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TITLE SOME EFFECTS OF MALEIC HYDRAZIDE ON CERTAIN PHYSIOLOGICAL RESPONSES OF CELERY (APIUM GRAVEOLENS)

AUTHOR HEZEKIAH JACKSON

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SOME EFFECTS OF MALEIC HYDRAZIDE ON CERTAIN PHYSIOLOGICAL RESPONSES OF CELERY (*APIUM GRAVEOLENS*)

By

Hezekiah Jackson

A THESIS

Submitted to the School of Graduate Studies of Michigan State College of Agriculture and Applied Science in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

Department of Horticulture

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AN ABSTRACT

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Approved ______________________________

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The effects of foliage sprays of various concentrations of maleic hydrazide on the growth and development of Cornell 19 celery plants were determined under field and greenhouse conditions. Time of application, cold exposure of plants, and soil nitrate levels were considered. Storage tests were also conducted to determine the effects of maleic hydrazide applied as a preharvest foliage spray on the sugar and nitrogen content of Cornell 19 and Utah 15 varieties of celery which were stored for various periods of time at $33 \pm 2^{\circ}$ F. Finally a series of fresh tissue analyses were carried out during the growing season to determine the effects of maleic hydrazide treatments, soil nitrate levels, and temperature exposures on the soluble nitrogen content of maturing Cornell 19 celery plants.

Foliage sprays of maleic hydrazide favored the development of seedstalk initials in Cornell 19 celery when applied at 50 to 100 ppm to plants which were from 13 to 16 weeks old. In striking contrast, when applied at 500 to 1000 ppm to older plants, seedstalk elongation was inhibited. Maleic hydrazide did not have comparable influences on initiation and inhibition of seedstalk formation and elongation, respectively, under greenhouse and field conditions. Low night temperature ($40 \pm 5^{\circ}$ F) exposures of young celery plants had a pronounced influence in hastening the date and increasing the per cent of seedstalk formation in both field and greenhouse tests. A high soil nitrate level (75 ppm) favored seedstalk growth and development under field conditions, but 100 ppm of soil nitrate under greenhouse conditions had an inhibitory effect on the same responses.

Celery plants which were exposed to low night temperatures and low levels of soil nitrates before transplanting to the field generally had a greater physiological tolerance for comparable spray concentrations of maleic hydrazide. The lethal injuries induced by maleic hydrazide treatments followed a definite pattern. Initial injury occurred as a chlorosis on the inner petioles and leaves, followed by a discoloration of the older petioles and leaves, and subsequent death of the plants.

Storage tests with two varieties (Cornell 19 and Utah 15) of celery were conducted wherein foliage sprays of maleic hydrazide (500, 1000, and 2500 ppm) were applied prior to harvest. The celery which was harvested and subsequently stored at $33 \pm 2^{\circ}$ F for various periods of time was analyzed for total, reducing, and non-reducing sugars; and for total and nitrate nitrogen. No significant alterations in total or nitrate nitrogen were observed. However, significant increases and decreases in sugars were characteristic of some of the maleic hydrazide treatments, but not others, and several inconsistencies were noted in the results of the two storage tests.

Tissue analyses of celery petioles harvested from plants of various ages and grown at 10, 20, and 75 ppm of soil nitrate, revealed that foliage sprays of maleic hydrazide of 100 to 250 ppm decreased the soluble nitrogen content.

The results of the present research concerned with the effects of maleic hydrazide in the development of celery plants is discussed in view of the reports of others relative to the influence of this chemical on the vegetative and flowering responses in plants. It is significant that as herein reported the formation of seedstalks in celery plants has been promoted by foliage sprays of maleic hydrazide even with plants not previously induced to flower by cold treatments.

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I. INTRODUCTION

The development of successful methods of controlling flowering in certain horticultural crops by chemical treatment would be of vast economic importance. This is likewise true of many crops other than those classified as horticultural. The purpose for which a crop is grown determines whether or not flowering is desirable. Many herbaceous horticultural crops possess desirable market and edible qualities in so long as they remain vegetative, and losses result to farmers when seedstalks develop prematurely. The development of varieties which have weaker flowering tendencies, may result in a reduction in vigor, edible and market qualities, and increase seed production problems.

Certain varieties of celery such as Cornell 19, when seeded in January and February, and later transplanted to the field to correspond with commercial practices in Michigan for the production of early celery, may shoot to seed prematurely. States important in celery production such as Michigan, New York, California, and Florida frequently have environmental conditions which may cause enormous losses to celery growers if many of the high quality varieties which usually have strong bolting tendencies are grown.

White and Kennard (67) reported that maleic hydrazide delayed flowering in strawberries and black raspberries with little apparent effect on other plant parts when low concentrations were applied. Obviously, if flowering could be controlled in certain varieties of celery, such as Cornell 19, with plant growth regulators, this method of control would be more feasible than resorting to the control of flowering by the production of less vigorous, frequently inferior in quality, non-bolting varieties. Since the first reported use of maleic hydrazide as a plant growth substance in 1949 by Schoene and Hoffman (48), many investigators as Fillmore (15), Crafts, Currier, and Day (8), Naylor (42, 43), Moore (40), Rood (47), Thurlow and Bonner (59), and White (66), have reported on the control of flowering and fruiting in different crops by the use of this substance.

The experiments which follow were conducted in the field and in the greenhouse to determine whether or not maleic hydrazide would control flowering in Cornell 19 celery, a variety generally accepted as being of high quality and locally known as Ivory or Golden Pascal. This high quality and otherwise acceptable variety is naturally very susceptible to bolting or premature seeding, when grown under the usual environmental conditions which prevail in Michigan during the growth of the early summer crop. Furthermore, in view of spectacular results with maleic hydrazide in storage tests with root crops such as onions and potatoes (69, 71, 72), storage experiments were also conducted to determine whether or not preharvest foliar sprays of maleic hydrazide would affect the keeping qualities of Cornell 19, Utah 15, and Utah 52-70 varieties of celery (71).

II. REVIEW OF LITERATURE

Effect of Plant Growth Substances Other Than Maleic Hydrazide on Flowering Responses in Plants

Effect on flower inhibition. Dostal and Hosek (13) were among the first to demonstrate that plant growth substances can inhibit floral initiation and development in plants. Using indoleacetic acid (IAA) applied in lanolin paste to the leaves of "ripe-to-flower" shoots of *Circaea*, they were able to inhibit floral initiation. Hamner and Bonner (22) and Thurlow and Bonner (59) applied indoleacetic acid to *Xanthium* plants that had been photo-induced to flower and obtained complete inhibition of flower initiation. Their work showed that hormone-like substances were capable of preventing flower initiation in short-day plants, even though they had been photoperiodically induced to flower. There still remained to be discovered a chemical means for preventing flowering on long-day, and indeterminate or day-neutral plants. Liverman and Lang (36) have indicated that a chemical means of preventing flowering in long-day plants might soon become a reality.

Green and Fuller (17), using indoleacetic acid on petunia plants, were able not only to prevent further floral initiation, but also to delay the opening of buds which had formed previous to the auxin application.

Hitchcock and Zimmerman (26) applied potassium alpha-naphthalene acetate at concentrations of 200, 400, and 800 ppm to apple, cherry, peach, pear, and plum trees. Flowering and fruiting were delayed depending upon the concentration of this substance that was applied and the kind and variety of fruit tree used (20). Results from this work showed that peach and plum trees were more sensitive to a specific concentration of potassium alpha-naphthalene acetate than the other fruit trees.

Wittwer, Coulter and Carolus (68), applied alpha-ortho-chlorophenoxypropionic acid to celery plants and observed an inhibition of seedstalk formation.

Effect on flower initiation. Some of the early work by Cooper (7), Clark and Kerns (5), Traub *et al* (60), and Van Overbeek (61, 62, 63, 64) with the pineapple, showed that certain plant growth substances were capable of promoting flower initiation. Clark and Kerns (5) applied alpha-naphthaleneacetic acid, naphthalene acetamide, naphthalene-thioacetamide, and a commercial product known as Fruitone to the pineapple at various concentrations. Flower initiation was observed depending upon the kind and concentration of plant growth substance applied. Cooper (7) applied naphthaleneacetic acid and ethylene to the pineapple plant. Naphthaleneacetic acid was applied as 0.01 per cent (100 ppm), 0.005 per cent (50 ppm), and 0.001 per cent (10 ppm) solutions. Though flower initiation was observed it was largely dependent upon the plant growth regulator used, its concentration and time of application, and the age of the pineapple plant (16).

Hitchcock and Zimmerman (23), working with tomato and Turkish tobacco plants, and indoleacetic, indolebutyric, indolepropionic, naphthaleneacetic, phenylacetic, and phenylpropionic acids as plant growth substances which were applied to the soil, observed some floral initiation. The extent of floral initiation was dependent upon the growth substance used, and its concentration, as well as the age and species of plant to which the chemicals were applied (24, 25, 70, 73, 74, 75, 76, 77, 78).

Leopold and Thimann (34) have shown as a result of work with two grasses (Chalco teosinte and winter barley) and alpha-naphthaleneacetic and indoleacetic acids, that floral initiation may be retarded or favored, depending upon the auxin economy within the meristems of the plants. High auxin levels retarded and low auxin levels favored floral initiation in these grasses.

Effect of Maleic Hydrazide on Flowering Responses in Plants

Reports which have appeared in the literature have suggested tha maleic hydrazide possesses a number of unique qualities that are not evident in other generally known plant growth regulators (1). Many of the investigations carried out with maleic hydrazide since 1949 have had as their purpose the elucidation of the possibilities which this chemical might possess for controlling flowering in economic plants. Results of research work reported thus far have shown generally that maleic hydrazide inhibited floral development in a large number of plants on which it has been applied.

Naylor and Davis (44) have shown that maleic hydrazide applied at concentrations of 0.2 per cent (2000 ppm), 0.4 per cent (4000 ppm), and 0.8 per cent (8000 ppm) killed blossoms present on Turkish tobacco plants. When maleic hydrazide was reduced to 0.1 per cent (1000 ppm) only 50 per cent of the blossoms present on Turkish tobacco plants were killed. Naylor and Davis (44) also observed that when the concentration of maleic hydrazide applied was reduced to 0.05 per cent (500 ppm) blossoming was not prevented in Turkish tobacco plants, but it was slower than in the controls.

Naylor (42), working with Turkish tobacco, maize, and cocklebur (<u>Xanthium</u>), reported that maleic hydrazide prevented or retarded flowering when applied to the soil or foliage of such plants. Higher concentrations of maleic hydrazide were required to produce the same effect when soil applications were employed.

On strawberries White (66) used 0.1 per cent (1000 ppm) and 0.4 per cent (4000 ppm) solutions of maleic hydrazide and delayed flowering for two weeks.

Some Effects of Maleic Hydrazide on Vegetative Responses in Plants

The effects of maleic hydrazide on the vegetative growth of plants are determined largely by the age, and species of plants treated and the concentration of the chemical applied (8). Compton (6) observed that maleic hydrazide applied at concentrations above 100 ppm reduced growth in Pisum sativum. At 50 ppm maleic hydrazide had less effect on the reduction of growth, and no growth reduction was apparent at 10 ppm. Compton (6) also observed that the resumption in growth of plants which had received 100 ppm of maleic hydrazide was mainly in the shoots rather than the roots.

Currier and Crafts (9) have shown that 0.2 per cent (2000 ppm) solutions of maleic hydrazide immediately stopped growth on two-week-old barley plants, but had no apparent effect on five-week-old Upland cotton. Young cotton in the cotyledon stage was seriously injured by maleic hydrazide. These investigators (9) noted also that the age of the grasses determined the injury observed from specific concentrations of maleic hydrazide. When maleic hydrazide was applied in below lethal concentrations, the inhibition of plant growth was mainly temporary (8, 9, 48).

Leopold and Klein (33) employed the slit-pea, pea straight growth, and the Avena straight growth test to determine the relation between auxin level within plants and reduction in growth observed from the application of various concentrations of maleic hydrazide. It was noted that maleic hydrazide had a greater inhibitory effect on plant growth when the natural auxin level was low than when the natural auxin level was high. This suggested that auxins may counteract the action of maleic hydrazide (33). Leopold and Klein (33) further concluded that maleic hydrazide should be classified as an antiauxin, because its behavior is similar to other chemicals which are classified as antiauxins. Though such compounds as 2,3,5-triiodobenzoid acid, coumarin, 2,4-dichloranisole, trans-cinnamic acid, and maleic hydrazide are classified as antiauxins, natural plant auxins have been shown to counteract the action of only maleic hydrazide and trans-cinnamic acid (33).

Wittwer and Paterson (71) have demonstrated that maleic hydrazide applied at concentrations of 500 to 2500 ppm to the foliage of mature onions in the field prevented subsequent sprouting and breakdown in storage. When maleic hydrazide was applied at concentrations of 1000 to 2500 ppm four to six weeks before harvest, sprouting was completely prevented in Irish Cobbler and Pontiac varieties of potatoes even when held in storage for seven months at 55° F (37, 71).

Peterson (46) showed that maleic hydrazide prevented sucker growth on tobacco plants with no significant effect on yield, quality, or burning properties.

Effect of Maleic Hydrazide on the Anatomy and Morphology of Plants

A knowledge of the morphological appearance and formative effects produced by the application of chemical substances which regulate plant growth is essential before their use on a large scale is adopted. Many investigators have observed changes in the gross appearance of plants after treatment with maleic hydrazide, but few agree as to what internal factors are responsible. Naylor and Davis (44) have reported that in many instances maleic hydrazide treated wheat, sunflower, and Turkish tobacco plants developed abnormal leaf shapes. In addition, Naylor and Davis (44) observed the following sequential changes in plants after treatment with maleic hydrazide: (a) loss of apical dominance, (b) expansion of leaves already formed, (c) an intensification of green color, (d) increase in anthocyanin pigment, and (e) some chlorosis. The degree of expression of these characters depended largely upon the concentration of maleic hydrazide used and age of the plant when treated.

Moore (40) noted that maleic hydrazide treated sweet corn and garden beet plants developed narrower leaves than the controls.

Darlington and McLeish (12), studying the action of maleic hydrazide on cell division in Vicia faba, noticed that high concentrations of maleic hydrazide, 0.005 M and above, did not stop mitosis. However, such concentrations inhibited cell division for two days. These investigators

(12) further observed that concentrations of maleic hydrazide at 0.005 M and above induced a large number of breakages in the heterochromatic portion of the chromosomes (35, 45, 65). It has not as yet been reported as to whether or not chromosome breakages are responsible for the male sterility which maleic hydrazide induces in maize, as reported by Naylor (42).

Greulach and Atchison (19) noted that maleic hydrazide inhibits cell division at low concentrations, but not cell enlargement. Greulach and Atchison also observed that high concentrations of maleic hydrazide stopped both cell division and cell enlargement.

Currier, Day, and Crafts (10) reported that maleic hydrazide may cause the collapse of the phloem elements, thereby allowing certain elaborated foods to differentially accumulate in specific parts of the plant.

There are other unique aspects of the actions of maleic hydrazide which distinguish it from most other plant growth regulators. Leopold and Klein (33) noted that maleic hydrazide stimulated the growth of lateral buds in plants, which effect differs from the lateral bud inhibition usually induced by other plant growth regulators.

Effect of Maleic Hydrazide on the Chemical Composition of Plants

Plant growth substances often cause changes in the chemical composition of plants (21). These changes may be direct or indirect expressions of any one of several responses such as reduced growth, increased growth, flower bud initiation, inhibition of flower bud formation, and an increased pigmentation of the foliage. Currier, Day, and Crafts (10) reported that maleic hydrazide treated young barley plants showed an increase in fructosan polysaccharides, but the sugars showed no significant change over the control. Tatum and Curme (55) reported that maleic hydrazide caused the accumulation of sugars in young corn plants. A comparison of results obtained from young barley (10) and young corn plants (55), would seem to suggest that maleic hydrazide has a differential influence on food accumulation within different plants.

Greulach (18) reported that maleic hydrazide treated tomato plants showed food accumulation in the stem and leaves. The age of the plant should always be considered when interpreting the response of plants to maleic hydrazide (18, 41).

