor of phenylalanine ammonia-lyase (PAL), which can be activated by

Figure 6. Later stages of desiccation of the foliage treated with AOA. Seedlings with desiccated leaves usually did not survive

Figure 7. Chemical spotting observed on foliage treated with AOA. Spotting was observed most often on Stage 3 seedlings

ethylene, may indicate that AOA is translocated through chloroplast membranes of parenchyma cells (15, 18). These compounds, PAL, ethylene, anthocyanin, chlorophyll, transaminases, proteins, etc., are known to be synthesized in the chloroplasts.

The effect of AOA on reducing anthocyanin and chlorophyll levels could explain the color change observed in petunias treated with AOA in this experiment (Figure 3). Inhibition of root growth and of pigment biosynthesis would decrease the ability of the seedlings to obtain water and nutrients, and to produce photosynthate necessary for survival and growth. This would account for the occurrence of chlorosis, wilting, root inhibition, etc. AOA inhibition also may occur in the roots, at the site of nitrogen metabolism, because the utilization of NH_4^+ and NO_3^- is reduced in plants treated with AOA (15). The reduction in utilization of NH_4^+ and NO_3^- caused by AOA would support the observation that seedling death was increased by fertilization during the period of treatments in preliminary experiments. Fertilizer application was limited to 75 mg per liter once per week until after the final chemical application was made to reduce the loss of plant material.

SUMMARY AND CONCLUSIONS

Chemical growth retardants are important in the commercial bedding plant industry to control plant growth, mainly height. These chemicals should be safe, easy to use, effective on a wide range of plant material, and be inexpensive. Four chemicals commonly used by the industry today are B-Nine, A-Rest, Cycocel, and Florel. However, the effectiveness of these chemicals is limited by safety, crop, cost, etc.

AOA was examined for its feasibility as a chemical growth retardant for bedding plants. Preliminary observations showed that AOA did cause a visual retardation in the growth of petunias, impatiens, and geraniums. This research examined in detail the effect of AOA on the growth of Petunia x hybrida 'White Flash' under a limited range of environmental conditions.

Results showed that AOA controlled the height of petunias from eight weeks after sowing until the onset of flowering at week 12. The difference in height was important. Treated petunias exhibited a growth curve similar to untreated petunias; however, the growth of the treated petunias was retarded as the number of applications or AOA concentration increased.

The difference in height may have been of commercial importance, depending on the time at which the grower wanted the growth controlled. The difference in plant height between treated and untreated plants increased until the onset of flowering at 12 weeks. However, the significance diminished when the plants were in full flower. This may,

or may not be of concern to the commercial grower because bedding plants are sold both with and without open flowers.

The stage of development at which the plants were treated was important, and this may have been related to the extent of root development prior to chemical treatment, though this parameter was not measured. Stage 1 seedlings were newly transplanted, and had sparse root development when treated with AOA. Stages 2 and 3 had well-established roots at the time of treatment. Though AOA caused extensive root inhibition, Stages 2 and 3 survived most of the treatments. The effect of AOA on Stage 1 seedlings with better established roots is unknown.

At the onset of flowering, week 12, results showed that different concentrations of AOA affected the height and diameter of Stage 2 differently from that of Stage 3. The difference in height indicated that the best control could be achieved by treating Stage 2 plants with concentrations of 12, 16, or 20 mM AOA in two or three applications. The difference in diameter was not great enough to be important commercially. The number of applications also affected plant height and diameter, though the difference between applications was not of commercial importance.

More importantly, it should be noted that when harvested, the height, diameter, fresh weight, and dry weight of Stage 2 plants was greater than that of Stage 3 plants. The exchange of ranking could be explained by the longer time to flower of Stage 2 plants, and the subsequent longer period of growth. No commercially significant differences existed at the time of full flower between stage,

application, or concentration for any variable measured.

By calculating an estimate of the untreated control plant means, the relationship of untreated petunias to AOA-treated petunias was determined to be linear. The importance of the main effect of concentration was reduced by its interaction with stage.

Results indicated that AOA affects the height of Petunia hybrida 'White Flash', provided that the plant was growing actively under the same environmental conditions as presented in this thesis. Controlling the growth of a bedding plant at this early stage of development would reduce the potential for elongation under high density populations. However, the significance of different treatments diminished as the petunias reached full flower. The grower must determine at what stage of development the control of plant growth is most important.

