

SOIL AND ATMOSPHERIC INFLUENCES ON PLANT  
WATER BALANCE WITH SPECIAL REFERENCE TO  
BLACKHEART OF CELERY (*APIUM GRAVEOLENS*)

Thesis for the Degree of Ph. D.  
MICHIGAN STATE UNIVERSITY  
GERARD H. GUBBELS  
1967



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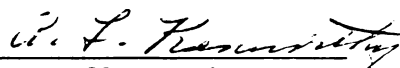
SOIL AND ATMOSPHERIC INFLUENCES ON PLANT  
WATER BALANCE WITH SPECIAL REFERENCE TO  
BLACKHEART OF CELERY (APIUM GRAVEOLENS)

presented by

Gerard H. Gubbels

has been accepted towards fulfillment  
of the requirements for

Ph.D. degree in Horticulture

  
Major professor

Date September 19, 1967

## ABSTRACT

### SOIL AND ATMOSPHERIC INFLUENCES ON PLANT WATER BALANCE WITH SPECIAL REFERENCE TO BLACKHEART OF CELERY (APIUM GRAVEOLENS)

by Gerard H. Gubbels

Characteristics of the celery plant and the development of blackheart were studied under various conditions of plant water balance affected by atmospheric conditions, soil moisture levels, osmotic concentrations and ion balances.

The application of low rates of irrigation (mist) to reduce plant water stress on hot days resulted in higher total fresh and dry weights, lower percentage of dry matter, higher sucker weight and no difference in marketable weight of celery grown in mineral soil and in nutrient solutions. No differences were present in muck soil. Mist applications during low temperature conditions reduced growth rate. Transpiration rate was reduced up to 27% but no marked changes in ion uptake accompanied this decrease. Misted plants showed the same degree of blackheart severity as control plants despite the increased vigor of the misted plants.

Low minimum soil moisture level (20-30% of the available soil moisture) in mineral soil resulted in lower fresh and dry weights, a higher percentage of dry matter, and no

consistent difference in the efficiency of water use as compared to high minimum soil moisture level (70-80% ASM).

The application of 750 pounds of Ca plus 652 pounds of Na per acre and double those rates to mineral soil to increase osmotic concentration of the soil solution resulted in higher fresh weight but similar dry weights compared to the control using the same volume of water. In nutrient solutions, 4.8 atm. and 0.3 atm. osmotic concentration of the same ion balance generally resulted in lower fresh and dry weights but higher percentages of dry matter compared to a 1.2 atm. solution. Water-use efficiency was lowest at the 0.3 atm. concentration but not significantly different at 1.2 and 4.8 atm. Blackheart symptoms were the most severe at the 1.2 atm. concentration.

In soil and nutrient solutions, fresh weight generally increased with decreasing Ca/K ratio but an associated decrease in the percentage of dry matter left only a small increase in dry weight. The large increase in fresh weight with decreasing Ca/K ratio was offset by a large increase in the sucker weight which resulted in no difference in marketable weight. Very low Ca/K ratio in soil and nutrient solutions resulted in a higher water-use efficiency while moderate Ca/K ratios resulted in no differences. High Ca/K ratio in nutrient solutions caused lower efficiency.

Blackheart symptoms increased with decreasing Ca/K ratios in nutrient solutions.

Blackheart symptoms increased in severity with increasing fresh weight of plant tops, sucker weight and K content of heart tissue, but decreased with increasing percentage of dry matter, Ca, B and Ca/K ratio in heart tissue.

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A THESIS

Submitted to  
Michigan State University  
in partial fulfillment of the requirements  
for the degree of

DOCTOR OF PHILOSOPHY

Department of Horticulture

1967

## ACKNOWLEDGMENTS

The author wishes to express his sincere appreciation to Dr. A. L. Kenworthy for his guidance and assistance throughout this research project and in the preparation of the manuscript. Appreciation is also expressed to Dr. R. L. Carolus for his help and advice in conducting the experiments and to Dr. J. B. Harrington, Dr. C. M. Harrison, Dr. R. E. Lucas, and Dr. C. W. Nicklow for their helpful suggestions.

The author wishes to express appreciation to his wife, Margaret, for her assistance and encouragement.