McIlrath (38), working with cotton plants, found that maleic hydrazide favored the accumulation of carbohydrates in treated plants compared with controls, while the non-carbohydrate constituents such as proteins were reduced by the chemical treatment.

III. STATEMENT OF THE PROBLEM

The numerous accounts which appear in the literature on the many diverse effects noted for maleic hydrazide as a plant growth regulator suggest that this chemical, if used properly, might control the initiation of flower primordia, delay or hasten the expression of symptoms accompanying the flowering process, and exert a measure of control over general plant growth.

In the experiments which follow, field, greenhouse, and storage tests were conducted on a large enough scale such that the results should give some definite suggestions as to the possibilities of maleic hydrazide as a plant growth substance for controlling flowering in celery, and as a chemical means of promoting the retention of market and edible quality in the storage celery.

IV. EXPERIMENTAL

General

The principle parts of these investigations, concerned with the effects of maleic hydrazide on the growth and development of celery, included two field plantings, one in the greenhouse, two storage experiments, and a series of fresh tissue analyses of plants started in the greenhouse and later transplanted to the field. The first field experiment was conducted in 1951 and the second in 1952. The greenhouse experiment was conducted during the fall and winter months of 1951-1952. The storage experiments were conducted during the fall of 1951 and the summer of 1952. The fresh tissue analyses were performed on celery grown during the spring and summer of 1951.

The Response of Celery Plants to Maleic Hydrazide as Influenced by Nitrate Levels and Temperature (1951)

Methods and procedure. Plants were started in the greenhouse and then transplanted to the field. Seed of Cornell 19 celery (Stock No. 31562, obtained from Ferry-Morse Seed Co., Detroit, Michigan) were sown February 18, 1951, in wooden flats which contained a 50-50 mixture of steam sterilized muck soil and fine sand. The flats were then placed in a 65° F house for germination. Early it was observed that the celery seed remained in a quiescent condition for four weeks when placed in an 80-85° F (night temperature) house, but germinated within a two-week period when held at 60° F night temperature. On March 13, four weeks after germination, the seedlings were transplanted into flats (three inches apart each way) which contained a 75-25 mixture of steam sterilized muck soil and fine sand, respectively. The plants remained at this spacing in the flats until they were set into the field on May 15. All plants were grown in a greenhouse maintained at 65° F night temperature until May 1.

The experiment was designed to determine, in a general way, some of the effects of maleic hydrazide, nitrogen, and temperature on the growth and development of Cornell 19 celery. Constant levels of phosphorus and potassium were maintained continuously while the plants were growing in the flats. The two nutrients were applied to the soil in solution form as parts per million (ppm) from chemically pure nutrient salts. Potassium was maintained in the soil solution at 30 ppm and phosphorus at 5 ppm. Nitrogen, on the other hand, was maintained at three different levels in the soil solution: 10, 20, and 75 ppm. Soil analyses were made each week to determine the nutrient status of the soil in the flats and for maintaining the proposed nutrient levels. All nutrients were applied weekly to maintain the above desired levels.

The 30 ppm potassium level was easily maintained with little further addition of nutrient solution once the desired level had been obtained. It was very difficult, however, to obtain and maintain the desired phosphorus level of 5 ppm. Several times the required amount of phosphorus was added at weekly intervals in solution form with little change in extractable phosphorus. The difficulty of obtaining the required phosphorus level suggests high phosphorus fixation in the soil mixture (39). The Spurway system (52) for determining active soil nutrients was used in all instances. The three nitrogen levels were fairly easily maintained.

On May 1, one-half of all flats, which contained twenty plants each, were moved from the greenhouse to an adjacent coldframe for the plants to receive a low temperature ($40 \pm 5^{\circ}$ F) treatment, and one-half were retained in the greenhouse at 65° F night temperature.

Water solutions of the 30 per cent formulation of the diethanolamine salt of maleic hydrazide (obtained from the United State Rubber Company, Naugatuck Chemical Division, Naugatuck, Conn.) were applied to the foliage of the celery plants also on May 1. The concentrations of maleic hydrazide applied were 25, 50, 100, and 250 ppm. Non-treated plants served as controls. No further application of maleic hydrazide was made through the duration of the experiment. All maleic hydrazide concentrations were applied with a three-gallon knapsack sprayer, using Dreft (one-tenth of one per cent solution) as a wetting agent.

On May 15, the plants were transplanted to a field of muck soil at the Michigan State College Muck Experimental Farm ten miles north of East Lansing, Michigan.

A split-plot experimental design was utilized in the field for evaluating the various treatments applied to the celery plants. The design consisted of three main blocks which corresponded to the three different nitrogen levels (10, 20, and 75 ppm). Ammonium nitrate, monocalcium phosphate, and potassium chloride were used as sources of nitrogen, phosphorus, and potassium, respectively. Each main nitrogen block contained plots of celery plants which had received four concentrations of maleic hydrazide (25, 50, 100, and 250 ppm), controls, and two temperatures ($40 \pm 5^{\circ}$ F and 65° F) with all possible combinations of these factors. The design further consisted to two randomized replications of each chemical and temperature treatment within each block. Twenty plants of a given treatment, comprising a single plot, were set six inches apart in rows that were thirty inches apart and ten feet long. The complete design consisted of 1200 celery plants.

One week before the plants were set in the field, 2000 pounds per acre of 0-10-30 fertilizer and 500 pounds of salt (NaCl) were broadcast and disked into the soil. On May 21 and June 12 an additional 1000 pounds per acre of 0-10-30 fertilizer was banded three inches from the plants and two inches deep. No effort was made to maintain specific levels of phosphorus and potassium after the plants had been transplanted to the field. However, ammonium nitrate was banded as described above for phosphorus and potassium at weekly intervals from May 20 to June 25 for the purpose of maintaining to a degree the three (10, 20, and 75 ppm) levels of nitrogen.

Results. Definite morphological differences in celery plants were observed by June 25, about 55 days after the application of maleic hydrazide was made. Figures 1 and 2 show the appearance of representative plants from different treatments. The higher the concentrations of maleic hydrazide applied, the greater were the morphological effects produced, and the degree of vegetative growth inhibition. There was also a difference in effect of maleic hydrazide on vegetative growth depending upon the nitrate level of the soil in which the plants were growing and upon previous temperature treatments. Plants which had received a low temperature ($40 \pm 5^{\circ}$ F) treatment before transplanting to the field, showed less maleic hydrazide injury than those which did not receive a low temperature treatment. It was also observed that plants grown at high nitrate levels and treated with high concentrations of maleic hydrazide were injured to a greater extent than plants grown at low nitrate levels and similarly treated with high maleic hydrazide concentrations (Figures 1 and 2).

High concentrations of maleic hydrazide were also observed to inhibit root growth. Concentrations which killed or greatly inhibited vertical growth of the celery growing points caused an enormous stem enlargement. This

Figure 1. The effects of temperature and low nitrogen level (10 ppm) on the response of celery plants to maleic hydrazide.

Left: control, low temperature (40 ± 5^{o} F)
Center: 250 ppm maleic hydrazide, low temperature (40 ± 5^{o} F)
Right: 250 ppm maleic hydrazide, high temperature (65^{o} F)

Figure 2. The effects of temperature and high nitrogen level (75 ppm) on the response of celery plants to maleic hydrazide.

Left: control, low temperature ($40 \pm 5^\circ$ F)
Center: 250 ppm maleic hydrazide, low temperature ($40 \pm 5^\circ$ F)
Right: 250 ppm maleic hydrazide, high temperature (65° F)

inhibition of vertical stem growth was accompanied in many instances by the vigorous sucker growth or laterals.

On June 10, about forty days after the date of maleic hydrazide application, many of the plants were recovering from injury induced by the high maleic hydrazide treatments. Thus, to a degree, the inhibition in growth from high concentrations of maleic hydrazide was temporary. Plants which received a low temperature treatment before transplanting to the field recovered to a greater degree than those which did not receive a low temperature treatment.

Maleic hydrazide, nitrogen, and temperature, separately and in combination influenced seedstalk development in Cornell 19 celery (Table I). The effects of the interaction of nitrogen and maleic hydrazide on the per cent seedstalk formation at various dates during the growing season are given. Low temperature exposure (two weeks in a coldframe prior to field transplanting) had a positive influence on seedstalk development, but the differences were not statistically significant. These data show that as the concentration of maleic hydrazide was increased from 25 to 100 ppm, the per cent of seedstalks that formed also increased. At 250 ppm, maleic hydrazide decreased seedstalk development during the early stages of plant growth. This was perhaps because of injury to the growing tips caused by the high, somewhat toxic, concentration. As the plants reached marketable maturity, those which received a high (250 ppm) concentration of maleic hydrazide showed a greater per cent

TABLE I

THE EFFECT OF VARIOUS CONCENTRATIONS OF MALEIC HYDRAZIDE AND LEVELS OF NITROGEN ON PER CENT SEEDSTALK FORMATION IN CORNELL 19 CELERY AT VARIOUS TIMES DURING THE GROWING SEASON (1951)*

Maleic hydrazide (ppm)	Dates of observation											
	June 21			July 5			July 18			August 3		
	NO_3 levels (ppm)			NO_3 levels (ppm)			NO_3 levels (ppm)			NO_3 levels (ppm)		
	10	20	75	10	20	75	10	20	75	10	20	75
0	20**	49	52	22	52	65	24	52	65	24	52	65
25	32	70	49	34	71	54	34	71	54	34	71	54
50	45	42	36	50	45	54	50	45	54	50	45	54
100	54	66	56	57	74	64	57	70	70	59	70	70
250	21	29	17	56	31	31	74	64	47	74	65	59
Means	34.4	51.0	42.0	43.8	54.6	53.6	47.8	60.4	58.0	48.2	60.6	60.4
Least differences necessary for significance												
5% level	19.6	28.3	27.2	18.2	40.5	30.2	16.2	29.8	33.8	16.7	35.7	26.2
1% level	27.5	39.7	38.2	25.6	56.8	42.4	22.7	41.8	47.3	23.4	50.1	36.7

*No significant differences were noted between temperatures
**Average percentages for four replications

of seedstalk formation than was evident in earlier periods of growth.

In a consideration of the means of all treatments, with plants grown at the medium nitrate level (20 ppm) there was a greater percentage of seedstalks formed than at either the low (10 ppm) or high (75 ppm) nitrate level. Generally with plant receiving no chemical treatments (controls) the percentage of seedstalks increased with an increase in nitrate level.

Maleic hydrazide not only caused a greater percentage of seedstalk formation in certain instances, but also larger and more extensive inflorescences were observed. One hundred parts per million, in most instances, appeared optimum for seedstalk induction.

Generally those factors which caused a greater per cent of seedstalk formation also caused an increase in the average height of inflorescences borne by the seedstalks. An exception is noted where the nitrogen level was high. Table II gives a statistical evaluation of seedstalk height measurements. In general, the heights in relation to treatment correspond directly to the percentages given in Table I.

The Response of Celery Plants to Maleic Hydrazide as Affected by Temperature and Various Times of Application (1952)

Methods and procedure. The second field experiment was designed to determine in a more extensive and in a more

TABLE II

THE EFFECT OF VARIOUS CONCENTRATIONS OF MALEIC HYDRAZIDE AND LEVELS OF NITROGEN ON AVERAGE HEIGHTS OF SEEDSTALKS DEVELOPED IN CORNELL 19 CELERY AT VARIOUS TIMES DURING THE GROWING SEASON (1951)

Maleic hydrazide (ppm)	Dates of measurements											
	June 21			July 5			July 18			August 3		
	NO_3 levels (ppm)			NO_3 levels (ppm)			NO_3 levels (ppm)			NO_3 levels (ppm)		
	10	20	75	10	20	75	10	20	75	10	20	75
0	1.10*	2.75	3.75	1.50	4.12	6.25	4.25	10.50	14.15	7.62	18.95	23.30
25	1.65	4.55	3.80	2.30	6.75	5.90	6.52	16.52	14.15	11.65	26.97	21.35
50	2.67	2.50	2.22	3.97	3.77	4.32	10.75	10.12	10.57	18.35	16.97	18.07
100	2.15	3.97	4.82	2.75	5.95	7.57	8.22	14.95	17.37	15.50	25.75	25.77
250	1.05	1.27	0.59	3.40	2.10	2.07	10.32	10.07	8.47	19.95	21.12	16.32
Means	1.72	3.00	3.60	2.78	4.54	5.22	8.01	12.43	12.94	14.61	21.95	20.96
Least differences necessary for significance												
5% level	1.04	1.52	2.39	1.69	2.39	3.05	3.26	6.73	6.58	6.10	12.20	11.48
1% level	1.46	2.13	3.36	2.38	3.36	4.27	4.58	9.43	9.22	8.55	17.10	16.09

*Represents average height in inches

detailed manner some of the physiological responses of Cornell 19 celery to various concentrations of maleic hydrazide applied at different stages of growth as affected by exposure of the young plants to two temperatures. Seed was sown January 13, 1952, in flats which contained the usual 50-50 mixture of steam sterilized muck soil and fine sand. Five weeks after germination on March 24, the seedlings were transplanted into flats being set two inches apart each way, with each flat containing approximately 100 seedlings. The flats contained the usual growing medium of a steam sterilized mixture of 75 parts muck and 25 parts of fine sand. The plants in all flats were given a weekly feeding of major and certain minor nutrients to ensure good growth and maintain uniform nutrient levels for all plants prior to differential temperature exposure and treatment with maleic hydrazide. Four weeks after transplanting to the flats, weekly application of nutrient solutions were discontinued.

On May 1, one-half of all flats were placed in an adjacent coldframe so that the plants might receive a low night temperature ($40 \pm 5^{\circ}$ F) treatment, and the other half of the flats were left inside the greenhouse at 65° F night temperature. Also, at this time, both the inside and outside groups of plants were divided into 12 lots to facilitate the later application of maleic hydrazide sprays. The first spray application of maleic hydrazide was made on April 16. (Note Table III for the spray schedule that was

TABLE III

CONCENTRATIONS OF MALEIC HYDRAZIDE APPLIED TO CORNELL 19 CELERY WITH CORRESPONDING DATES OF APPLICATION*

Date of application	Maleic hydrazide concentrations (ppm)				
April 16, 1952	0	8	15	25	33
April 23, 1952	0	25	50	75	100
April 30, 1952	0	50	100	200	300
May 7, 1952	0	50	100	200	300
May 14, 1952	0	50	100	200	400
May 21, 1952	0	50	100	200	400
May 28, 1952	0	50	100	250	500
June 4, 1952	0	50	100	250	500
June 11, 1952	0	100	250	500	1000
June 18, 1952	0	100	250	500	1000
June 25, 1952	0	100	250	500	1000
July 2, 1952	0	100	250	500	1000

*At both temperatures

followed throughout the course of this experiment).

One-twelfth of all plants, including both those which were placed into the coldframe to receive a low temperature treatment and those which remained in the greenhouse, were sprayed with a range of maleic hydrazide solutions weekly. A three-gallon knapsack sprayer was used to apply the solutions. Thus, over a 12-week period, the maleic hydrazide spray schedule was completed. Spray applications made on April 16, 23, 30, May 7 and 14 were applied to the plants while they were still in the flats prior to field transplanting, and those made between May 21 and July 2 inclusive, were applied after the plants had been set into the field. The maleic hydrazide spray schedule commenced with four-inch plants and was completed when the plants were approximately 15 inches tall. The second field experiment was established on the Michigan State College Muck Experimental Farm in approximately the same location as the first, (1951), field experiment.

All plants were set in the field between May 15 and 17. The soil was well prepared and 2000 pounds of 0-10-30 fertilizer and 500 pounds of salt (NaCl) were added per acre as broadcast applications one week before the plants were transplanted.

The plants were placed according to a field design consisting of 12 blocks, which corresponded to the 12 different dates of spray applicate (Table III). Each block contained forty ten-foot rows and each ten-foot row contained twenty celery plants. The blocks were further divided into twenty rows of plants that received low temperature treatments and twenty rows which did not receive a low temperature treatment. Within each temperature group there were four maleic hydrazide treatments and a control each of which was replicated four times pertaining to each block or date of spray application. Thus a single block comprised a total of 800 celery plants and 9600 celery plants were included in the complete experiment. Dates of application, temperature exposures, maleic hydrazide concentrations including controls, and replications were randomized in the design.