These experimental results do not guarantee the efficacy of AOA. To further assess the potential of AOA as a commercial growth retardan, many important considerations should be made. AOA does not cause plant responses tyupical of chemical growth retardants currantly used, such nhanced greening (5). AOA does affect plant growth and vigor, as evidenced by chlorosis, loss of turgor, desiccation, and restriction of root growth. These are not desirable qualities of a chemical growth regulator (6). It is known that the effectiveness of chemical growth regulators is limited by the prevailing environmental and cultural conditions (28). This thesis research examined the effects of AOA on one cultivar and under restricted environmental conditions and cultural techniques. The effectiveness of AOA on other species and cultivars, and

under different light, moisture, nutrition, and temperature conditions cannot be concluded from this research. These areas require further investigation (11).

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During my graduate school experience, my analytical skills grew and developed. Knowledge was gained, not only through coursework and research, but through working with people, searching for and applying

information, and solving problems. These skills are not restricted in their use, but will be applicable to everyday situations and concerns.

APPENDIX: PLUG CULTURE OF PETUNIAS, IMPATIENS, AND BEGONIAS IN THE COMMERCIAL GREENHOUSE

Most bedding plant operations have a fast-paced spring season. Hectic schedules of flat-filling, seeding, moving, watering, planting, and shipping are maintained from January through May, or longer. Little time is available for the grower to study and document the progress of the crop, apart from a few vague notes and mental observations.

Diligent record keeping becomes essential for the grower to maintain productivity and remain competitive in the industry. Complete records of daily procedures and observations are extremely valuable. Records are used to familiarize new employees with the operation, assess the performance of a selected cultivar, help improve techniques, and solve production problems. Accurate records can allow the grower to compare root media, watering methods, or germination techniques.

The objective of my thesis research was to evaluate a new chemical, (aminooxy)acetic acid (AOA), as a growth retardant for bedding plant production. I first attempted to replicate the environment and culture typical of a commercial greenhouse. However, the lack of documentation of current cultural commercial practices made it difficult to establish an accurate comparison between research and commercial settings. Water quality, light quality, and the growing medium varied among greenhouses and growing regions. As a result, I accepted an invitation to work in a commercial greenhouse operation, Bergen Wholesale, Inc., during the 1984 bedding plant season to increase my knowledge of plant growth and to

document plug production methods. Studies were conducted comparing production techniques of petunias, impatiens, and begonias in the commercial range.

Plug production is a highly technical method for growing bedding plants. First, seeds are sown mechanically into specialized trays. They are germinated under the controlled environmental conditions of light, temperature, and moisture. Seedlings are transferred to a greenhouse environment that provides supplemental light, nutrition, moisture, and temperature for rapid establishment and continued growth. Plug seedlings at the proper stage of development are transplanted with their entire root ball into commercial cell packs for continued growth and then marketing.

Plug production allows seedlings to remain in the plug trays longer than seedlings grown in bulk seed flats. Seeds sown and germinated in bulk flats are at a high density, and the seedlings must compete with one another for light, moisture, nutrients, and space. Seedlings must be transplanted bare-root into cell packs before becoming overcrowded and elongated. Disrupting the already-weak root systems causes further delays in their development. For example, petunias require six weeks or more in bulk flats, resulting in a total production time of 10 to 12 weeks. In contrast, plug seedlings can be maintained in trays until two to three weeks before sale, and they require only seven to ten weeks of total production time. This decrease in production time allows two to three additional crops per season.

Soil preparation

The goal of the Bergen Wholesale greenhouse operation was to produce a high-quality product in as little time as possible. To accomplish this goal, plugs were grown at 24 to 27°C medium temperature, 45 to 60% relative humidity, and daily fertilization. The well water had a pH of 8.0 to 8.5 and 4 to 6 meq/liter bicarbonate. The plug medium was prepared by using 35% Sphagnum (for air porosity), 35% Hypnum peat moss (for increased buffer capacity and a neutral pH), and 30% #3 vermiculite (for increased water-holding capacity). The following amendments were added per cubic meter of medium: 0.59 kg iron sulfate (to lower the pH), 1.78 kg superphosphate (0-20-0) (to aid root development after germination), 1.19 kg calcium sulfate (to provide calcium without affecting the pH), and 1.19 kg Esmigran (to provide micronutrients).

Each component was measured by volume, and the amendments were measured by weight. Ingredients were mixed together in 0.765-m^3 or 1.53-m^3 quantities in a converted 4.59-m^3 concrete mixer. Moisture was added while mixing. After mixing, the medium was hand-sifted through a 6.25-mm wire-mesh screen to remove large particles. The medium was stored dry until needed. The pH was approximately 4.6, and helped to control the effect of the bicarbonate in the water supply.