## TABLE OF CONTENTS

|                                                                                                                                         | Page |
|-----------------------------------------------------------------------------------------------------------------------------------------|------|
| INTRODUCTION . . . . .                                                                                                                  | 1    |
| LITERATURE REVIEW . . . . .                                                                                                             | 3    |
| I. Plant Water Balance . . . . .                                                                                                        | 3    |
| II. Mist Irrigation . . . . .                                                                                                           | 5    |
| III. Soil Moisture . . . . .                                                                                                            | 7    |
| IV. Osmotic Concentration . . . . .                                                                                                     | 8    |
| V. Ion Balance . . . . .                                                                                                                | 10   |
| VI. Blackheart . . . . .                                                                                                                | 11   |
| OUTDOOR EXPERIMENTS . . . . .                                                                                                           | 18   |
| I. Effects of Soil and Environmental Treatments<br>on Celery Grown Under Controlled Soil<br>Moisture Conditions (1965) . . . . .        | 18   |
| II. Effects of Soil and Environmental Treatments<br>on Celery Grown Under Controlled Soil<br>Moisture Conditions (1966) . . . . .       | 26   |
| III. Effects of Soil and Environmental Treatments<br>on Celery Grown Under Field Conditions<br>(1965) . . . . .                         | 45   |
| IV. Effects of Soil and Environmental Treatments<br>on Celery Grown Under Field Conditions<br>(1966) . . . . .                          | 49   |
| GREENHOUSE EXPERIMENTS . . . . .                                                                                                        | 53   |
| I. Effects of Ca/K Ratio and Environmental<br>Conditions on Celery Grown in Nutrient<br>Solutions . . . . .                             | 53   |
| II. Effects of Ca/K Ratio, Solution<br>Concentration and Environmental<br>Conditions on Celery Grown in<br>Nutrient Solutions . . . . . | 68   |
| GENERAL DISCUSSION . . . . .                                                                                                            | 88   |
| CONCLUSIONS . . . . .                                                                                                                   | 95   |
| LITERATURE CITED . . . . .                                                                                                              | 98   |

## LIST OF TABLES

| Table                                                                                                                                                             | Page |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------|------|
| 1. Top growth, water use, and wilting of celery plants in relation to environment, ion balance and soil moisture level . . . . .                                  | 22   |
| 2. Top growth, water use, and wilting of celery plants in relation to nutrition, environment and soil moisture level . . . . .                                    | 30   |
| 3. Mineral content of celery heart tissues related to nutrition, environment and soil moisture level . . . . .                                                    | 36   |
| 4. Mid-day soil, air and leaf temperatures in mist and control plots. Mean of seven days during which mist was applied (August 27 to September 2, 1966) . . . . . | 40   |
| 5. The effect of environment and nutrition on the growth of celery plants (1965) . . . . .                                                                        | 48   |
| 6. The effect of environment and nutrition on the growth of celery plants (1966) . . . . .                                                                        | 51   |
| 7. Growth of celery plants related to environment and nutrient solution Ca/K ratio . . . . .                                                                      | 58   |
| 8. Mineral content of celery heart tissue in relation to environment and nutrient solution Ca/K ratio . . . . .                                                   | 61   |
| 9. Blackheart ratings, transpiration and Ca/K ratio in celery heart tissue related to environment and nutrient solution Ca/K ratio . . . . .                      | 63   |
| 10. The relationship of blackheart ratings and nutrient solution Ca/K ratio to celery plant characteristics (simple linear correlation coefficients) . . . . .    | 64   |

| Table |                                                                                                                                                          | Page |
|-------|----------------------------------------------------------------------------------------------------------------------------------------------------------|------|
| 11.   | Growth of celery plants related to environment, nutrient solution Ca/K ratio and concentration . . . . .                                                 | 72   |
| 12.   | Mineral content of celery heart tissue related to environment, nutrient solution Ca/K ratio and concentration . . . . .                                  | 75   |
| 13.   | Blackheart ratings, transpiration and Ca/K ratio in celery heart tissue related to environment, nutrient solution Ca/K ratio and concentration . . . . . | 78   |
| 14.   | Relationship of blackheart rating and nutrient solution Ca/K ratio to celery plant characteristics (simple linear correlation coefficients) . . . . .    | 80   |
| 15.   | Mean daily 8:30 a.m. and 2:00 p.m. leaf, heart, air and solution temperatures (C) between August 25 and September 5, 1966 . . . .                        | 81   |