Though four maleic hydrazide concentrations and a control were used on each date of spray application, the concentrations were increased according to the degree of plant development. Thus, the highest concentration of maleic hydrazide applied on April 16, the first date of spray application, when the plants were six inches tall, was 33 ppm; while the highest concentration applied on the last date of spray application, July 2, after the plants had reached a height of approximately 15 inches, was 1000 ppm. Therefore, concentrations of maleic hydrazide were applied in an increasing order based upon age or stage of development of the plants. This procedure was deemed necessary to prevent serious injury to the growing plants in the younger stages of growth which were found in previous tests to be very susceptible to injury with maleic hydrazide.

Results.

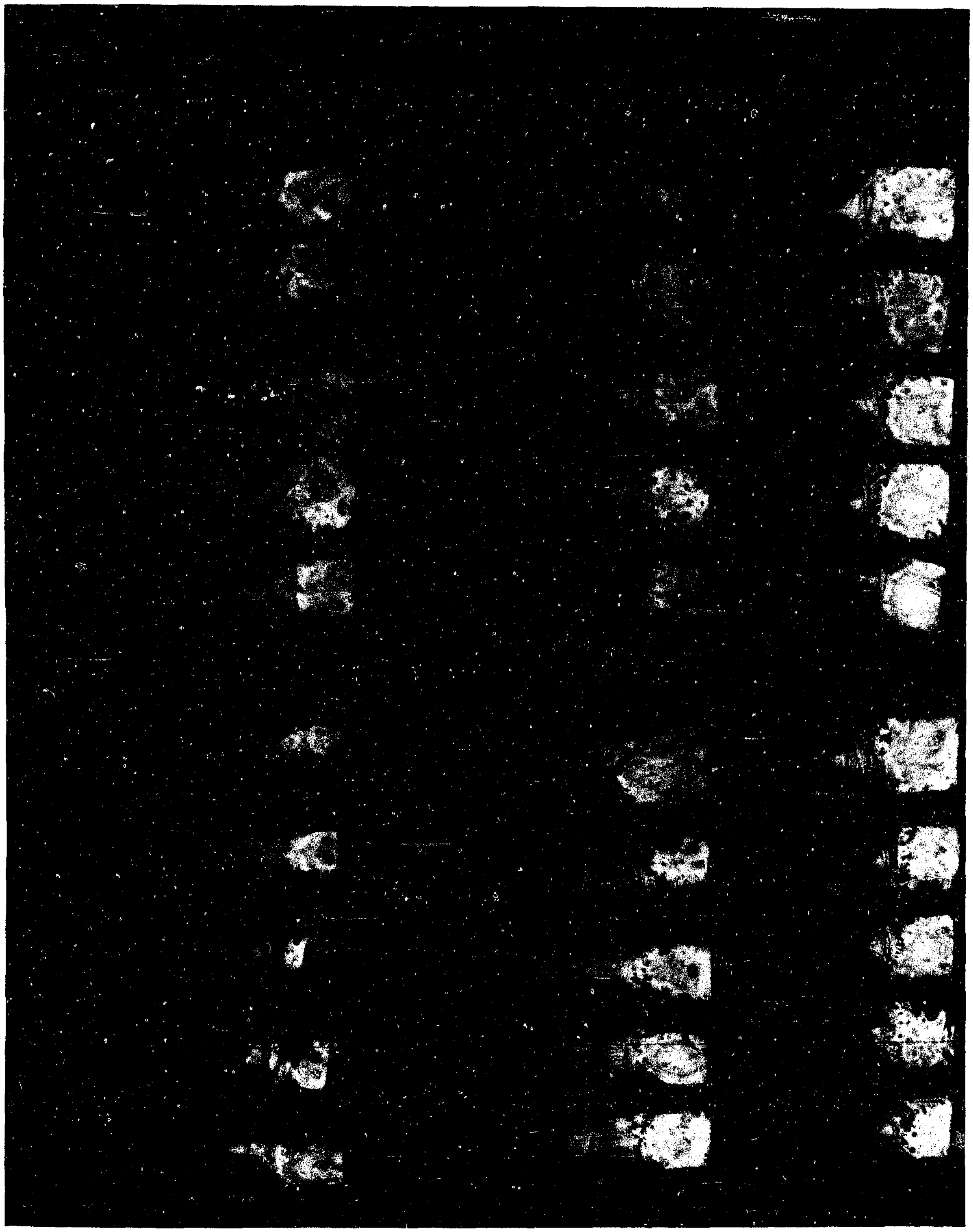
a. Relative injury by maleic hydrazide. About one month after transplanting the plants to the field, it could be observed that those plants which received from 200 to 400 ppm of maleic hydrazide during the earlier stages of growth were beginning to turn yellow, and many of them were dead about seven weeks following spray application. As plants approached maturity the application of maleic hydrazide concentrations of 200 to 400 ppm was not injurious. Therefore whether or not a particular concentration of maleic hydrazide was injurious to vegetative growth, depended largely upon the age of the celery plants at the time of treatment.

b. Effect of maleic hydrazide on seedstalk initiation. Randomized samples of whole plants from the different treatments were collected at weekly intervals between July 2 and August 15 to determine the effect of different concentrations of maleic hydrazide on seedstalk initiation. To ascertain whether or not seedstalk initiation had taken place, all petioles were removed from the plants to expose the growing points. In Figure 3 the seedstalk initials are illustrated which resulted from maleic hydrazide application to 13 - 17-week old celery plants. Plants represented in Figure 3 received a low temperature treatment before transplanting to the field. Maleic hydrazide applied at 100 ppm significantly increased seedstalk initiation as compared to non-treated controls when applied to 17 - 20-week old celery

Figure 3. Growth of seedstalk initials in "cold induced" Cornell 19 celery plants as influenced by early applications of maleic hydrazide.

Top: Left, 100 ppm maleic hydrazide applied April 23
Right, 100 ppm maleic hydrazide applied April 30
Center: Left, 100 ppm maleic hydrazide applied May 7
Right, 100 ppm maleic hydrazide applied May 14
Bottom: Left, 100 ppm maleic hydrazide applied May 21
Right, control

Photographed July 2, 1952



plants. These results were observed on July 2, approximately ten weeks after maleic hydrazide was applied.

Though maleic hydrazide had a greater effect on seedstalk initiation in plants which received a low night temperature ($40 \pm 5^\circ$ F) exposure before transplanting to the field, it also had a significant effect on seedstalk initiation in those plants which did not receive a low night temperature (65° F continuously) treatment before transplanting to the field. Figure 4 represents seedstalk initials of celery plants which did and which did not receive a cold induction period before they were transplanted to the field. It is quite obvious from Figure 4 that maleic hydrazide at 100 ppm caused seedstalk initiation in celery plants which had not received a cold induction period prior to field transplanting. Concentrations of maleic hydrazide below 75 ppm were relatively ineffective in promoting seedstalk initiation in plants which were approximately 18 weeks old at the time of treatment if they had not been exposed to low night temperatures before transplanting to the field.

Age or size of the celery plants at the time of treatment with maleic hydrazide and concentrations of maleic hydrazide applied were found to be very important in affecting subsequent plant development. The length of seedstalk initials observed were related to the age of the celery plants and the maleic hydrazide concentrations applied. Seedstalk initials illustrated in Figures 5 and 6 show that

Figure 4. Growth of seedstalk initials in "cold" and "not cold induced" Cornell 19 celery plants as influenced by early maleic hydrazide application (May 7).

Top: cold induced
Bottom: not cold induced
Columns: Left to right, 0, 50, 75, and 100 ppm maleic hydrazide

Photographed July 2, 1952

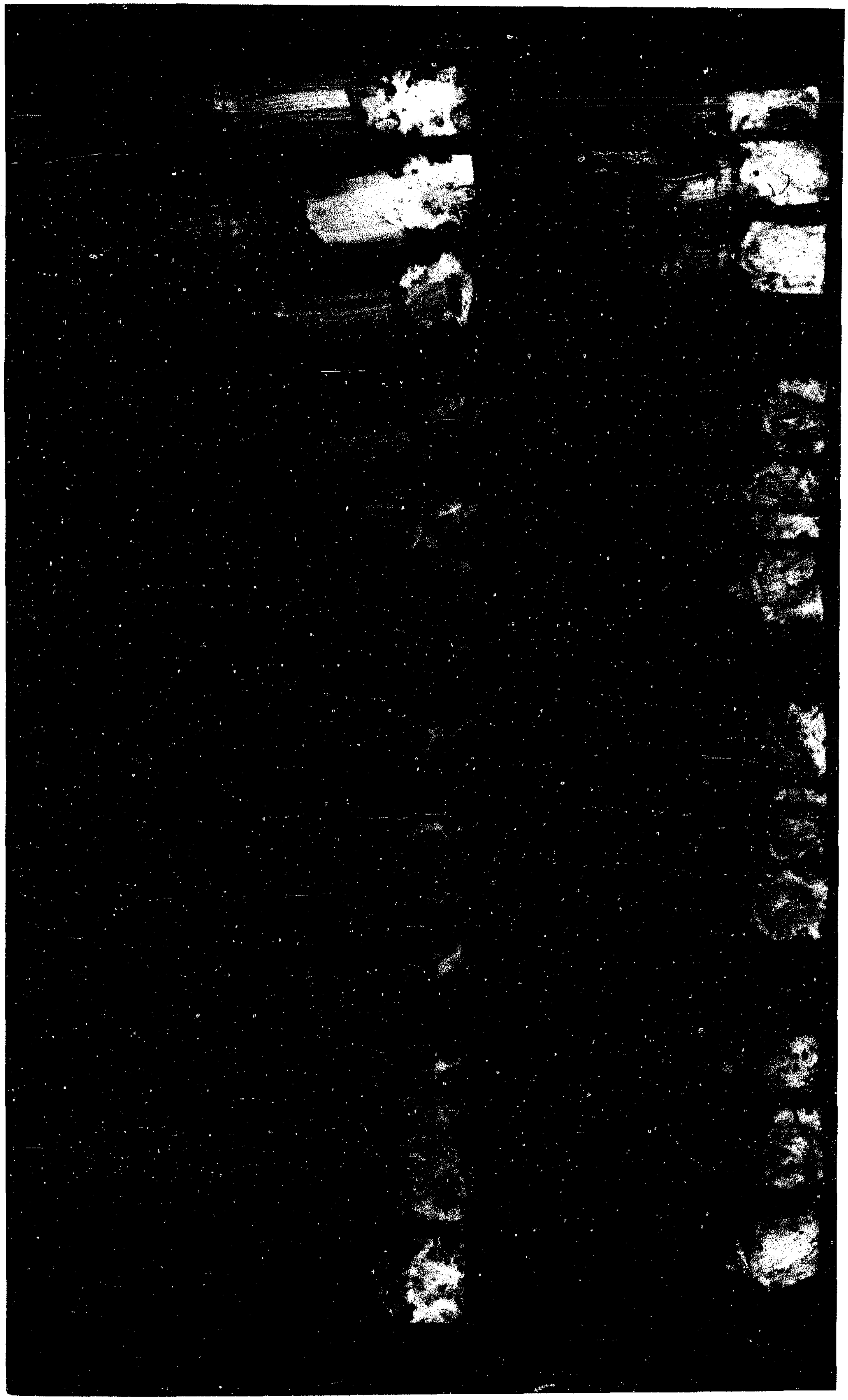


Figure 5. Growth of seedstalk initials in "cold induced" Cornell 19 celery plants as influenced by early maleic hydrazide applications.

Top: May 7
Center: April 30
Bottom: April 23
Columns: Left to right, 0, 50, and 100 ppm maleic hydrazide

Photographed July 2, 1952

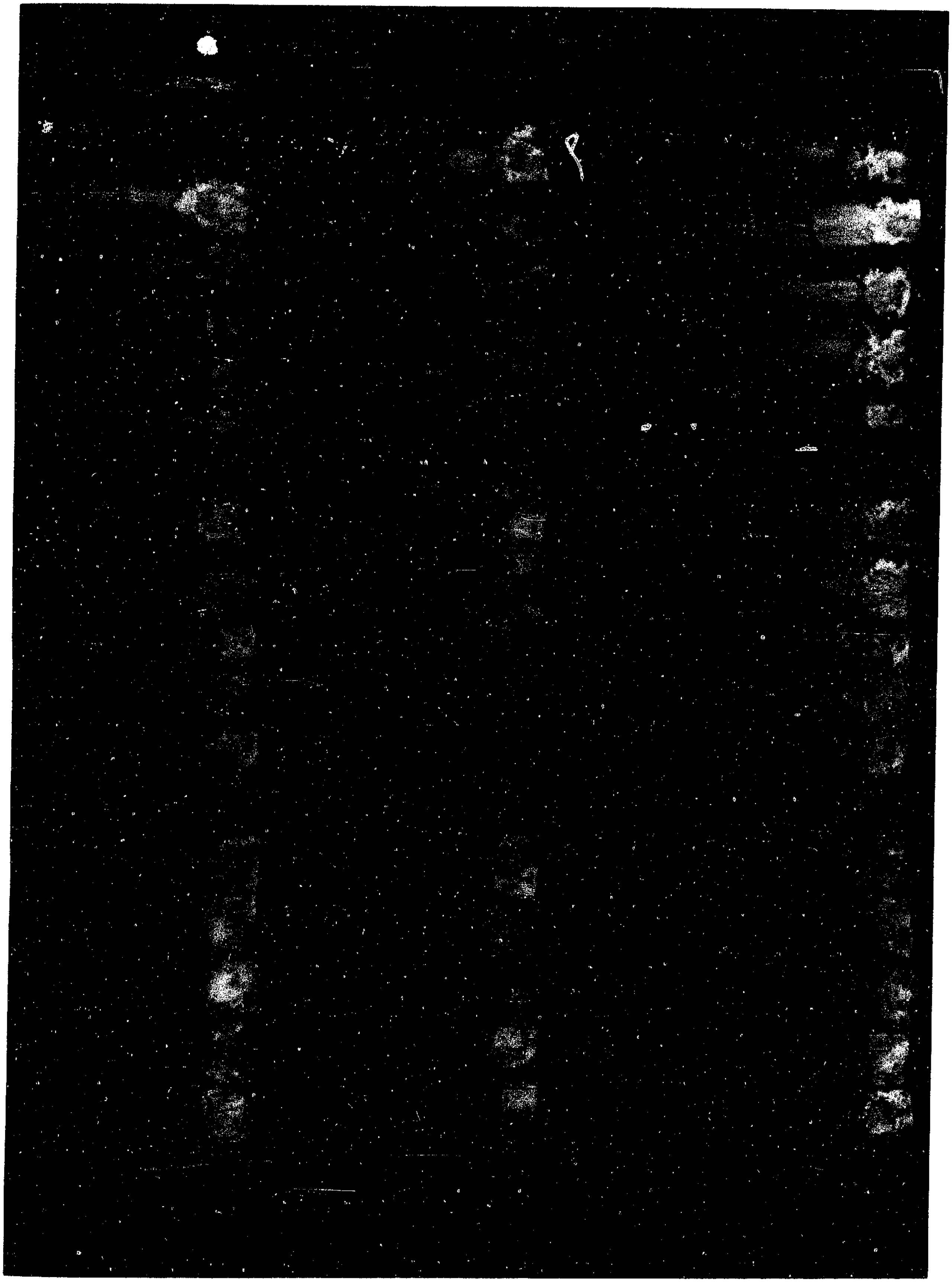
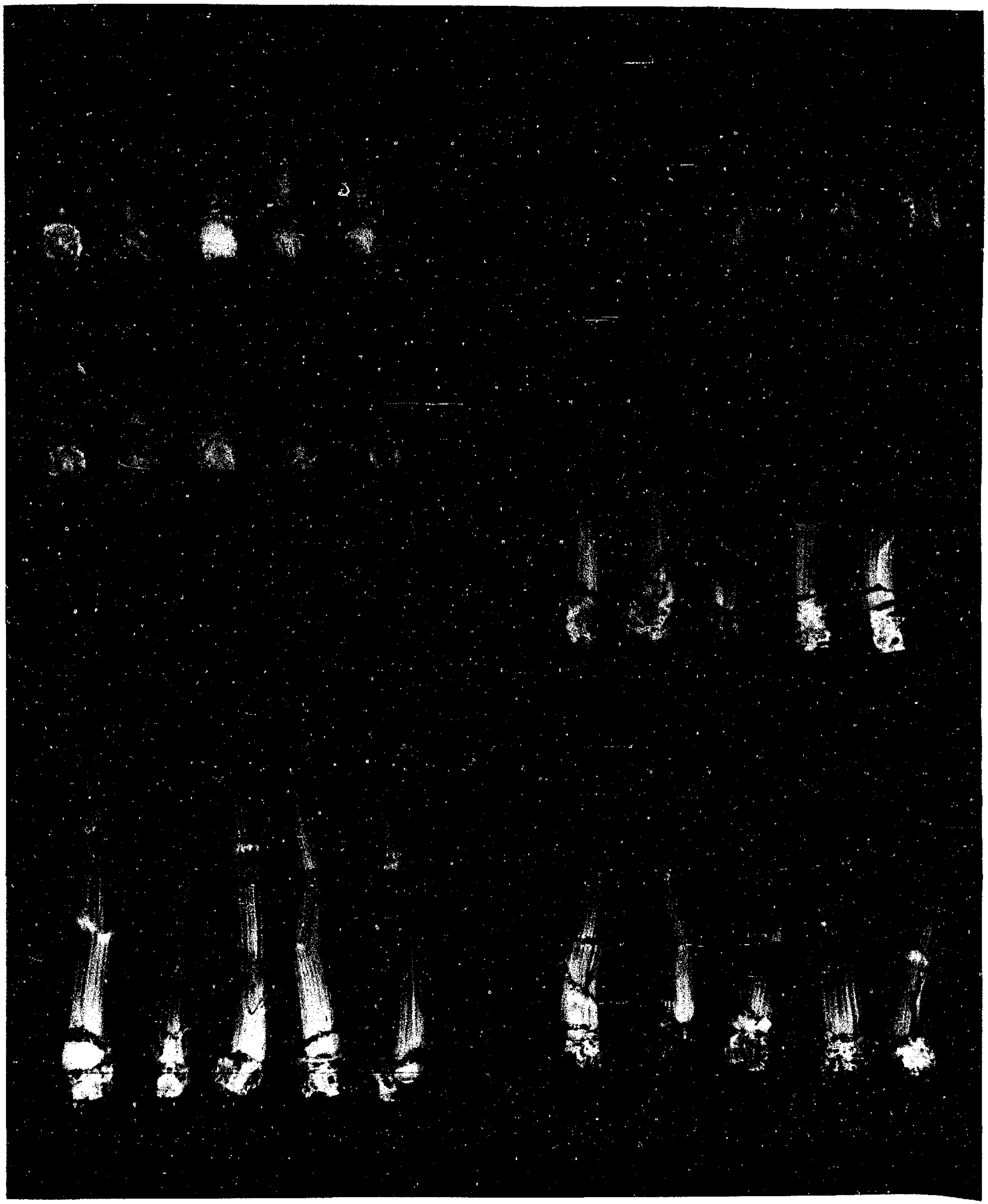