Observation of the low 65 to 80% petunia germination led us to speculate that this medium did not allow optimum drainage and aeration. Vermiculite expanded and held excessive moisture when wet, thus reducing the aeration in the medium. A fine-grade perlite was substituted for the vermiculite to loosen the medium. Germination and subsequent plug growth

improved by 10 to 20%.

Sowing

Seed trays were filled with prepared medium and placed on a germination cart, which had been washed and disinfected with a spray solution of eight parts water to one part bleach. Each cart had six shelves and held a total of 54 plug trays. Each tray rested in a drainage flat and was supported by three saucers placed lengthwise to level the tray. The seed trays were watered thoroughly before sowing.

A mechanical Blackmore^{R} plug seeder was cleaned and tested before the season for the 406 and 648 trays. Precise adjustments were made for each seed type to assure that the operation was accurate and at full capacity. Accuracy was evaluated by stopping the machine once per tray and observing seed pickup and drop. Petunias and begonias were double seeded by passing the tray through the seeder twice to insure full trays. Trays then were placed on germination carts and wheeled into the germination chamber.

Germination

A controlled-growth-environment room was designed for plug germination. The chamber, constructed of plywood, had eight compartments for plug carts. Seed germination and seedling growth were observed through a window in the door of each compartment. The entire chamber was painted white to reflect light.

Inside the chamber, the compartments were separated by six rows of cool-white fluorescent lamps on each side. Each row of lights was positioned approximately 15 cm above each row of trays on the cart. New

lamps were installed at the beginning of each bedding plant season. The chamber was heated with the energy given off by the fluorescent lamp ballasts. An air conditioner forced cool air downward through a perforated ceiling to maintain temperatures. Petunias were germinated at 26°C soil temperature; begonias, 27°C; and impatiens, 23°C.

Watering

Plug flats were hand-watered with mist nozzles to prevent seeds from washing out of the cells. Three 3.79-liter (1-gallon/min.) Foggit^{R} nozzles were connected by sections of 19-mm (3/4-inch) PVC pipe. The trays were misted two to three times daily because of the small quantity of moisture applied with each watering. The plug trays were observed and watered carefully according to the needs of each tray. Trays thoroughly watered before seeding usually required misting twice daily.

Lighting

Two brands of fluorescent lamps, Norelco Cool White and Duro-Test: Vita Lite, were installed in the germination chambers. Light intensity measurements at plant level were taken each month with a hand-held meter. The light intensity emitted by Norelco cool white lamps ranged from 500 to 590 footcandles (fc) directly beneath the lamps and 100 to 150 fc in the center of the trays (halfway between the lamps). Duro-Test: Vita Lite emitted approximately 320 to 380 fc beneath the lamps and 80 to 90 fc in the center of the trays.

Irradiance, or photosynthetically active radiation (PAR), was measured by using a quantum sensor. The Norelco Cool White lamps emitted approximately 58 to 65 microeinsteins $s^{-1}m^{-2}$ directly beneath the light

source and 15 to 25 microeinsteins $s^{-1}m^{-2}$ in the center. Duro-Test: Vita Lite lamps emitted approximately 45 to 50 microeinsteins $s^{-1}m^{-2}$ beneath the source and 15 to 25 microeinsteins $s^{-1}m^{-2}$ in the center. The difference between the light levels on the outer edges and the centers of the trays probably caused uneven plant growth. Seedlings on the outer edges developed more rapidly than in the center. Removal of the seedlings from the chamber at an early stage of development resulted in less uneven growth than when the seedlings remained in the germination facility.

Timing

Petunias germinated in approximately three days and were removed as soon as the cotyledons began to unfold, three to four days later to prevent excessive elongation. Impatiens germinated in approximately five days and were removed in four to five more days, just as the cotyledons began to unfold. Begonias were removed when the seed leaf was approximately 1 mm in diameter.

Growing-on after germination -- Stage A

Seedlings were removed from the germination area and transferred to an environment suitable for continued growth and development. The growing-on phase was divided into two stages. Stage A acclimatized the seedlings to the greenhouse environment and promoted rapid growth, and Stage B continued growth or regulated growth of the seedlings with cooler temperatures.