## LIST OF FIGURES

| Figure                                                                                                                                                       | Page |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------|------|
| 1. Celery plant showing severe blackheart symptoms . . . . .                                                                                                 | 13   |
| 2. The effect of the interaction of environment and soil moisture level on the degree of wilting of celery plants (0 - no wilt, 10 - severe wilt). . . . .   | 23   |
| 3. The effect of the interaction of environment and N level on top fresh weight of celery plants . . . . .                                                   | 31   |
| 4. The effect of the interaction of N and available soil moisture (ASM) on the dry weight of celery top growth . . . . .                                     | 31   |
| 5. The effect of the interaction of soil moisture level and environment on the dry weight of celery top growth . . . . .                                     | 33   |
| 6. The effect of the interaction of Ca/K ratio and soil moisture level on marketable weight of celery . . . . .                                              | 33   |
| 7. The effect of the interaction of Ca/K ratio and soil moisture level on the volume of water transpired per gram of dry matter produced by celery . . . . . | 34   |
| 8. The effects of the interaction of Ca/K ratio and N on the P content of celery heart tissue . . . . .                                                      | 37   |
| 9. The effects of the interaction of N level and soil moisture on the Ca/K ratio in celery heart tissue . . . . .                                            | 37   |
| 10. The effects of the interaction of Ca/K ratio and environment on the B content of celery heart tissue . . . . .                                           | 37   |

| Figure |                                                                                                                                                                                                                                                                                       | Page |
|--------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------|
| 11.    | The effect of mist on leaf and canopy temperatures on a typical hot day (August 28, 1966). Maximum air temperature was 29.4 C; relative humidity, 41%; pan evaporation, 4.57 mm.; wind travel, 56 Km.; sky, mostly sunny. Mist duration was approximately 60 sec. per application . . | 41   |
| 12.    | The effects of the interaction of Ca/K ratio and environment on the top fresh weight of celery grown in nutrient solutions in the greenhouse . . . . .                                                                                                                                | 59   |
| 13.    | The effect of the interaction of Ca/K ratio and environment on the fresh weight of celery roots grown in nutrient solutions in the greenhouse . . . . .                                                                                                                               | 59   |
| 14.    | The effect of the interaction of Ca/K ratio and nutrient solution concentration on marketable weight of celery . . . . .                                                                                                                                                              | 73   |
| 15.    | The effect of the interaction of Ca/K ratio and nutrient solution concentration on the percentage of dry matter in celery roots . . .                                                                                                                                                 | 73   |
| 16.    | The effect of the interaction of Ca/K ratio and nutrient solution concentration on the K content of celery heart tissue . . . . .                                                                                                                                                     | 76   |
| 17.    | The effect of the interaction of Ca/K ratio and nutrient solution concentration on the volume of water transpired per gram of dry matter produced . . . . .                                                                                                                           | 76   |
| 18.    | The effect of mist on transpiration rate on a typical hot day (August 26, 1966) with some cumulus cloud. Mist was in operation from 9:00 a.m. until 4:00 p.m. . . . .                                                                                                                 | 83   |
| 19.    | The relationship between transpiration, blackheart rating and growth rate from August 17 to September 18, 1966. (1) Mean daily transpiration; (2) Mean blackheart rating; (3) Mean growth rates . . . . .                                                                             | 84   |

## INTRODUCTION

Plant water balance is important in many plant processes. Growth, photosynthesis and respiration are among the major plant processes that are adversely affected by a deficit of water in the plant. Plant water balance may be affected by a combination of plant, atmospheric and soil conditions. The atmosphere may be modified by light rates of irrigation and thus prevent or reduce the development of water stress in the plant. Manipulation of the soil moisture level, the ion balance and the salt concentration in the soil may further alter the water balance.

Blackheart of celery, a physiological disorder characterized by the deterioration of heart tissue, has been closely associated with the water relations of the plant. Blackheart symptoms generally appear during or after periods of high temperature, at which time transpiration and moisture stress would be at a maximum. Low soil moisture level and high salt content have also been linked with the disorder. These two factors play a significant role in the water balance of plants. A low Ca content in the celery heart tissue is characteristic of plants exhibiting blackheart symptoms. In the case of celery, Ca may affect the

water balance in the plant or the converse may be true--the water balance may affect the Ca uptake and/or metabolism.