Figure 6. Growth of celery seedstalk initials in "cold induced" celery plants as influenced by age of plants when treated with 100 ppm of maleic hydrazide.

Left column:	Top,	control
	Center,	May 21
	Bottom,	April 23
Right column:	Top,	May 14
	Center,	May 7
	Bottom,	April 30

Photographed July 14, 1952



early applications of maleic hydrazide induced bolting earlier than was observable in the control plants. This was true regardless of whether or not the plants had been exposed to low night temperatures before transplanting to the field.

c. Effect of maleic hydrazide on seedstalk inhibition. In direct opposition to the stimulation effects of early applications of maleic hydrazide on the formation and growth of seedstalk initials, inhibition of seedstalk elongation was observed on plants which received high concentrations (500 - 1000 ppm) of maleic hydrazide during the later stages of plant development subsequent to the initiation of flowering, but before bolting was yet evident.

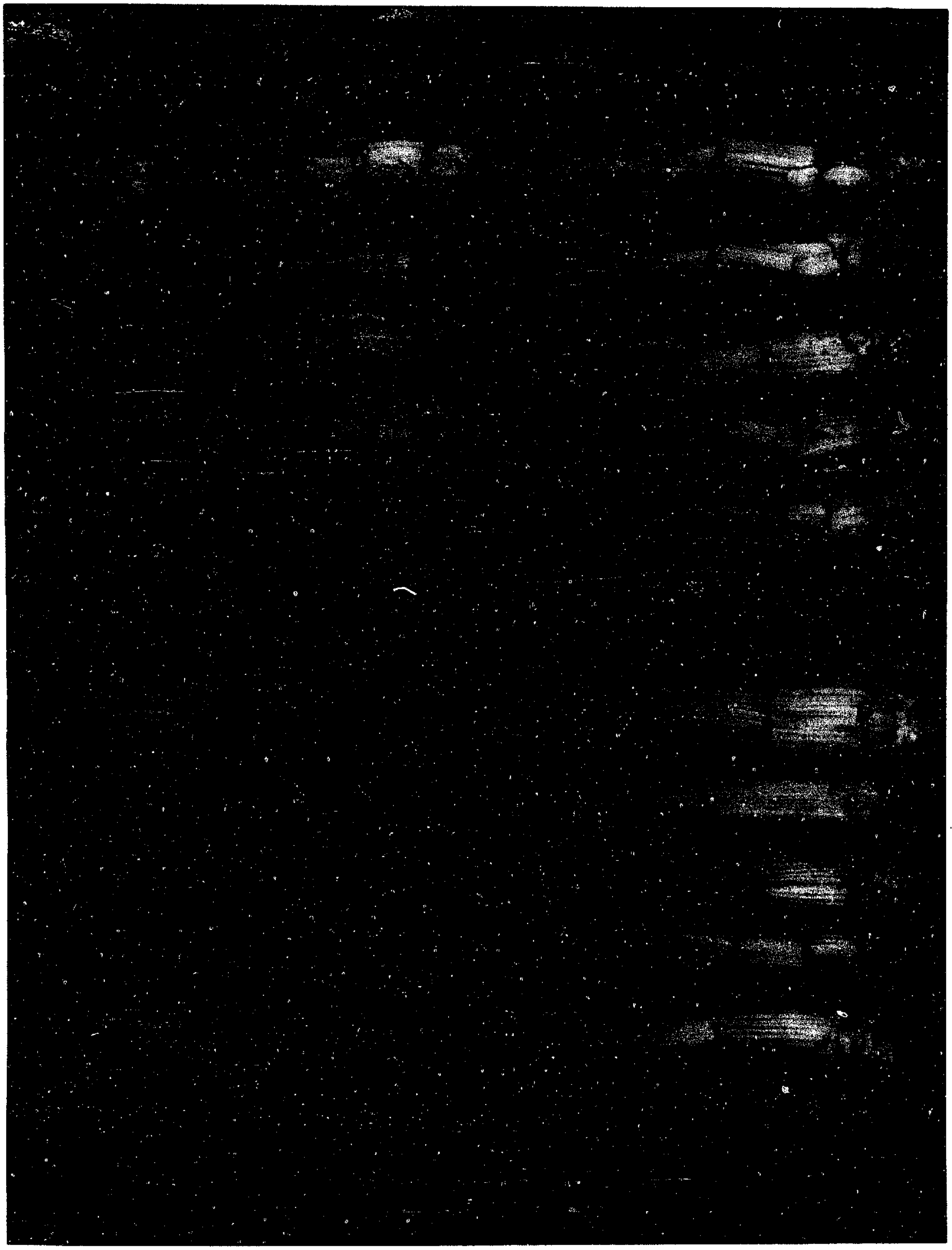
In Figure 7 is illustrated seedstalk initials from celery plants which received relatively low (100 - 250 ppm) and relatively high (500 - 1000 ppm) concentrations of maleic hydrazide applied with respect to the later stages of growth. Results of these studies indicated that early and low concentrations of maleic hydrazide (100 - 250 ppm) induced seedstalk initiation and elongation while later and high concentrations (500 - 1000 ppm) inhibited seedstalk elongation. Celery plants in their early stages of growth and development cannot usually tolerate concentrations of maleic hydrazide exceeding 100 ppm.

d. Appearance and development of inflorescences. Plants which received maleic hydrazide that caused early

Figure 7. Growth of seedstalk initials in "cold induced" Cornell 19 celery plants as influenced by increased concentrations of maleic hydrazide applied June 18.

Left column: Top, 500 ppm maleic hydrazide
Bottom, 100 ppm maleic hydrazide
Right column: Top, 1000 ppm maleic hydrazide
Center, control
Bottom, 250 ppm maleic hydrazide

Photographed July 28, 1952



seedstalk initiation were generally those on which flower buds and anthesis could first be observed. An exception to this general observation was noticed on those plants which received early applications of maleic hydrazide and were not cold induced before setting in the field.

Although 100 ppm of maleic hydrazide caused the earliest observable seedstalk initials in plants which did not receive a cold induction exposure before transplanting to the field, this same concentration caused a retardation in later floral development. Inflorescences developed faster and reached a greater final height on those plants which received 75 rather than 100 ppm of maleic hydrazide. The retardation in the development of seedstalks from 100 ppm of maleic hydrazide applied in the early growing stages of celery plants likely resulted from slight injury at this concentration. Figure 8 shows from left to right the effect of 75, 0, and 100 ppm of maleic hydrazide on the development of inflorescences on celery plants that did not receive a cold induction period. The absence of development of inflorescences or seedstalks on celery plants which received high concentrations of maleic hydrazide (500 and 1000 ppm) applied during the later stages of growth is illustrated in Figure 9. A marked inhibition in vegetative growth was observed from the application of 1000 ppm of maleic hydrazide on July 2.

e. Statistical analyses of data on seedstalk formation. To determine the variable effects of temperature, concen-

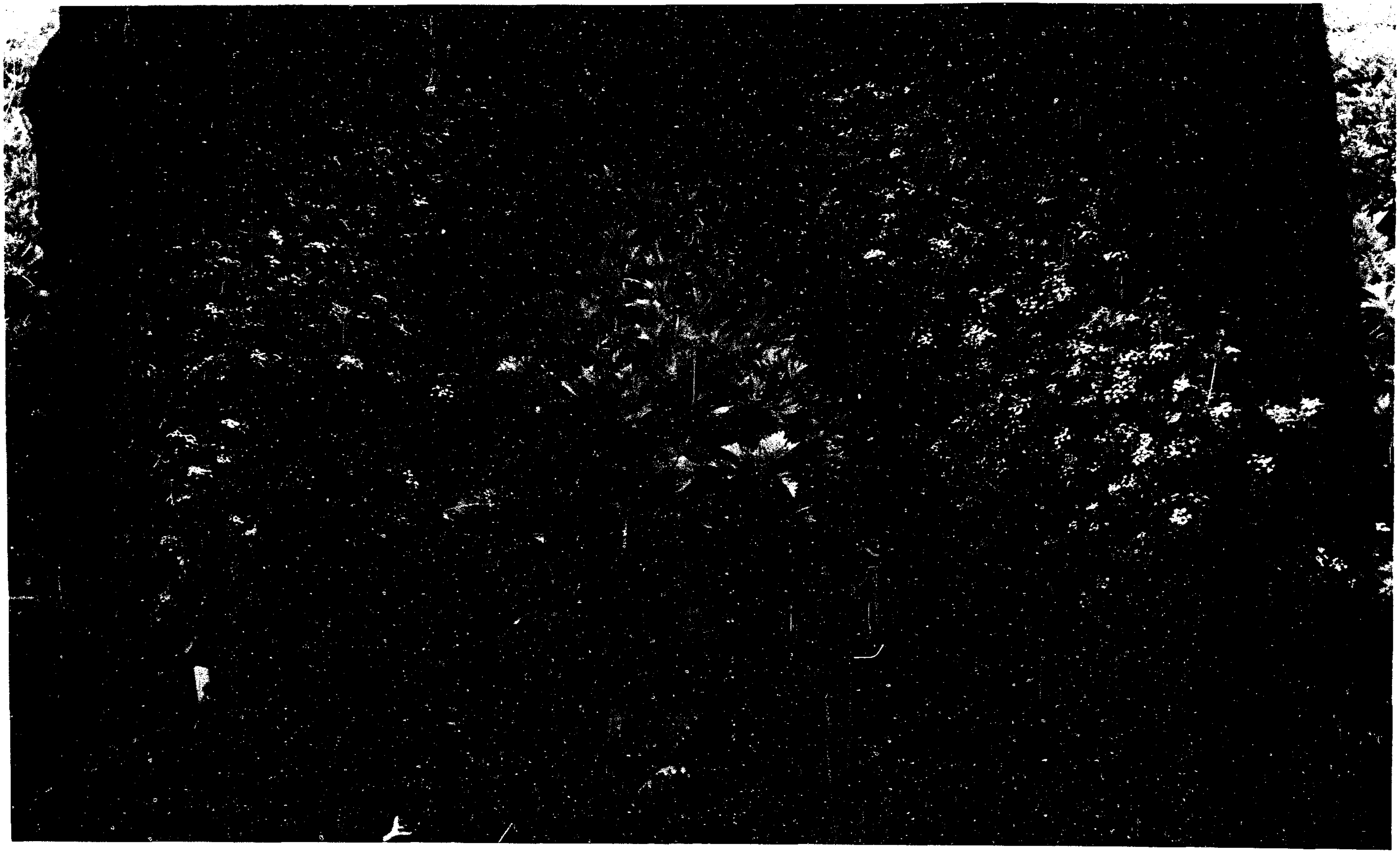


Figure 8. The influence of early applications of maleic hydrazide applied April 23 on the growth and development of inflorescences in "not cold induced" Cornell 19 celery plants.

Left to right: 75, 0, and 100 ppm maleic hydrazide

Photographed August 15, 1952

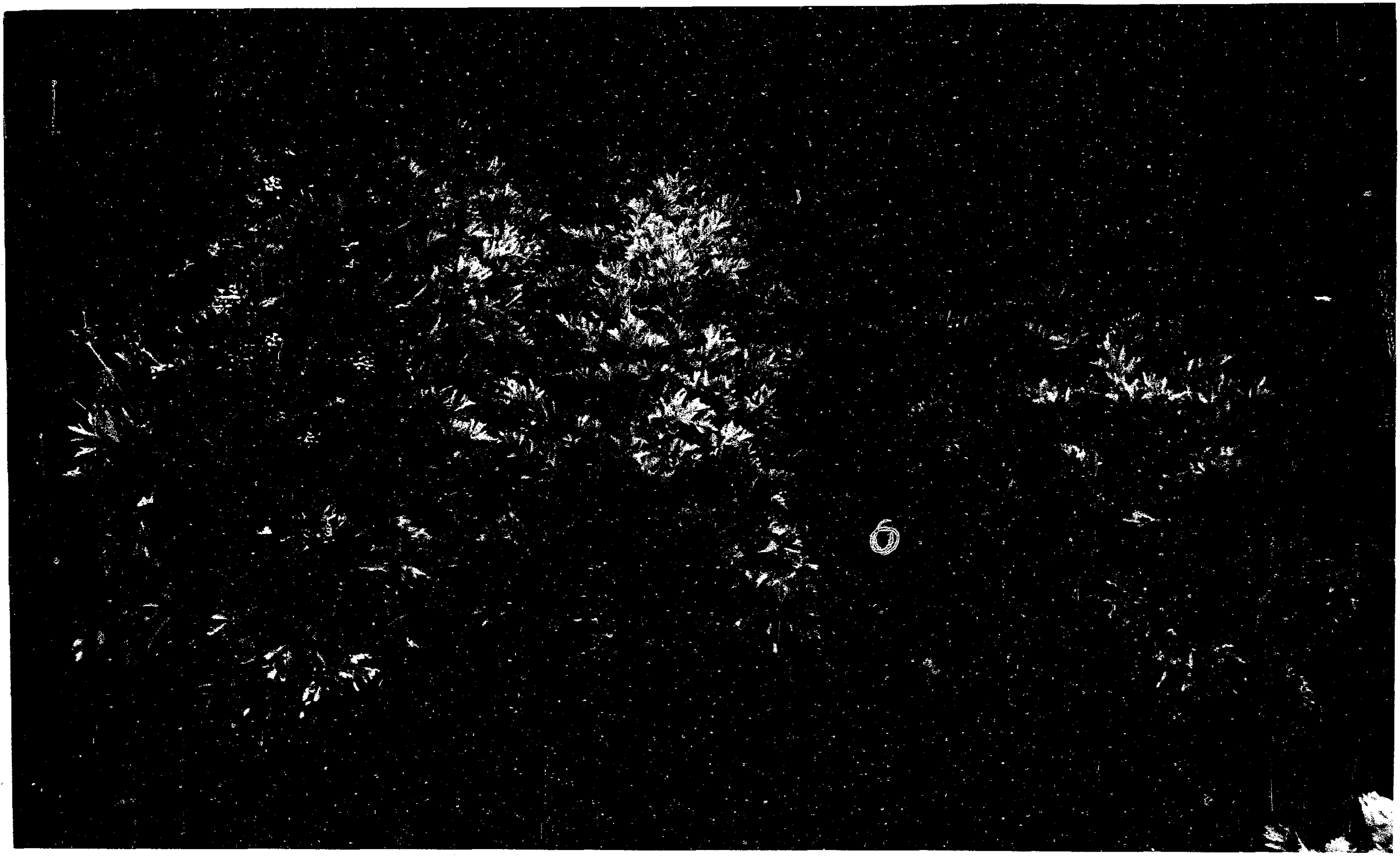


Figure 9. The influence of high concentrations of maleic hydrazide applied July 2, on the growth and development of inflorescences in "cold induced" Cornell 19 celery plants.