The Stage A acclimatization area was created by constructing a polyethylene tent within the greenhouse. All carts and benches were

disinfected with a spray solution of eight parts water to one part bleach to prevent any transfer of disease. Steam heat below the benches maintained the temperatures in Stage A at 24 to 27°C ambient, and 21 to 24°C soil. These temperatures encouraged rapid growth and development.

Misting

The plug seedlings were watered once daily with overhead mist, except during cloudy weather when the seedlings were watered by hand as needed.

Light

The germinated seedlings were placed under supplemental high-intensity, high-pressure sodium lamps immediately after removal from the germination chamber. The lamps operated from 4:30 p.m. to 8:00 a.m. from January through April. Begonia and impatiens seedlings remained more compact, developed thicker main stems, and produced more foliage and greener foliage. Irradiance measurements at plant level were taken every two weeks at 12:00 noon, Daylight Standard Time, by using a quantum sensor. Under natural light, an average, cloudy March day provided approximately 250 microeinsteins $s^{-1}m^{-2}$ in contrast to approximately 660 microeinsteins $s^{-1}m^{-2}$ on an average, clear March day. A clear May day provided approximately 850 microeinsteins $s^{-1}m^{-2}$. Irradiance measurements under the supplemental lamps recorded 180 to 230 microeinsteins $s^{-1}m^{-2}$ on a cloudy March day and 660 to 760 microeinsteins $s^{-1}m^{-2}$ on clear days. Supplementary lighting was not applied in May.

Fertilization

Fertilization was supplied with each irrigation in Stage A to supplement the nutrients in the medium (calcium sulfate, iron sulfate, superphosphate, and Esmigran). Petunia and impatiens seedlings were fertilized with 100 mg/liter total nitrogen obtained from 73 mg/liter ammonium nitrate and 27 mg/liter potassium nitrate fertilizers. Begonias were not fertilized when irrigated. Soluble salt readings from the irrigation water were taken once weekly to monitor the performance of the injector.

Growth regulators

The high humidity, warm soil temperatures, and constant fertilization in Stage A promoted rapid, lush seedling growth and excessive stem elongation. Growth regulators were applied to most plug seedlings in Stage A. Petunias were sprayed weekly as needed, beginning at the first true-leaf stage (approximately 10 to 20 mm plant diameter) with 2000 mg/liter B-Nine. A 1:100 spray injector was used. Growth regulators were applied in cloudy weather and early morning.

Scheduling

Petunias and impatiens remained in Stage A one to two weeks before being moved to Stage B for growing-on or holding. At that time, petunia seedlings were 13 to 25 mm in diameter, or at the first or second true-leaf stage. Impatiens were moved when their cotyledons were fully expanded and the first true leaves were visible. Begonias remained in Stage A up to five weeks, and they were moved to Stage B at the second to third true-leaf stage. The begonia seedlings were transplanted at this

time if the plug had formed a firm rootball.

Growing-on -- Stage B

Wooden benches were washed and disinfected with a spray solution of dilute bleach. The seedling trays were placed on inverted flats on the benches to allow air circulation around the roots. Exposing the tender roots to the air promoted root pruning and reduced excessive seedling elongation.

Temperature

Seedling growth in Stage B was controlled by temperature. Bedding plants were grown with 21 to 24°C soil temperatures to hasten plant growth. Growth was controlled from January through April with night soil temperatures of 18 to 21°C. Growth was inhibited by placing seedlings in a 16 to 18°C area. Before shipment in late April, Stage B temperatures were increased to 24 to 27°C to hasten seedling growth. Warm growing was preferred to cold because seedlings held at 13 to 16°C for four weeks were stunted, malformed, and slow to flower. Plug seedlings, especially begonias held at cold temperatures did not develop roots into the transplanting medium.

Moisture

Seedlings were watered daily or as needed during cloudy weather. The plugs were kept constantly moist, but not waterlogged by using a bench-misting system. Hand-watering assured that corners and edges not reached by the mist were watered adequately.

Fertilization

Fertilizer usually was applied with each irrigation. Shoot growth, soil and water pH, and soluble-salt levels were monitored once each week to assure optimum levels of nutrients. The plugs were leached with clear water if high salt levels were present. The fertilizer was injected via a 1:100 double-headed injector. Petunias and begonias received 150 mg/liter of nitrogen from 110 mg/liter ammonium nitrate and 40 mg/liter potassium nitrate when the growing temperatures were 18°C and above. Impatiens received 150 mg/liter total nitrogen from 75 mg/liter calcium nitrate and 75 mg/liter potassium nitrate. Plants were fertilized with calcium nitrate and potassium nitrate when the growing temperatures were below 18°C to prevent ammonium toxicity. Trace elements were added to supplement those initially incorporated into the medium. Sulfuric acid was added at the rate of 0.16 ml/liter of water to lower the pH. Phosphoric acid was used originally but resulted in iron-deficient plants.