The purpose of this study was to determine the effects of soil and atmospheric treatments on the water balance of celery and the incidence of blackheart.

## LITERATURE REVIEW

### I. Plant Water Balance

The activity of many of the processes within the plant may be affected by the water status of the tissues. A cessation or checking of cell division or cell enlargement or both may result from a substantial decrease in the hydration of the protoplasm in the cells of a meristematic tissue (34, 42). Reduction in the water content of leaf cells may result in a reduced rate of photosynthesis. Slavik (41) stated that even slight reductions of the water potential directly reduced photosynthesis. In work by Denmead and Shaw with corn (8), measurements of dry matter production suggested that once the soil moisture content was less than the turgor loss point, the plants virtually ceased to assimilate. Moss (36) reported that probably the first effect of moisture stress was to cause the stomates to close. Pisek and Winkler (37) found that stomates usually began to close when water content had fallen only 2 to 12% below saturation in the leaves. A water deficit may increase respiration rate to the extent that damage and even death of the tissue may follow (42).

In summarizing the effects of water stress on plant growth, Kramer (27) listed further effects such as: increased root-shoot ratio; increased thickness, cutinization and lignification of cell walls; reduced leaf area; increased leaf thickness; increased conversion of starch to sugar, altered nitrogen metabolism, increased rate of RNA destruction; altered mineral metabolism; and rapid senescence of leaves.

Plant water balance may be affected by a combination of plant, atmospheric and soil conditions (26). Kramer (27) reported that water stress developed in plants when the rate of water loss by transpiration exceeded the rate of absorption by the roots. Transpiration was affected by leaf area and structure, extent of stomatal opening and the steepness of vapor pressure gradient from leaf to air (27). Rate of absorption by the roots was controlled by the rate of water loss, extent and efficiency of the root system, soil aeration, soil temperature, concentration of the soil solution and the soil moisture tension (27). Water absorption tended to lag behind water loss because there was resistance to movement in the plant, most of which occurred in the roots where water had to cross the relatively compact layers of cells in the epidermis, cortex and endodermis (27). Kramer (27) emphasized that the water status of the soil gave no indication of the water status of the plant because even with the soil water near field capacity, the plant could

still be under considerable moisture stress due to atmospheric conditions.

The lowest stage in plant water stress has been termed incipient wilting (34). In this stage the loss of turgor is partial and does not result in visible drooping or rolling (34). This is in contrast to temporary or transient wilting in which there are visible signs of wilting with subsequent recovery of turgor (34). In permanent wilting, the plant wilts and does not recover unless moisture is added to the soil (34). Gates (14) found that with tomato plants even moderate wilting reduced total growth and claimed that it was erroneous to suppose that plant growth was only affected near the permanent wilting point. Williams and Shapter (53) working with barley and rye confirmed this, and furthermore found that the plant parts growing most actively at the time of a water deficit were most affected.

## II. Mist Irrigation\*

The application of low rates of water to plant foliage was reported by Stocker et al. (44) to have benefited crops by keeping their leaves turgid and stomates open, and in preventing a midday decrease in photosynthesis.

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\*An application of low irrigation rates through sprinklers delivering small sized water drops.

Other studies (4, 7, 47) have indicated that during periods of high temperature evaporative cooling from very low irrigation rates of .04 to .06 inch per hour reduced plant and air temperature and increased relative humidity in the plant canopy. This resulted in a reduced rate of transpiration and reduced moisture stress in the plant with subsequent increase in yield and quality in some crops.

Gates (15) stated that leaf temperatures may rise well above the optimum range of physiological activity (25 to 30 C for many temperate region plants) when transpiration is no longer able to keep up with the rising heat load as the solar radiation approaches its midday peak. This can result in a temporary reduction or cessation of photosynthetic activity (15).