Left to right: 0, 1000, and 500 ppm maleic hydrazide

Photographed August 15, 1952

tration, and time of application of maleic hydrazide on the per cent seedstalk formation in all treatments, each celery plant was examined for floral initiation. Information on the earliness of seedstalk initiation was more accurately obtained by collecting randomized samples of whole plants at weekly intervals from July 2 to August 15 from all treatments. Data on the per cent seedstalks and the average height of seedstalks that had formed by August 25 are shown in Tables IV and V, respectively. There were significant increases in per cent seedstalks that were formed on celery plants which received early applications of maleic hydrazide as compared with those which received the later applications. There were also significant increases in bolting percentages in plants which received a cold induction period before transplanting to the field in contrast to those which did not receive a cold induction period, but were held at 65° F night temperature until transplanted to the field. In all instances, a greater number of cold induced plants bolted than those which were not cold induced.

Table V presents the average heights of seedstalks in plants treated with maleic hydrazide on the various dates. A definite correlation exists between the per cents of seedstalks that were formed and the average heights of the seedstalks. Generally those conditions which caused the highest percentages of seedstalks also caused the greatest average heights of these seedstalks. The average height of seedstalks was greater from plants which were cold induced and received

TABLE IV

THE EFFECT OF TWELVE DATES OF APPLICATION OF MALEIC HYDRAZIDE AND TWO TEMPERATURES (40 ± 5^{o} F and 65^{o} F) ON PER CENT OF PLANTS WHICH HAD FORMED SEEDSTALKS ON AUGUST 25, 1952 IN CORNELL 19 CELERY

Temperature	Dates of application												Means
	April			May				June				July	
	16	23	30	7	14	21	28	4	11	18	25	2	
40 ± 5^{o} F	83.85	64.50	60.75	55.75	59.50	63.75	64.50	72.25	48.90	51.40	32.00	42.25	58.28
65^{o} F	31.25	60.50	46.00	34.00	43.50	58.25	63.00	56.25	17.25	34.65	12.25	13.25	39.18
Means	57.50	62.50	53.37	44.87	51.50	61.00	63.75	64.25	33.07	43.02	22.12	27.75	48.73

Least differences necessary for significance
Dates x temperatures:
5% level - 20.60
1% level - 27.10

TABLE V

THE INFLUENCE OF TWELVE DATES OF APPLICATION OF MALEIC HYDRAZIDE AND TWO TEMPERATURES (40 ± 5° F and 65° F) ON THE AVERAGE HEIGHT OF SEEDSTALKS WHICH HAD FORMED ON AUGUST 25, 1952 IN CORNELL 19 CELERY

Temperature	Dates of application												Means
	April			May				June				July	
	16	23	30	7	14	21	28	4	11	18	25	2	
40 ± 5° F	26.00	23.05	20.85	20.45	15.80	19.45	22.50	20.25	11.10	12.90	8.15	11.25	17.64
65° F	6.95	19.05	15.45	11.25	10.50	16.70	21.70	10.85	3.25	7.85	2.10	3.00	10.72
Means	16.47	21.05	18.15	15.85	13.15	18.07	22.10	15.55	7.17	10.37	5.12	7.12	14.18

Least differences necessary for significance
Dates x temperatures:
5% level - 7.67
1% level - 10.11

the early applications of maleic hydrazide. Celery plants which were not cold induced and received later applications of maleic hydrazide produced the least number and the shortest seedstalks. With respect to dates of application and concentrations of maleic hydrazide, a significant interaction in percentage of seedstalks formed was noted. There was also a significant difference in the average heights of seedstalks formed based upon the date on which maleic hydrazide was applied and the concentrations used. Tables VI and VII provide data relative to the interaction of dates on which maleic hydrazide was applied and corresponding concentrations. There was also a significant triple interaction between dates x temperatures x concentrations for both per cent seedstalk formation and average heights of observed inflorescences (Tables VIII and IX).

Tables X and XI show that dates, temperatures, and treatments singly and in combinations had significant influences on the percentages of seedstalks formed and the average seedstalk heights attained. In Table X, the analysis of variance table for per cent seedstalk formation, but not for seedstalk height as shown in Table XI, shows there was a significant difference (5% level) between replications. The significance of different factors in Table XI dealing with seedstalk heights corresponds generally to those shown in Table X.

TABLE VI

THE EFFECT OF TIME OF APPLICATION AND VARIOUS CONCENTRATIONS OF MALEIC HYDRAZIDE ON PER CENT SEEDSTALKS WHICH HAD FORMED ON AUGUST 25, 1952 IN CORNELL 19 CELERY

Concentration	Dates of application												Means
	April			May				June				July	
	16	23	30	7	14	21	28	4	11	18	25	2	
0	43.37	41.25	61.87	33.12	28.12	67.50	68.12	57.50	27.50	26.37	26.87	41.25	43.57
1	58.12	58.12	79.37	88.12	68.12	80.00	81.25	62.50	42.50	71.25	40.00	51.25	65.05
2	53.75	71.25	73.12	71.87	75.62	78.75	82.50	65.00	50.62	48.75	35.62	43.75	62.55
3	64.37	79.37	29.37	24.37	46.87	65.62	75.62	73.75	41.25	43.75	7.50	2.50	46.95
4	68.12	62.50	23.12	6.87	38.75	13.12	11.25	62.50	3.50	25.00	0.62	0.00	26.27
Means	57.54	62.49	53.37	44.87	51.49	60.99	63.74	64.25	33.07	43.02	22.12	27.75	48.87

Least differences necessary for significance
Dates x concentrations:
5% level - 20.60
1% level - 27.10

TABLE VII

THE INFLUENCE OF TIME OF APPLICATION AND VARIOUS CONCENTRATIONS OF MALEIC HYDRAZIDE ON THE AVERAGE HEIGHT OF SEEDSTALKS WHICH HAD FORMED ON AUGUST 25, 1952 IN CORNELL 19 CELERY

Concentration	Dates of application												Means
	April			May				June				July	
	16	23	30	7	14	21	28	4	11	18	25	2	
0	12.62	10.62	14.75	7.50	6.75	18.62	20.50	12.25	7.12	5.75	7.75	10.75	11.24
1	15.25	16.12	30.75	35.75	19.62	24.37	26.25	15.37	9.87	17.35	9.75	13.75	19.52
2	14.37	23.00	29.25	25.87	19.37	23.62	30.62	14.75	11.12	13.00	7.00	10.62	18.54
3	19.00	30.37	9.87	8.25	11.37	21.00	26.75	20.37	7.12	10.62	1.00	0.50	13.85
4	21.12	25.12	6.12	1.87	8.62	2.75	6.37	15.00	0.62	5.12	0.12	0.00	7.73
Means	16.47	21.04	18.14	15.84	13.14	18.07	22.09	15.54	7.17	10.36	5.12	7.12	14.17

Least differences necessary for significance
Dates x concentrations:
5% level - 7.67
1% level - 10.11

TABLE VIII

THE EFFECT OF THE INTERACTION OF DATES X TEMPERATURES X CONCENTRATIONS ON PER CENT SEEDSTALKS WHICH HAD DEVELOPED ON AUGUST 25, 1952, IN CORNELL 19 CELERY

Temperature	Concentration	Dates of application												Means
		April			May				June				July	
		16	23	30	7	14	21	28	4	11	18	25	2	
40 ± 5° F	0	70.50	46.25	61.25	41.25	46.25	62.50	66.25	68.75	47.50	43.75	45.00	61.25	55.04
	1	86.25	62.25	78.75	97.50	77.50	76.25	92.50	61.25	52.50	78.75	52.50	72.50	74.04
	2	82.50	78.75	67.50	83.75	83.75	78.75	70.00	70.00	81.25	62.50	53.75	72.70	73.76
	3	90.00	73.75	53.75	42.50	46.25	85.00	71.25	80.00	58.75	60.00	7.50	5.00	56.12
	4	90.00	61.25	42.50	13.75	43.75	16.25	22.50	81.25	4.50	30.00	1.25	0.00	33.92
	Means	83.85	64.45	60.75	55.75	59.50	63.75	64.50	72.25	48.90	55.00	32.00	42.29	58.57
65° F	0	16.25	34.25	62.50	25.00	10.00	72.50	70.00	46.25	7.50	9.00	8.75	21.25	31.93
	1	30.00	53.75	80.00	78.75	58.70	83.75	70.00	63.75	32.50	63.75	27.50	30.00	56.03
	2	25.00	63.75	78.75	60.00	67.50	78.75	95.00	60.00	20.00	35.00	17.50	15.00	51.34
	3	38.75	85.00	5.00	6.25	47.50	46.50	80.00	67.50	23.75	27.50	7.50	0.00	36.27
	4	46.25	63.75	3.75	0.00	33.75	10.00	0.00	43.75	2.50	20.00	0.00	0.00	18.64
	Means	31.25	60.10	46.00	34.00	43.49	58.30	63.00	56.25	17.25	31.05	12.25	13.25	38.84

Least differences necessary for significance
Dates x Temperatures x Concentrations:
5% level - 20.60
1% level - 27.10

TABLE IX

THE EFFECT OF THE INTERACTION OF DATES X TEMPERATURES X CONCENTRATIONS ON THE AVERAGE HEIGHT OF SEEDSTALKS WHICH HAD DEVELOPED AUGUST 25, 1952, IN CORNELL 19 CELERY

Temperature	Concentration	Dates of application												Means
		April			May				June				July	
		16	23	30	7	14	21	28	4	11	18	25	2	
40 ± 5° F	0	22.00	12.75	16.00	9.75	11.25	17.50	19.75	17.50	12.00	9.75	13.50	17.00	14.89
	1	24.00	19.25	30.25	42.00	24.00	22.50	31.00	20.25	13.75	18.50	14.75	17.50	23.14
	2	23.75	28.50	28.25	31.50	22.25	25.00	25.00	18.50	19.00	15.75	11.00	17.75	22.18
	3	30.00	30.25	18.50	15.25	11.00	28.50	24.00	24.50	10.00	14.25	1.25	1.00	17.37
	4	30.25	24.50	11.25	3.75	10.50	3.75	12.75	20.50	0.75	6.25	0.25	0.00	10.37
	Means	26.00	23.05	20.85	20.45	15.80	19.45	22.50	20.25	11.10	12.90	7.95	10.65	17.59
65° F	0	3.25	8.50	13.50	5.25	2.25	19.75	21.25	7.00	2.25	1.75	2.00	4.50	7.60
	1	6.25	13.00	31.25	29.50	15.25	26.25	21.50	10.50	6.00	16.25	4.75	7.00	15.62
	2	5.00	17.50	30.25	20.25	16.50	22.25	36.25	11.00	3.25	10.25	3.00	3.50	14.91
	3	8.00	30.50	1.25	1.25	11.75	13.50	29.50	16.25	4.25	7.00	0.75	0.00	10.33
	4	12.00	25.75	1.00	0.00	6.75	1.75	0.00	9.50	0.50	4.00	0.00	0.00	5.10
	Means	6.90	19.05	15.45	11.25	10.50	16.70	21.70	10.85	3.25	7.85	2.10	3.00	10.71

Least differences necessary for significance
Dates x Temperatures x Concentrations:
5% level - 7.67
1% level - 10.11

TABLE X

ANALYSIS OF VARIANCE TABLE OF PER CENT SEEDSTALKS WHICH HAD FORMED AUGUST 25, 1952, IN CORNELL 19 CELERY AS INFLUENCED BY TEMPERATURE, DATES OF APPLICATIONS, AND CONCENTRATION OF MALEIC HYDRAZIDE

Source of variance	Degrees of freedom	Total sum of squares	Mean squares	F
Total	479	464,431		
Dates	11	94,166	8,560	39.2**
Replication	3	2,095	698	3.2*
Replication x Dates	33	12,781	387	1.7 NS
Temperature	1	43,797	43,797	200.9**
Temperature x Dates	11	21,516	1,956	8.9**
Concentration	4	95,464	23,866	109.4**
Concentration x Dates	44	89,934	2,043	9.3**
Concentration x Temperature	4	1,694	423	1.9 NS
Concentration x Dates x Temperature	44	32,249	733	3.3**
Error	324	70,735	218	

**Highly significant (1% level)
*Significant (5% level)
NS Not significant

TABLE XI

ANALYSIS OF VARIANCE TABLE OF AVERAGE HEIGHTS OF SEEDSTALKS WHICH HAD FORMED AUGUST 25, 1952, IN CORNELL 19 CELERY AS INFLUENCED BY TEMPERATURE, DATES OF APPLICATION, AND CONCENTRATION OF MALEIC HYDRAZIDE

Source of variance	Degrees of freedom	Total sum of squares	Mean squares	F
Total	479	59,784		
Dates	11	13,887	1,262	40.7**
Replication	3	129	43	1.4 NS
Replication x Dates	33	1,295	39	1.3 NS
Temperature	1	5,712	5,712	184.3**
Temperature x Dates	11	2,379	216	6.9**
Concentration	4	9,390	2,348	75.7**
Concentration x Dates	44	13,645	310	10.0**
Concentration x Temperature	4	131	33	1.0 NS
Concentration x Dates x Temperature	44	3,156	72	2.3**
Error	324	10,060	31	

** Highly significant (1% level)
NS Not significant

The Response of Celery Plants to Maleic Hydrazide under Greenhouse Conditions as Influenced by Temperature, Nitrate Levels, and Time of Application

Methods and procedure. The greenhouse experiment was designed to study under controlled conditions of temperature and nutritional levels of nitrogen some physiological responses of Cornell 19 celery to maleic hydrazide. Seeds were planted August 25, 1951, and final records of the plants were made on May 17, 1952. Procedures used in seeding, early care of the plants, and the application of maleic hydrazide were similar to those already described for the field experiments. The seedlings were transplanted individually on October 20, 1951, into standard eight-inch clay pots containing a 75-25 mixture of steam sterilized muck soil and fine sand, respectively.

A total of 324 potted plants were divided into three different groups of 108 plants each. The groups were placed into separate greenhouses, and each greenhouse was maintained at a different night temperature. The night temperatures selected were 40, 60, and 70° F. All greenhouse temperatures designated are night temperatures. The plants in each greenhouse were grown at three different nitrogen levels: 10, 20, and 100 ppm. Phosphorus was maintained at a constant level of 5 ppm and potassium at a constant level of 30 ppm. The pH was maintained at about 6.5. Maleic hydrazide was applied at 50 and 100 ppm. Nutrient levels were maintained as described for the first field experiment (52). Non-treated lots of plants comprised control comparisons for each temperature, nitrogen level, and maleic hydrazide concentration. To obtain some information on the effect of age of the plants and maleic hydrazide concentrations applied, one-third of the plants were sprayed November 17, a second third December 10, and the remainder on December 30, 1951.