Growth regulation

Plug seedlings were growing in conditions of constant moisture availability, 18 to 21°C temperatures, and frequent application of an ammonium-containing fertilizer. Chemical growth-regulator use was continued in Stage B. The same chemicals were used as in Stage A, but at higher concentrations. Petunias and most other bedding crops were treated with weekly spray applications of 3000 mg/liter B-Nine.

Scheduling

The duration in Stage B was dependent on the environmental conditions and the crop species. Petunias remained in Stage B two to four weeks before being transplanted at the four to five true-leaf stage. Begonias remained in Stage B for three to four weeks.

Finishing

Seedlings were transplanted into cell packs and grown in the greenhouse or placed outside to finish. The medium for transplanted bedding plants included 60% Hypnum peat moss, 25% #2 vermiculite, and 15% styrofoam beads. Hypnum absorbed moisture more readily than Sphagnum and did not dry out as quickly. The vermiculite increased the water-holding capacity, and the styrofoam beads provided approximately 18% porosity. It was observed that the 18% air porosity was crucial for quick seedling root-out.

The following amendments were added to the medium to control the high 8.0 water pH and 4 to 6 meq/liter bicarbonate content: 1.9 kg magnesium sulfate, 4.15 kg superphosphate (0-20-0), 6.4 kg gypsum, esmigran, and 0.17 kg manganese sulfate per cubic meter. Gypsum provided calcium without affecting the pH. The medium components were mixed and steam pasteurized in a converted 4.59 m^3 concrete mixer. Flats containing cell packs were filled mechanically and stacked on wooden pallets until needed. Usually, flats were filled on the day that or the day before they were needed so that the medium remained moist. A moist medium was desirable because the transplanted seedlings were not watered until placed in the greenhouse.

Culture

Once transplanted, trays of seedlings were loaded onto carts, transferred to the greenhouse, placed on the asphalt floor, and immediately watered by hand with a 4 mg/liter Subdue and 61 mg/liter Benlate solution. Fungicides were applied as a preventive measure on susceptible crops, such as snapdragons, Portulaca, Alyssum, Celosia, and Vinca. Steam pipes located within the permeable asphalt floor maintained soil temperatures at 20 to 21°C to slow or maintain growth or at 24°C and above to hasten the growth. Air temperatures ranged from 16°C nights to 21°C days. Fast crops were grown at 21 to 24°C, allowing up to three crops for the spring bedding plant season.

The quality could be controlled by withholding moisture, adjusting the type of fertilizer, and using chemical growth regulators. An overhead watering system was used to water plants. The constant supply of moisture, combined with 350 mg/liter of total nitrogen from 175 mg/liter ammonium nitrate, 100 mg/liter calcium nitrate, and 75 mg/liter potassium nitrate encouraged rapid, succulent plant growth. The light intensity through two layers of polyethylene covering provide sufficient light to encourge leaf expansion. Impatiens baskets were shaded by hanging beneath lath. The irradiance was equivalent to that in the Stage B area, approximately 1200 microeinsteins $s^{-1}m^{-2}$ in full sun and 400 microeinsteins $s^{-1}m^{-2}$ under shade. These conditions encouraged good visual root, shoot, and foliage development. Plants flowered within two to four weeks after transplanting. Plant height was controlled by chemical growth regulators, such as 3000 mg/liter to 4000 mg/liter of

B-Nine. The plants were hardened off, or acclimatized approximately one week before shipment by lowering the temperatures, reducing the moisture, and removing the ammonium nitrate fertilizer. Flats were placed outdoors in cold frames to slow the growth of the transplants even further. The transplants were shipped when approximately 10 to 15 cm in height and in flower.

Summary

I gained practical knowledge of commercial crop production during the time spent at Bergen Wholesale, Inc., including regulating plant growth by manipulating temperature, moisture, nutrition, light, and applying chemical growth retardants. The importance of uniform particle size and distribution, air porosity, and nutrient charge in the medium was evident in the crop quality. I also learned that research techniques are not always feasible for the commercial grower, nor relevant to the needs of the consumer. An understanding of the cultural practices and capabilities of a commercial growing operation is vital for practical research.