McMillan and Burgy (32) by the use of lysimeters found that the total evapotranspiration of a stand of grass was identical whether the surface of the stand was wetted or dry, indicating that the transpiration rate was reduced proportionally to the evaporation of the sprinkled water. The effect of transpiration rate on the ion uptake of intact plants has been reviewed by Slatyer (40). From the extensive work on this subject, he concluded that transpiration increased uptake under some conditions, especially when the requirements of the plant were high and ion concentration was also high both within the stele and external to it. Michael and Marschner (35) found that mustard plants grown

at relative humidities so regulated that transpiration was reduced to 1/7 to 1/10 of that in dry air absorbed considerably less Cs, slightly less Ca and P, but K absorption was not affected. Work done by Freeland (13) indicated that with plants grown in nutrient solutions an increase in transpiration resulted in an increase in mineral absorption but different mineral ions were not absorbed at the same rate and the rate of absorption of each ion varied with the kind of plant used. In his experiments, high transpiration caused bean and corn plants to take up relatively less Ca and more K.

### III. Soil Moisture

Water was not found to be equally available to the plant over the entire range from field capacity to permanent wilting (8, 26). Actual transpiration was found to decrease with decreasing soil moisture (8, 26). Denmead and Shaw (8) found that soil moisture content at which the decline in relative transpiration rate occurred, varied from a volumetric soil moisture content of 23% when the potential rate was 1.4 mm/day to 34% when potential transpiration rate exceeded 6 mm/day. Carolus et al. (7) found that as the available soil moisture level (ASM) increased from low to high, under high temperature conditions, tomato fruit number increased 47% and fruit size 49%; however, under low temperature conditions fruit size did not vary significantly and fruit number was reduced 23%.

Janes (23) working with celery found that rate of growth was retarded when soil moisture was depleted to 40% of field capacity compared to plants in which the moisture levels were maintained above 60 and 80%. The plants at the low soil moisture were smaller and of lower quality. In studies with potatoes, Wheaton et al. (52) reported that depletion to the 10 or 40% level before irrigating resulted in lower yields of marketable potatoes when compared to higher minimum soil moisture levels. Furthermore, more bushels of potatoes per inch of applied water were obtained with those treatments producing the highest yields.

#### IV. Osmotic Concentration

High osmotic pressure of the root medium has been reported to contribute to water stress in plants (3, 11, 21, 26, 39). Kramer (26) stated that it made little difference whether water absorption was decreased by high osmotic pressure of the soil solution or by high soil moisture tension. Slatyer (39) claimed that a real water stress was induced by osmotic substances but the effect was not identical with that of soil water tension. He found the imposition of osmotic substrates caused an initial, rapid outflow of water and loss of turgor. There was a gradual recovery in turgor as solute uptake and increase in internal osmotic potential caused an inflow of water. Other workers in this field (11, 21) have noted the progressive stunting of plants and the

attendant smaller darker green leaves which in most cases resembled drought symptoms. They supported the view that a water deficit induced by high osmotic pressure of the root medium was the factor restricting growth.

Plants on saline soils may not show symptoms of wilting despite the fact that their growth may be limited by moisture availability (3). The relatively high osmotic pressures of the soil solution in saline soils maintained a moderate moisture stress throughout the irrigation cycle (3).

Transpiration rate generally decreased with increased osmotic pressure in the nutrient medium (10, 11, 28). Eaton (10) grew corn and tomato plants with their roots divided between two or more solutions of unequal concentrations. The plants developed more roots and absorbed more water in the dilute than in the concentrated solutions. He found that osmotic pressures rather than specific ion effects were primarily involved. Eaton (11) further reported an increase in the efficiency of water use by several crops at moderate salinity but a decrease at higher levels of salinity.

In water culture experiments Kidson (25) found increased osmotic concentrations resulted in a reduction in the Ca level in the leaves of tomato plants. Geraldson (17, 18) noted that excessive total salts can cause Ca to be low in celery heart tissue, but a predominance of Na may be the important factor in reducing Ca uptake.

## V. Ion Balance

The water economy of several species was found by Schmied (38) to be modified by supplying them with B, Cu, Mn or Zn. In summarizing the general effect of fertilizers on water use, Viets (48) stated: "Whether fertilizers increase consumptive use not at all or only slightly, all evidence indicates that water-use efficiency, or dry matter produced per unit of water used, can be greatly increased if fertilizers increased yield."