For the purpose of observing responses of 26-week old celery plants to temperatures different from those at which they had been growing for 22 weeks, a transfer of all plants to a different temperature was made on March 21, 1952. At the time of this transfer, no evidence of seedstalk formation was observable. Plants which had been growing in a 40° F house were transferred to a 70° F house; and those which had been growing in a 70° F house were transferred to a 40° F house. The plants which had been growing in a 60° F house were transferred to a 50° F house.

Weekly measurements (in inches) were taken from April 5 to May 17, 1952, of the seedstalks that formed.

Results. Temperature had a pronounced effect on the vegetative growth of celery plants. Plants grown in the 40° F house were dwarfed and generally stunted. Those grown in the 60° F house maintained desirable vegetative growth. At 70° F most of the plants grew very rapidly and formed long, slender petioles. In Figure 10, from left to right, are illustrated representative plants which were

Figure 10. Comparative response of Cornell 19 celery plants to various nitrate levels when grown at 60° F night temperature.

Left to right: 100, 20, and 10 ppm nitrates

Photographed January 5, 1952

grown in the 60° F house at 100, 20, and 10 ppm of soil nitrates, respectively. The most desirable plants produced were those which received 20 ppm of nitrates and were grown at 60° F. It can be seen also from Figure 10 that both 10 and 100 ppm of nitrates had inhibitory effects on vegetative growth.

Figure 11 shows the effect of low temperature (40° F) and various soil nitrate levels on vegetative growth in celery plants. Plant growth was inhibited at 40° F regardless of the nitrate levels used. A comparison of plants in Figures 10 and 11 will show that at 60° F, 100 ppm of nitrates produced a larger plant than 10 ppm of nitrates. Whereas at 40° F, a larger plant was produced with 10 ppm of nitrates than with 100 ppm of nitrates. This difference in growth would suggest that at 40° F 100 ppm of nitrates was toxic, thereby inhibiting vegetative growth. At 60° F, conditions for physiological activities of the plant were favored over those at 40° F for plant growth. This led to the absorption and utilization of more soil nitrates which was manifested in increased vegetative growth.

At 70° F, the growth of the plants was proportional to the soil nitrate levels, being smallest at the lowest nitrate level (10 ppm) and largest at the highest nitrate level (100 ppm). This growth pattern would seem to indicate that at 70° F environmental conditions for plant growth were such that additional soil nitrates caused increased vegetative growth.

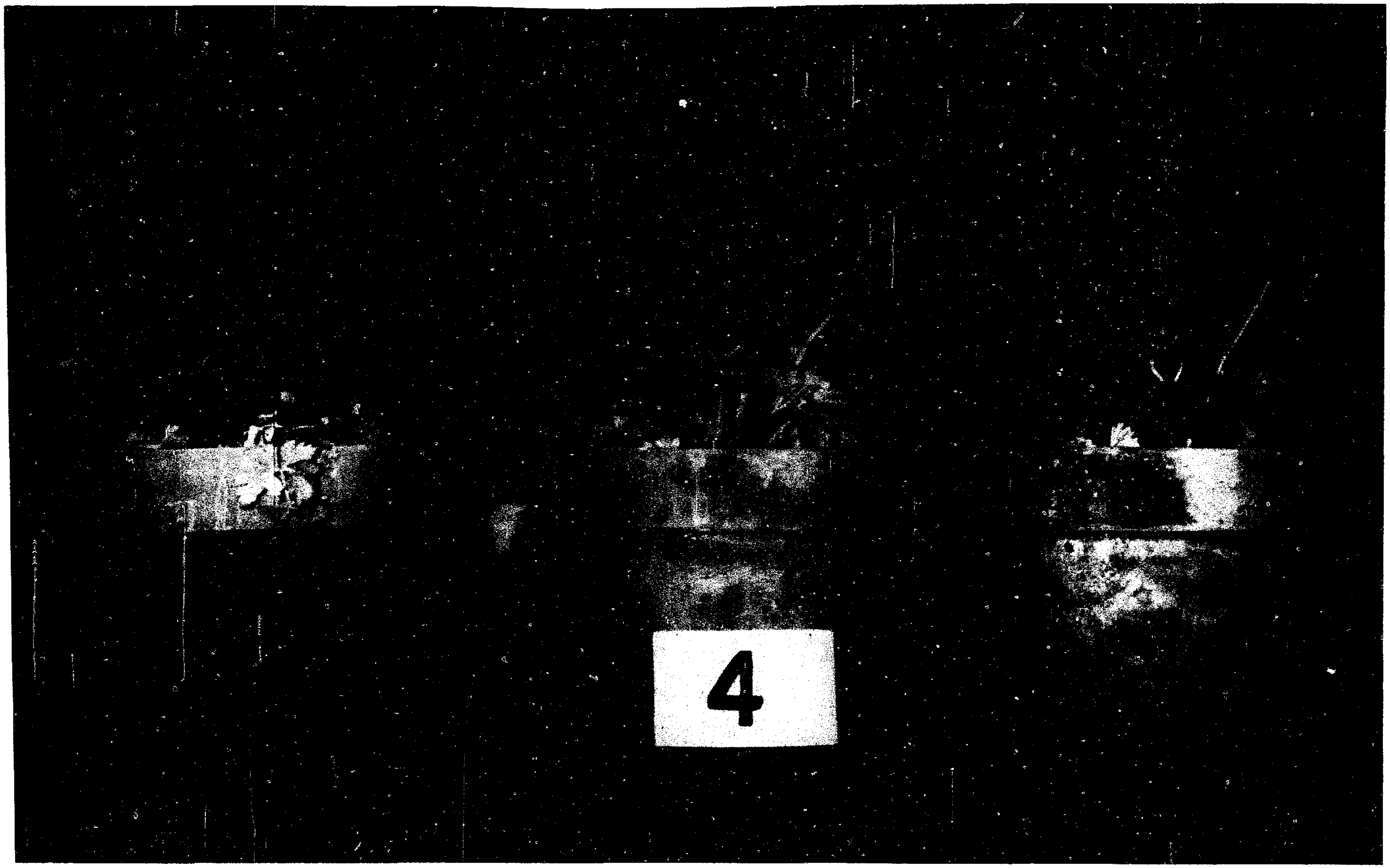


Figure 11. Comparative response of Cornell 19 celery plants to various nitrate levels when grown at 40° F night temperature.

Left to right: 100, 20, and 10 ppm of nitrates

Photographed January 5, 1952

Maleic hydrazide also had a pronounced effect on morphology and vegetative growth of the celery plants. The effects were related in many respects to the temperatures at which the plants were growing and the soil nitrate levels. Figures 12 and 13 show the comparative effects of 100 ppm of maleic hydrazide on celery plants when grown at low and high temperatures, respectively. One of the most obvious effects observed, of maleic hydrazide on young celery plants, was the production of a chlorotic condition especially near the growing points, and an enlargement of the stem. Stem enlargement was greatest at high temperature and high nitrate level. Death of the growing points occurred in many instances prior to stem enlargement. At low temperature this chlorotic condition was confined mostly to the young petioles. The chlorosis, however, was observed even on the older petioles of plants which were grown at 70° F.

Measurements taken of the seedstalks were statistically analyzed to compare the influence of the three levels of soil nitrates, maleic hydrazide concentrations, and the dates of maleic hydrazide application, on the final average height of the seedstalks. Data represented by Tables XII to XVII apply only to measurements taken May 17, 1952.

Transferring of plants from the 40° F house to the 70° F on March 21 caused a rapid elongation of the seedstalks which were not visible prior to the transfer. Very little effect on seedstalk elongation, however, was observed by the transfer of plants from the 70° F to the 40° F house

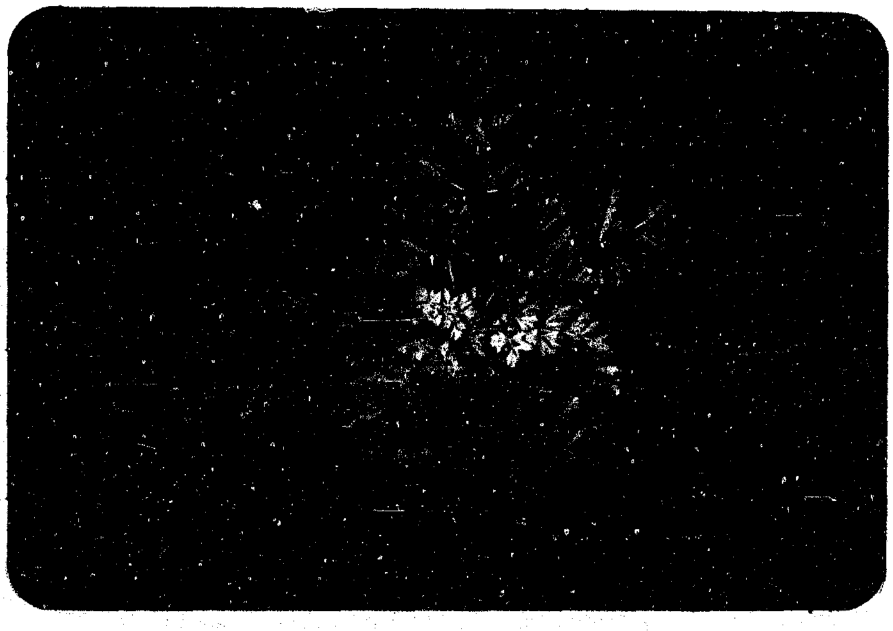


Figure 12. The response of Cornell 19 celery plant to 100 ppm of maleic hydrazide, 20 ppm of nitrate, and grown at 40° F night temperature.

Photographed January 5, 1952

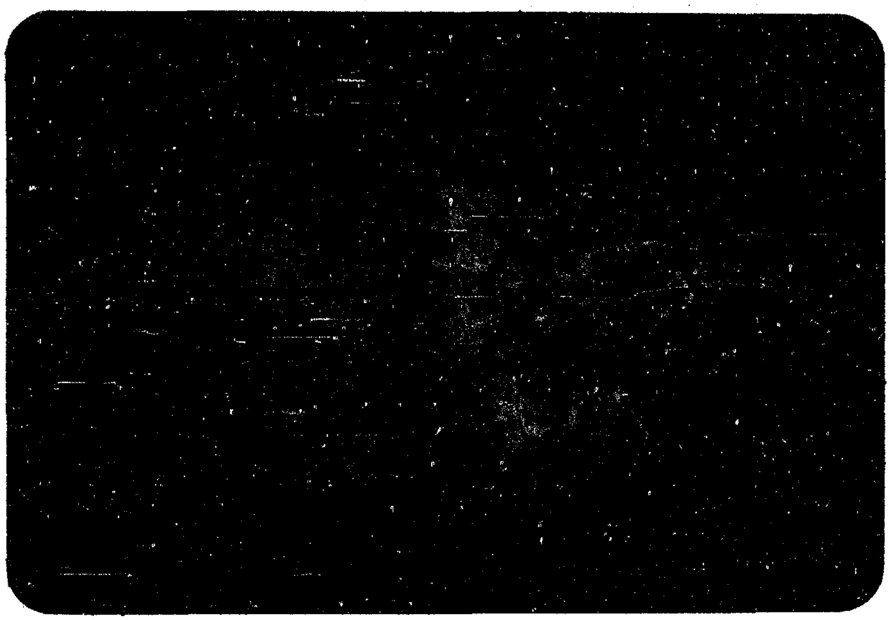


Figure 13. The response of Cornell 19 celery plant to 100 ppm of maleic hydrazide, 20 ppm of nitrate, and grown at 70° F night temperature.

Photographed January 5, 1952

TABLE XII

THE EFFECTS OF MALEIC HYDRAZIDE AND TEMPERATURE ON THE FINAL HEIGHT OF SEEDSTALKS DEVELOPED IN CORNELL 19 CELERY (MAY 17, 1952)

Maleic hydrazide (ppm)	Height of seedstalks in inches			
	40° F	60° F	70° F	Means
0	39.83	19.70	14.40	24.64
50	38.50	18.70	15.20	24.13
100	36.19	17.90	14.40	22.83
Means	38.17	18.41	14.66	23.86

Least differences necessary for significance
Concentration x Temperature:

	5% level	1% level
40° F	1.93	2.56
60° F	1.62	2.14
70° F	1.80	2.39

TABLE XIII

THE EFFECTS OF DATES OF APPLICATION OF MALEIC HYDRAZIDE AND TEMPERATURE ON THE FINAL HEIGHT OF SEEDSTALKS DEVELOPED IN CORNELL 19 CELERY (MAY 17, 1952)

Dates of application	Height of seedstalks in inches			
	40° F	60° F	70° F	Means
November 17, 1951	39.72	21.25	15.46	25.47
December 10, 1951	40.34	20.27	14.67	25.09
December 30, 1951	34.65	14.92	13.93	21.16
Means	38.23	18.81	14.68	23.90

Least differences necessary for significance –
Dates of application x Temperature:

	5% level	1% level
40° F	1.93	2.56
60° F	1.62	2.14
70° F	1.80	2.39

TABLE XIV

THE EFFECTS OF VARIOUS LEVELS OF NITROGEN AND TEMPERATURE ON THE FINAL HEIGHT OF SEEDSTALKS DEVELOPED IN CORNELL 19 CELERY (MAY 17, 1952)

Nitrogen concentrations	Height of seedstalks in inches			
	40° F	60° F	70° F	Means
NO_3 - 10 ppm	39.34	26.54	14.00	26.62
NO_3 - 25 ppm	38.92	15.53	14.25	22.90
NO_3 - 100 ppm	36.45	14.46	15.71	22.20
Means	38.23	18.84	14.65	23.90

Least differences necessary for significance
Nitrogen x Temperature:

	5% level	1% level
40° F	1.93	2.56
60° F	1.62	2.14
70° F	1.80	2.39

TABLE XV

ANALYSIS OF VARIANCE TABLE ON THE FINAL HEIGHT OF SEEDSTALKS DEVELOPED IN CORNELL 19 CELERY AS INFLUENCED BY TEMPERATURE (40° F), NITRATES, DATES OF APPLICATION, AND MALEIC HYDRAZIDE CONCENTRATIONS (MAY 17, 1952)

Source of variance	Degrees of freedom	Total sum of squares	Mean squares	F
Total	107	3098		
Replications	3	42	14.0	--
Nitrates	2	175	87.5	5.2**
Dates	2	693	346.5	20.5**
Concentrations	2	244	122.0	7.2**
Dates x Concentrations	4	337	84.3	4.98**
Dates x Nitrates	4	55	13.7	--
Nitrates x Concentrations	4	115	28.7	1.7 NS
Nitrates x Dates x Concentrations	8	121	15.1	--
Error	78	1319	16.9	

** Highly significant (1% level)
NS Not significant

TABLE XVI

ANALYSIS OF VARIANCE TABLE ON THE FINAL HEIGHT OF SEEDSTALKS DEVELOPED IN CORNELL 19 CELERY AS INFLUENCED BY TEMPERATURE (60° F), NITRATES, DATES OF APPLICATION, AND MALEIC HYDRAZIDE CONCENTRATIONS (MAY 17, 1952)

Source of variance	Degrees of freedom	Total sum of squares	Mean squares	F
Total	107	8498		
Replications	3	11	3.7	0.31 NS
Nitrates	2	3257	1628.9	136.88**
Dates	2	814	407.2	34.21**
Concentrations	2	53	26.9	2.26 NS
Dates x Concentrations	4	337	84.4	7.09**
Dates x Nitrates	4	2470	617.7	51.90**
Nitrates x Concentrations	4	87	21.9	1.84 NS
Nitrates x Dates x Concentrations	8	535	66.9	5.62**
Error	78	929	11.9	

** Highly significant (1% level)
NS Not significant

TABLE XVII

ANALYSIS OF VARIANCE TABLE ON THE FINAL HEIGHT OF SEEDSTALKS DEVELOPED IN CORNELL 19 CELERY AS INFLUENCED BY TEMPERATURE (70° F), NITRATES, DATES OF APPLICATION, AND MALEIC HYDRAZIDE CONCENTRATIONS (MAY 17, 1952)

Source of variance	Degrees of freedom	Total sum of squares	Mean squares	F
Total	107	1591		
Replications	3	53	17.6	1.1 NS
Nitrates	2	64	32.0	2.2 NS
Dates	2	38	19.0	1.3 NS
Concentrations	2	14	7.0	--
Dates x Concentrations	4	105	26.3	1.8 NS
Dates x Nitrates	4	87	21.7	1.5 NS
Nitrates x Concentrations	4	15	3.7	--
Nitrates x Dates x Concentrations	8	69	8.6	--
Error	78	1146	14.7	

NS Not significant

and the 60° F house to the 50° F house.