Wostmann (54) found that plants in complete nutrient solutions with high K transpired more than in high Ca solution, while single salt solutions of  $\text{Ca}(\text{NO}_3)_2$  resulted in higher transpiration rates than such from  $\text{KNO}_3$  solutions. Furthermore, if the ratio of K to Ca was varied in culture solutions, then the transpiration, calculated in mg/square decimeter of leaf surface increased with increasing K supply. Biebl (5) concluded that in single salt solutions and highly unbalanced K applications to the soil, transpiration rates were lowered due to the K. However, in several salt or mixed applications, high K applications increased transpiration values. In explaining these results Biebl (5) summarized the antagonistic effects of K and Ca. He stated that K promoted swelling of the protoplasm which resulted in reduction of water loss while Ca promoted contraction which resulted in increased water loss; K affected the morphological-anatomical conditions of the periderm, facilitating

water loss while Ca had the opposite effect, resulting in cuticular transpiration being lower due to Ca than to K; the opening of the stomata was promoted by K and retarded by Ca.

## VI. Blackheart

Blackheart of celery was first reported in 1897 by Kinney (46). It has since been reported in almost every area where celery is grown with most severe occurrences in California, Texas and Florida. In some years all or a large portion of a crop has been lost.

Investigators generally have agreed that blackheart is a physiological disorder (1, 2, 12, 18, 29, 45, 46, 49). The first symptom is the development of brown lesions on the tips of tender leaflets in the heart or crown of the plant (2, 18). Then the whole leaf turns brown and finally the leaf and petiole turn black (2, 18). In severe cases the entire center of the plant decays and a secondary infection by Erwinia carotovora may cause a slimy black rot to occur (45). Figure 1 shows a celery plant with severe blackheart symptoms.

Foster and Weber (12) found that plants grown to maturity and then allowed to remain in the field were most subject to blackheart. Blackheart was most severe in Florida in the late crop during April and May because the celery was near maturity at the time when conditions conducive to blackheart development generally occur.

Figure 1. Celery plant showing severe blackheart symptoms.



Most investigators have agreed that the disorder is closely tied to unbalanced water relations and heavy fertilizer applications, especially of N (1, 2, 6, 12, 19, 20, 45, 46, 49, 50, 51). Other conditions reported as associated with blackheart have been: over maturity (12), vigorous growth (46), excess K (20), deficient K (29), low Ca (2, 17, 18, 45), high soluble salts (1, 6, 17, 18, 46, 49), and hot, dry weather (46). Landry (29) observed that the addition of K to some soils decreased blackheart, but in nutrient cultures, a high Ca/K ratio was relatively more effective. Beckenback and Spencer (1) observed that blackheart was associated with high  $\text{NO}_3$  nitrogen and excess soluble salts in the soil. Westgate (49) concluded that blackheart increased with the use of excess fertilizer and the accumulation of soluble salts. In experiments by Foster and Weber (12), blackheart was produced repeatedly in the field by flooding. About 48 hours after the water reached the surface from sub-irrigation the disorder appeared in the growing hearts.

United States Department of Agriculture workers (46) after an extensive survey concluded that blackheart was caused by drought or by excessive soil moisture due to heavy rains or excessive irrigation. Excessive irrigation apparently caused asphyxiation of the roots and ultimate death of the root hairs, thus creating a condition of drought. In Florida, blackheart was more prevalent on light sandy soils

than on muck soils indicating a better water balance on muck. They concluded that heavy fertilizer applications, vigorous, succulent, rapidly growing plants were most severely affected.

Cannell et al. (6) in studying the effects of irrigation and fertilizer found that yields increased with decreasing soil moisture tension while blackheart increased with increasing moisture tension and increasing fertilizer rates. Leaf concentration of Ca, Mg and Mn increased with the drier moisture treatments while P, B and Mo decreased. P content in the petioles increased in the lower soil moisture tension treatments.

In studying the effect of soluble salts on the prevalence and severity of blackheart, Geraldson (17, 18) grew celery in nutrient solutions ranging in concentration from 1500 to 12,000 ppm soluble salts with the ratio between salts constant. All of the plants developed blackheart, but symptoms developed sooner and were more severe in the lower than in the higher concentrations. The Ca content of young leaves was markedly less in blackhearted plants than in healthy plants (0.1 to 0.4% as compared to 0.5 to 1.0%). Analyses of older leaves indicated variations of 2.5 to 4.0% Ca, but these differences were not significant. Ca solutions applied directly to the heart of celery plants completely controlled blackheart. Regardless of the amount of Ca in the nutrient culture all plants developed blackheart unless a foliar Ca spray was applied. Although Ca

sprays to the hearts of the plants once or twice a week during conditions when blackheart is likely to occur are recommended as a general cultural practice by Lucas and Wittwer (30), it has been reported by Bergman (2) that many growers have applied sprays without marked success.