Maleic hydrazide had a decided effect on the final average height of seedstalk observed, depending largely upon temperature, nitrate level, and date of application. The seedstalks attained a greater final height where the soil nitrate level was low and also in the case of the low temperature (40° F) exposure (Table XIV). Seedstalks were generally taller where maleic hydrazide was applied at 50 ppm and at the earlier dates (Table XIII). Maleic hydrazide alone seemed to have had very little effect on final seedstalk height as compared with nitrogen and temperature. Plants grown at 40° F were the earliest in bolting and showed the greatest percentage of bolting.

Generally those plants which received the earliest applications of maleic hydrazide produced the tallest seedstalks. The effects of time of application of maleic hydrazide and temperature on the height of the seedstalks are given in Table XIII. The seedstalks were tallest on plants that had been exposed to the 40° F temperature and when maleic hydrazide was applied at the earliest date.

The Effect of Maleic Hydrazide Concentrations on Soluble Nitrogen Content of Maturing Celery Plants as Influenced by Nitrate Levels and Temperature

Methods and procedure. This experiment was undertaken to ascertain whether different maleic hydrazide concentrations applied to celery plants grown at different temperatures and soil nitrate levels would affect the soluble nitrogen content of celery during different stages of growth up to the time of market maturity. Plants (Cornell 19) for this experiment were selected from the split-plot design described under the first, (1951), field experiment. On June 15, July 10, and August 3, 1951, samples of fresh petioles were collected for nitrogen determinations. The outer and more mature petioles were selected in all instances. Five plants were taken at random from each of the four replications and all treatments including controls, in order that the results of the chemical analysis could be statistically evaluated.

For obtaining samples for chemical analysis, three-inch sections were taken from outer petioles and then diced into 2 mm pieces. The section of petiole taken for analysis was the portion beginning one inch below the base of the origin of the first leaves, and extending three inches downward. The 2 mm pieces of plant material from each replication and treatment were then thoroughly mixed from which preparation a five-gram aliquot was sampled.

Further procedures used in obtaining uniform samples for chemical analyses were according to the methods described by Carolus (2).

Results. The parts per million of soluble nitrogen (nitrate nitrogen and other nitrogenous compounds obtained from extraction of plant material with acetic acid) characteristic of the different treatments indicates that maleic hydrazide to some extent influenced the soluble nitrogen content of freshly harvested petioles of celery plants approaching maturity. The use of maleic hydrazide did not cause a significant difference in soluble nitrogen content in celery plants with the samples taken in June or July at the low (10 ppm) nitrate level. Chemical analyses of the samples taken in August showed, however, that the controls had a significantly higher soluble nitrogen content at the low (10 ppm) nitrate level. In striking contrast, at the medium (20 ppm) nitrate level, the greatest differences (increases) in soluble nitrogen content in the petioles resulting from the maleic hydrazide treatments occurred during the months of July and June.

Again, however, with the highest soil nitrate level (75 ppm), a significant difference (decrease) in soluble nitrogen content of the petioles occurred only during the month of June (Table XVIII).

The Effect of Preharvest Sprays of Maleic Hydrazide on the Sugar and Nitrogen Content of Two Varieties of Celery as Influenced by Time in the Field After Spray Applications and Length of the Storage Period (1951)

Methods and procedure. Two commercially acceptable varieties of celery, Cornell 19 (a golden type) and Utah 15 (a green type from Ferry-Morse, Detroit, Michigan) were used in the first storage tests. The experiment was designed to determine the effects of preharvest foliar sprays of maleic hydrazide on the percentage composition of total, reducing, and non-reducing sugars, and total and nitrate

TABLE XVIII

THE EFFECTS OF VARIOUS CONCENTRATIONS OF MALEIC HYDRAZIDE AND SOIL NITRATE LEVELS ON THE ACETIC ACID SOLUBLE NITROGEN OF PETIOLES OF CORNELL 19 CELERY AT VARIOUS TIMES DURING THE GROWING SEASON (1951)

Maleic hydrazide (ppm)	Parts per million of soluble nitrogen in the petioles								
	Sampled June 15			Sampled July 10			Sampled August 3		
	NO_3 levels			NO_3 levels			NO_3 levels		
	10	20	75	10	20	75	10	20	75
0	759	1287	1561	1013	1261	1565	1300	1275	1717
25	692	1626	1375	797	1476	1750	1012	1325	1575
50	727	1725	1700	571	1506	1568	1012	1365	1787
100	787	1537	1426	725	1246	1575	1051	1312	2002
250	551	753	1226	762	1119	1775	1085	1275	1835
Means	703.20	1385.60	1457.60	773.60	1321.60	1646.60	1092.00	1310.40	1783.20
Least differences necessary for significance									
5% level	528	414	274	596	365	400	117	293	639
1% level	876	687	454	990	606	665	187	487	1060

nitrogen content of celery plants held under a number of different storage conditions, and harvested at a time when the crop had reached acceptable market maturity.

The design consisted of twelve 30-foot rows with sixty plants each for each of the two celery varieties. The two varieties of celery plants were sprayed September 19 with three concentrations of maleic hydrazide (500, 1000, and 2500 ppm). Comparable non-treated plots (rows) served as control comparisons. Each treatment was replicated three times. One-third of the celery from each plot (20 rows) was harvested September 21 and placed in storage until November 17 at 33 ± 2^{o} F. A second third of the celery was harvested on September 29, from which samples were prepared without a period of storage. For samples, the entire aerial portion of three celery plants was selected at random from each replication and treatment. The remaining third was harvested on October 3, and placed at the same storage temperature until November 17 as the first lot of celery harvested September 21. High humidity (approximately 95 per cent relative humidity) was maintained in the storage by periodically spraying water over the celery. At the completion of each storage period, the samples were prepared by drying at 60^{o} C and ground in a large Wiley mill so as to pass through a 60-mesh screen.

For total, reducing and non-reducing sugar analyses, five-gram single samples of ground material were taken from each of the three replications and various treatments.

Chemical analyses were conducted according to procedures outlined in "Methods of Analysis - Association of Official Agricultural Chemists" (31).

One-gram single samples from each of the three replications and various treatments were taken for total nitrogen analyses. The preparation of samples was identical to that described above for sugar analyses. Gunnings Method Modified to include nitrate nitrogen was used for total nitrogen determinations (31).

For nitrate nitrogen determinations, 0.5-gram single samples of the plant material prepared as described above for sugar and total nitrogen determinations was used. Chemical analysis was according to "Jones Modification of the Robertson Method" (31).

Results. The values obtained for the sugar determinations are listed in Table XIX, and they suggest that different preharvest sprays of maleic hydrazide influenced the sugar content of celery at harvest time and during storage. Statistical analysis of the data showed that maleic hydrazide treatments caused a significant increase in per cent sugar content in stored celery as compared with the controls (Table XIX). The two varieties of celery used for this storage test also showed a significant difference in sugar content when harvested 11 days after treatment. There was a significant interaction between variety and treatment (Table XX). The celery plants which remained in the field 15 days and in storage 45 days after

THE INFLUENCE OF PREHARVEST SPRAYS OF MALEIC HYDRAZIDE AND STORAGE AFTER TREATMENT ON THE PER CENT SUGARS (TOTAL, REDUCING, AND NON-REDUCING) IN CORNELL 19 AND UTAH 15 VARIETIES OF CELERY (1951)

Variety	Maleic hydrazide (ppm)	Method of handling after treatment with maleic hydrazide								
		Field - 11 days* Storage - none			Field - 15 days Storage - 45 days			Field - 2 days Storage - 58 days		
		Per cent sugars			Per cent sugars			Per cent sugars		
		Total	R	NR	Total	R	NR	Total	R	NR
Cornell 19	control	3.00	1.50	1.55	5.52	2.00	3.52	8.02	4.30	3.71
	500	6.72	4.94	1.78	8.13	2.69	5.23	6.61	2.22	4.35
	1000	5.26	3.04	2.21	7.28	1.89	5.39	4.89	1.21	3.67
	2500	6.00	3.79	2.21	6.94	2.48	4.45	7.73	3.38	4.35
	Means	5.24	3.32	1.93	5.14	2.26	4.65	6.81	4.65	4.02
Utah 15	control	6.40	3.68	2.71	4.38	1.55	2.83	5.02	2.45	2.60
	500	4.88	2.53	2.36	5.90	2.08	3.81	8.27	5.01	2.26
	1000	7.16	4.17	2.99	6.98	3.02	3.96	8.20	4.73	3.46
	2500	5.34	2.60	2.74	4.92	1.19	3.39	5.82	2.67	3.15
	Means	5.95	3.24	2.70	5.54	1.96	3.49	6.82	3.71	2.86
Least differences necessary for significance										
5% level		1.46	1.26	0.61	0.67	0.68	0.52	1.13	0.61	1.11
1% level		2.04	1.77	0.85	0.95	0.96	0.73	1.58	0.85	1.55

*Indicates days remained in field after application of spray material

TABLE XX

ANALYSIS OF VARIANCE TABLE ON PER CENT TOTAL SUGARS IN CORNELL 19 AND UTAH 15 VARIETIES OF CELERY AS INFLUENCED BY DIFFERENT PERIODS OF STORAGE AND VARIOUS PREHARVEST SPRAYS OF MALEIC HYDRAZIDE (1951)

Source of variance	Degrees of freedom	Method of handling after treatment with maleic hydrazide								
		Field - 11 days[a] Storage - none			Field - 15 days Storage - 45 days			Field - 2 days Storage - 58 days		
		Total sum of squares	Mean squares	F	Total sum of squares	Mean squares	F	Total sum of squares	Mean squares	F
Total	23	40.10			45.70			44.20		
Replication	2	0.81	0.40	1.20 NS	0.57	0.28	--	0.90	0.45	4.5 NS
Variety	1	11.26	11.26	35.10 *	3.60	3.60	4.44 NS	0.001	0.001	--
Error (a)	2	0.65	0.32		1.63	0.81		0.20	0.10	
Treatment	3	19.10	6.32	15.00**	7.60	2.53	3.72 *	3.50	1.16	8.30**
Treatment x Variety	3	3.27	1.09	2.50 *	24.10	8.03	11.80**	37.90	12.63	90.20**
Error (b)	12	5.01	0.42		8.16	0.68		1.70	0.14	

** Highly significant (1% level)
* Significant (5% level)
NS Not significant
a Indicates days remained in field after application of spray material

maleic hydrazide applications, showed the greatest differences in the percentages of the sugar fractions among the maleic hydrazide treatments, and in contrast, those which remained in the field 11 days after maleic hydrazide applications and had no storage period showed the least differences in sugar composition resulting from maleic hydrazide treatments.

Table XXI shows the influence of preharvest sprays of maleic hydrazide on the per cent of total nitrogen and nitrate nitrogen in stored celery. A statistical analysis of the data shows that preharvest foliar sprays of maleic hydrazide had little influence on the per cent of total nitrogen and nitrate nitrogen in stored celery with the exception of nitrate nitrogen in Cornell 19 which remained in the field 15 days and in storage 45 days after maleic hydrazide treatments.

The Effect of Preharvest Sprays of Maleic Hydrazide on the Sugar Composition of Two Varieties of Celery Plants as Influenced by Various Times of Storage (1952)

Methods and procedure. Two varieties of celery, Cornell 19, a golden type, and Utah 52-70, a green type selected from Utah 15, were used for the second storage test. The experiment was designed in part to repeat certain phases of the first test and to determine the effects of maleic hydrazide on the sugar content of celery stored for different periods of time. The field design consisted of twelve ten-foot rows (plots) containing twenty plants each for each of the two celery varieties.

THE INFLUENCE OF PREHARVEST SPRAYS OF MALEIC HYDRAZIDE AND STORAGE ON THE PER CENT NITROGEN (TOTAL AND NITRATE) IN CORNELL 19 AND UTAH 15 VARIETIES OF CELERY (1951)

Variety	Maleic hydrazide (ppm)	Method of handling after treatment with maleic hydrazide					
		Field - 11 days* Storage - none		Field - 15 days Storage - 45 days		Field - 2 days Storage - 58 days	
		Per cent nitrogen		Per cent nitrogen		Per cent nitrogen	
		Total	Nitrate	Total	Nitrate	Total	Nitrate
Cornell 19	control	2.71	0.14	2.65	0.07	2.52	0.06
	500	2.51	0.18	2.88	0.24	2.68	0.17
	1000	2.36	0.04	2.71	0.06	2.85	0.15
	2500	2.29	0.10	2.61	0.16	2.58	0.11
	Means	2.46	0.11	2.71	0.13	2.65	0.12
Utah 15	control	2.49	0.20	2.70	0.25	2.68	0.16
	500	2.52	0.29	2.64	0.19	2.61	0.10
	1000	2.27	0.15	2.63	0.24	2.32	0.03
	2500	2.34	0.11	2.55	0.22	2.39	0.13
	Means	2.40	0.18	2.63	0.22	2.50	0.10
Least differences necessary for significance							
5% level		0.39	0.19	0.26	0.09	0.13	0.21
1% level		0.55	0.26	0.36	0.13	0.19	0.30

*Indicates days remained in field after application of spray material

TABLE XXII

ANALYSIS OF VARIANCE TABLE ON PER CENT TOTAL NITROGEN IN CORNELL 19 AND UTAH 15 VARIETIES OF CELERY AS INFLUENCED BY DIFFERENT PERIODS OF STORAGE AND VARIOUS PREHARVEST SPRAYS OF MALEIC HYDRAZIDE (1951)

Source of variance	Degrees of freedom	Method of handling after treatment with maleic hydrazide								
		Field - 11 days[a] Storage - none			Field - 15 days Storage - 45 days			Field - 2 days Storage - 58 days		
		Total sum of squares	Mean squares	F	Total sum of squares	Mean squares	F	Total sum of squares	Mean squares	F
Total	23	0.34			1.36			1.20		
Replication	2	0.11	0.055	11.00 NS	0.12	0.060	--	0.23	0.115	23.0 *
Variety	1	0.02	0.020	4.00 NS	0.05	0.050	--	0.12	0.120	24.0 *
Error (a)	2	0.01	0.005		0.15	0.075		0.01	0.005	
Treatment	3	0.04	0.013	2.10 NS	0.14	0.013	2.60 NS	0.20	0.060	2.4 NS
Treatment x Variety	3	0.09	0.030	5.00 *	0.26	0.086	1.70 NS	0.34	0.113	4.5 *
Error (b)	12	0.07	0.006		0.64	0.050		0.30	0.025	

* Significant (5% level)
NS Not significant
a Indicates days remained in field after application of spray material

On July 23, 1952, three concentrations of maleic hydrazide (500, 1000, and 2500 ppm) were applied to the two varieties of celery plants with non-treated plots serving as controls. There were three replications of each treatment. The plants were permitted to remain in the field until July 31, at which time they were harvested, trimmed, put in crates, and placed in a storage room held at $33 \pm 2^{\circ}$ F. The celery had reached market maturity at the time of harvest.

Water was sprayed over the stored celery periodically to maintain a high relative humidity (95-98 per cent). One-third of the celery (the entire aerial portion of three plants per replication and treatment) was removed on August 15, sampled, dried, and ground after a 15-day storage period. Sampling, drying, and grinding were similar to that described under the first storage test for 1951. A second third of the celery was taken out of storage on August 29, after a 29-day storage period, for sampling, drying, and grinding. On September 12, after a 43-day storage period, the remaining third of the celery was removed from storage and representative samples similarly prepared in the usual manner for chemical analyses.

The methods and procedure used for sugar determination were identical to those described under methods and procedure for sugar determinations in the 1951 storage test. Total nitrogen and nitrate nitrogen determinations were not made.

<u>Results</u>. Generally the per cent of sugars was lower and less significant statistically from this storage test than from the first storage test. However, the data in Table XXIII show that after 43 days of storage significant increases in sugar content resulted from treatment of Utah 52-70 with maleic hydrazide; however, a decrease was generally noted with Cornell 19.

THE INFLUENCE OF PREHARVEST SPRAYS OF MALEIC HYDRAZIDE AND STORAGE ON THE PER CENT SUGARS (TOTAL, REDUCING, AND NON-REDUCING) IN CORNELL 19 AND UTAH 52-70 VARIETIES OF CELERY (1952)

Variety	Maleic hydrazide (ppm)	Method of handling after treatment with maleic hydrazide								
		Storage - 15 days			Storage - 29 days			Storage - 43 days		
		Per cent sugars			Per cent sugars			Per cent sugars		
		Total	R	NR	Total	R	NR	Total	R	NR
Cornell 19	control	1.42	1.16	0.29	2.75	1.55	1.20	4.89	3.27	1.61
	500	2.10	1.56	0.54	2.42	1.58	0.83	2.99	1.92	0.08
	1000	1.75	1.41	0.34	2.69	1.62	1.07	2.85	1.59	1.26
	2500	1.49	1.23	0.26	2.68	1.66	1.02	3.69	2.03	1.67
	Means	1.69	1.34	0.35	2.63	1.60	1.03	3.60	2.20	1.40
Utah 52-70	control	1.66	1.18	0.47	3.54	2.02	1.51	2.23	0.90	1.32
	500	1.67	1.41	0.26	4.46	2.77	1.67	3.89	1.99	1.90
	1000	1.96	1.28	0.68	2.81	1.37	1.11	3.44	1.75	1.69
	2500	2.47	1.79	0.67	3.94	2.16	1.77	3.40	1.31	2.08
	Means	1.94	1.41	0.52	3.68	2.08	1.51	3.24	1.48	1.74
Least differences necessary for significance										
5% level		0.95	0.63	0.43	1.70	1.43	0.54	1.24	1.06	0.53
1% level		1.34	0.88	0.61	2.40	2.01	0.76	1.74	1.49	0.74

TABLE XXIV

ANALYSIS OF VARIANCE TABLE ON PER CENT TOTAL SUGARS IN CORNELL 19 AND UTAH 52-70 VARIETIES OF CELERY AS INFLUENCED BY DIFFERENT PERIODS OF STORAGE AND VARIOUS PREHARVEST SPRAYS OF MALEIC HYDRAZIDE (1952)

Source of variance	Degrees of freedom	Method of handling after treatment with maleic hydrazide								
		Storage - 15 days			Storage - 29 days			Storage - 43 days		
		Total sum of squares	Mean squares	F	Total sum of squares	Mean squares	F	Total sum of squares	Mean squares	F
Total	23	6.31			26.46			23.78		
Replication	2	0.13	0.065	1.30 NS	3.91	1.95	97.50 *	0.10	0.050	--
Variety	1	0.36	0.360	7.20 NS	6.70	6.70	335.00**	0.80	0.800	--
Error (a)	2	0.10	0.050		0.04	0.02		4.64	2.320	
Treatment	3	0.64	0.210	--	1.60	0.53	--	0.60	0.200	--
Treatment x Variety	3	1.51	0.520	1.79 NS	2.84	0.95	1.00 NS	11.70	3.900	7.95**
Error (b)	12	3.57	0.290		11.37	0.95		5.94	0.490	

** Highly significant (1% level)
* Significant (5% level)
NS Not significant

V. GENERAL DISCUSSION

Some Effects of Maleic Hydrazide on the Vegetative Growth of Celery Plants

The effects of foliage applications of maleic hydrazide on the vegetative growth of celery (variety Cornell 19) were dependent largely upon age of the plants when treated, concentrations of maleic hydrazide applied, previous temperature exposures, and the nitrate nitrogen status of the soil in which the plants were growing. Results from these studies showed that greater injury occurred from comparable concentrations of maleic hydrazide applied on plants which did not receive low night temperature ($40 \pm 5^{\circ}$ F) exposures before transplanting to the field than on those which received a low temperature treatment prior to field transplanting. Celery plants which received low temperature treatments prior to transplanting undoubtedly were in a physiological condition which permitted greater tolerance to higher concentrations of maleic hydrazide without observable injury.

High soil nitrate levels induced rapid growth of celery plants. Such plants were more susceptible to maleic hydrazide injury than those which grew less rapidly at the lower levels of nitrate. Maleic hydrazide inhibited vegetative growth more wherever conditions for growth were more favorable (15, 28, 29, 33).

Little injury was observed on any of the plants, regardless of age or previous handling, which received concentrations of maleic hydrazide below 100 ppm (6). In the case of older celery plants, much higher concentrations of maleic hydrazide were applied with little apparent injury (8). Thus, old maturing plants are capable of tolerating high concentrations of maleic hydrazide with less inhibition of vegetative growth than young growing plants (6, 8, 48). Schoene and Hoffman (48), Compton (6), and Crafts, et al (8) also observed that maleic hydrazide inhibited vegetative plant growth temporarily if physiologically tolerable concentrations were applied. Observations made during the course of these studies indicated that temporary inhibition of vegetative growth in celery plants was dependent upon whether or not physiologically tolerable concentrations of maleic hydrazide were applied (79).

The highest physiologically tolerable concentration of maleic hydrazide that could be applied to celery plants would certainly depend upon a number of factors. Reference to Figure 2 shows that 250 ppm of maleic hydrazide seriously injured celery plants which did not receive a low temperature treatment before transplanting to the field, and grown at a high soil nitrate (75 ppm) level. These plants were nine weeks old at the time maleic hydrazide was applied. Other observations revealed that 300 ppm of maleic hydrazide completely killed 13-week old celery plants. In striking contrast, 1000 ppm of maleic hydrazide did not kill 20-week old celery plants (Figure 9).

When maleic hydrazide concentrations were high enough to inhibit terminal vegetative growth, some stimulation of lateral bud growth was observed (79). In many instances where terminal vegetative growth was inhibited, no later terminal growth took place. This would seem to indicate that further division of the apical cells was inhibited permanently, and that apical dominance was destroyed. Enlargement of the celery plant stems was noticed in most cases where apical dominance was destroyed. This was true especially under greenhouse conditions when the plants were grown at 70° F night temperatures and at 100 ppm of soil nitrate.

Studies by Leopold and Klein (33) and Bonner and Bandurski (1) showed that auxins are necessary for apical dominance in plant growth. Work with plant growth regulators such as triiodibenzoic acid, coumarin, 2,4-chloranisole, and trans-cinnamic acid has shown that these substances possess capacities to lessen or destroy apical dominance (33). Therefore, these plant growth regulators are classed as anti-auxins because of their inhibitory action on apical growth in plants.

Maleic hydrazide destroys apical dominance in celery plants, depending upon concentrations applied and age of the plant; thus, it would seem that this compound acts as an anti-auxin with celery plants (33). The anti-auxin action of maleic hydrazide seems to be dependent upon the natural auxin level already present within celery plants. If the auxin level is high and low concentrations of maleic hydrazide are applied, apical dominance is not completely destroyed, but is decreased according to the amount of maleic hydrazide present. The temporary inhibition of apical growth in celery plants if certain concentrations of maleic hydrazide are applied suggests that natural plant auxins have overcome the inhibitory effect of this anti-auxin.

The Effects of Maleic Hydrazide on Flowering in Celery Plants

It has been reported in the literature that maleic hydrazide exerts variable influences on the reproductive processes in various plants. Naylor (43), using 0.1 per cent (1000 ppm), 0.2 per cent (2000 ppm), 0.4 per cent (4000 ppm), and 0.8 per cent (8000 ppm) of maleic hydrazide on *Xanthium* plants, noted that 0.1 per cent colutions of maleic hydrazide reduced flowering by 50 per cent (32, 34). White and Kennard (67) used maleic hydrazide at 1000, 1500, 2000, and 3000 ppm on apples, strawberries, and black raspberries and noted responses from no effect on flower inhibition in apples to a delay of blossoming from 24 to 38 days in black raspberries. Thus, variable reproductive responses of different plants to treatment with maleic hydrazide have been fairly well established.

Even though the investigations herein reported did not clearly indicate that maleic hydrazide will prevent floral initiation in Cornell 19 celery plants, there were clear indications, however, that high concentrations of this compound applied to older celery plants would inhibit seedstalk elongation which may or may not be an independent process (Figure 7). Clear distinctions have not been reported in the literature by investigators between inhibition of flower primordia formation and inhibition of anthesis as influenced by maleic hydrazide concentrations. Results of these studies with celery plants showed that the reduced number of flowers which formed at high concentrations of maleic hydrazide were due primarily to inhibition of growth and development of seedstalks subsequent to floral initiation. Maleic hydrazide applied at 50, 75, and 100 ppm to nine-week old celery plants significantly increased the per cent and earliness of seedstalk initiation (Figures 3 and 5). The extent of increase in earliness and per cent of seedstalk initiation was determined by the age of the plants at the time of maleic hydrazide application, nitrate levels maintained in the soil, and previous temperature exposures. Thus there were indications that maleic hydrazide can hasten flower initiation in celery, and celery normally a biennial, can be induced by chemical treatment to react as an annual.

These findings would seem to indicate that maleic hydrazide has greater possibilities as a reproductive growth promoting substance, in the case of Cornell 19 celery, than as a substance for the inhibition of floral initiation. Such observations would seem to assume vast economic importance from the standpoint of the plant breeder, seed grower, and the control of flowering and fruiting responses of horticultural crops, in general.

Lang (30) has pointed out that sugar has substituted for light inductive periods in both long-day and short-day plants such as Spinacia, Hyoscyamus, Xanthium, and Chenopodium in inducing floral initiation. Whether or not sugar promotes the production of substances which are necessary for flower initiation is not definitely known (53, 54, 56). The hastening of floral initiation in Cornell 19 celery by maleic hydrazide treatments would seem to have a relation to the function of sugar in inducing floral initiation in the genera mentioned above. The capacity which maleic hydrazide possesses to induce floral initiation in long-day plants as Cornell 19 celery might result from two changes which occur within the plant, namely, (a) lowering of the natural auxin level, and/or (b) an increase in the carbohydrate nitrogen ratio.

General observations indicated that those plants which were induced to flower from early maleic hydrazide treatments produced larger inflorescences than the controls. This increase in size of the seedstalks and inflorescences from early maleic hydrazide treatments, suggests that after maleic hydrazide had induced floral initiation, natural auxin accumulation counteracted further effects of maleic hydrazide. Therefore accumulated auxins could be used for seedstalk elongation and development.

Though low temperature treatments advanced the date of floral initiation, those plants which did not receive a low temperature treatment but were sprayed early with maleic hydrazide, later produced inflorescences just as large as the cold-induced plants (11, 50, 57, 58). Whether maleic hydrazide induces internal responses in celery plants which are similar to those brought about by low temperature exposure is not known but it is highly suggestive (51). When young celery plants received both maleic hydrazide and low temperature treatments floral initiation was greatly favored. Figure 8 shows inflorescences which resulted from early applications of maleic hydrazide on plants which did not receive a low temperature treatment for seedstalk initiation.

There appeared to be a relationship between the appearance of seedstalk initials and the growth and maturity of inflorescences. Plants on which seedstalk initials were first observed (July 2) were those on which full bloom (August 10) first occurred and ripened seed (October 5) were first evident.

The unique plant growth regulatory effects which maleic hydrazide possesses to induce seedstalk initiation at low concentrations when applied early in the development of the celery plant, and to prevent seedstalk elongation at high concentrations later in the development of the same plant, may be partly explained from its anti-auxin characteristics. Low auxin levels are required for seedstalk initiation and high auxin levels are required for subsequent growth and development (30). It has been demonstrated by Leopold and Klein (33) that maleic hydrazide functions as an anti-auxin and results obtained from maleic hydrazide applications on celery plants show that this chemical perhaps lowered the auxin level in young celery plants to the extent that floral initiation was favored. By the same token, the anti-auxin effect of maleic hydrazide likely enabled it to inhibit seedstalk elongation when applied at high concentrations during the later stages of flower formation, but prior to seedstalk development when the auxin economy of the meristems was much different. High auxin levels are required for the elongation and development of seedstalks (1, 30, 33).

The Influence of Maleic Hydrazide on the Quality of Stored Celery

Investigations as to the possibility of the use of preharvest foliage sprays of maleic hydrazide to prevent storage losses in celery seemed feasible from reports by Wittwer and Paterson (14, 71) that this chemical reduced storage losses and influenced favorably the carbohydrate status in sugar beets and potatoes; and recent work by Smock (49) on the reduction of storage losses with apples.

The reduction in storage losses as evidenced by sugar percentages in celery plants by the use of maleic hydrazide was investigated. Results of these studies indicated that maleic hydrazide under some conditions may reduce sugar losses in celery, although significant variety interactions were noticed. The degree to which storage losses were reduced depended to some extent upon the length of time the plants remained in the field after maleic hydrazide was applied. A comparison of Tables XIX and XXIII shows that maleic hydrazide did not greatly influrnce sugar percentages in celery that was harvested in July of 1952. Table XIX shows that preharvest foliage sprays of maleic hydrazide had a greater influence on sugar percentages of celery plants harvested in September of 1951.

Currier, Day, and Crafts (10), working with cotton and barley, and Naylor (41), with corn, observed that maleic hydrazide at 0.2 per cent (2000 ppm) and 0.4 per cent (4000 ppm) favored sugar accumulation. The accumulation of sugars following maleic hydrazide treatments may result from collapse of the phloem elements (10). The effect of maleic hydrazide on sugar accumulation in stored celery might be explained further from observations made by White (66) and Isenberg (27) which showed that maleic hydrazide inhibits the activity of various dehydrogenases essential in certain phases of plant respiration involving the utilization of sugar. Generally a large proportion of the storage losses in many perishables may be considered those which involve sugars.

VI. SUMMARY

Maleic hydrazide applied as a foliage spray at concentrations of 50, 75, and 100 ppm to Cornell 19 celery plants which were 13 to 16 weeks old (6-8 inches in height) significantly hastened the formation of seedstalk initials and increased both the percentage of plants forming seedstalks and the average heights of seedstalks, while spray concentrations of maleic hydrazide of 500 to 1000 ppm applied to plants 20 to 22 weeks old (12-16 inches in height) inhibited seedstalk elongation. Maleic hydrazide induced seedstalk development in celery plants which had not been exposed to a low night temperature ($40 \pm 5^\circ$ F) treatment before transplanting to the field.

Exposure to low night temperature markedly increased the ability of young celery plants to tolerate high concentrations of maleic hydrazide, while young celery plants grown at high soil nitrate levels (75 - 100 ppm) under greenhouse and field conditions were less tolerant. In the field, an increase in height of seedstalks which formed was noted in plants grown at high (75 - 100 ppm) levels of soil nitrates.

In the greenhouse with Cornell 19 celery plants grown at 40, 60, and 70° F night temperatures, the most pronounced positive influence on seedstalk initiation and subsequent growth and development of seedstalks occurred at 40° F. This was true irrespective of maleic hydrazide treatments. A low soil nitrate level (10 ppm) favored seedstalk growth and development regardless of the temperature at which the plants were growing.

Storage tests with two varieties (Cornell 19 and Utah 15) of celery were conducted wherein foliage sprays of maleic hydrazide (500, 1000, and 2500 ppm) were applied prior to harvest. The celery which was harvested and subsequently stored at 33 ± 2° F for various periods of time was analyzed for total, reducing, and non-reducing sugars; and for total and nitrate nitrogen. No significant alterations in total or nitrate nitrogen were observed. However, significant increases and decreases in sugars were characteristic of some of the maleic hydrazide treatments, but not others, and several inconsistencies were noted in the results of the two storage tests.

Tissue analyses of fresh celery petioles harvested from plants of various ages and grown at 10, 20, and 75 ppm of soil nitrate, revealed that foliage sprays of maleic hydrazide of 100 to 250 ppm decreased the soluble nitrogen content.

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