Geraldson (18), Landry (29) and Bergman (2) obtained data showing that blackheart symptoms generally increased in severity with decreasing Ca/K ratio in nutrient solutions, but rate of growth and yield were higher at low Ca/K ratios.

Takatori et al. (45) noted that an increase in N content of nutrient solutions without an increase in Ca resulted in increased blackheart. Higher Ca levels in the nutrient solutions containing high N reduced the percentage and severity. Increasing the N concentration of the nutrient solution reduced the Ca absorption of the plants and increased the K absorption.

In an experiment with tomatoes, Geraldson (20) found that excess soluble Mg, K, Na or  $\text{NH}_4$  salts or a deficiency of soluble Ca salts caused a decreased Ca uptake and an increased prevalence and severity of blossom-end rot of tomatoes. On an equivalent basis,  $\text{NH}_4$  affected the Ca uptake most severely, while Na had the least effect. Other investigations (16, 31, 33) have pointed out that Na had an adverse effect on the uptake of Ca.

Geraldson (20) has proposed that all of the factors most frequently associated with the occurrence and severity

of blackheart can be placed into two categories--excessive soluble  $\text{NH}_4$ , K, Mg, or Na or a deficiency of soluble Ca causing a decrease in Ca uptake; and, excessive total salts, even when Ca ratio is considered adequate, causing a decrease in Ca uptake.

## OUTDOOR EXPERIMENTS

The water balance of celery was studied using treatments thought to be conducive to moisture stress and those not conducive combined in factorial arrangements to determine the relative effects of each. In the following experiments low soil moisture, high K and Na, and high osmotic concentrations were employed in an attempt to increase moisture stress while misting, high soil moisture, high Ca and low osmotic concentrations were employed to decrease stress.

### I. Effects of Soil and Environmental Treatments on Celery Growth Under Controlled Soil Moisture Conditions (1965)

#### Procedure

Utah 52-70 celery seed was sown in muck and grown to transplanting size. On July 2, 1965 the plants were transplanted on the Michigan State University Horticulture Farm into drums 2 feet in diameter and 2 feet high containing Plainfield sand to which 2 inches of Houghton muck had been mixed into the surface. At the bottom of each drum was a 3-inch layer of coarse sand to facilitate drainage. The drums were sunk into the ground to near the level of the surrounding soil. Prior to planting, 10-52-17 fertilizer at

200 pounds per acre and  $\text{KNO}_3$  at 300 pounds per acre were applied. Five plants were grown in each drum.

On August 2, the following treatments were added in a split-split plot design with two replications:

Main plots

- 1 Mist
- 2 Control

Sub-plots

- 1 Control
- 2 1500 lbs. Ca/A as  $\text{CaCl}_2$
- 3 2190 lbs. K/A as  $\text{KCl}$
- 4 1305 lbs. Na/A as  $\text{NaCl}$
- 5 750 lbs. Ca plus 652 lbs. Na/A as Cl salts
- 6 1500 lbs. Ca plus 1305 lbs. Na/A as Cl salts

Sub-sub-plots

- 1 Low soil moisture (20-30% ASM)
- 2 High soil moisture (70-80% ASM)

Mist was applied from small mist nozzles between the hours of 10:00 a.m. and 4:00 p.m. on days when the temperature rose above 24 C except on days of changeable weather, when mist was applied during only part of this 6-hour period. A Mist-A-Matic Model B control system (E. C. Geiger, North Wales, Pennsylvania) was used to control the mist. It contained a counterbalanced metal screen which tipped down and turned off a solenoid valve when water accumulated. When the water evaporated, it tipped back up turning the solenoid valve on. The counterbalance was adjusted so that the foliage was moist with no appreciable amount of water being added to the soil. The mist system was operated on 24 days for 124 hours.

The sub-plot salt treatments were added in three applications--August 2, August 9 and September 1, totaling the amounts indicated above. Treatments 2, 3, 4 and 5 were the same osmotic concentration, and treatment 6 double that concentration.

Moisture levels in the sub-sub-plots were permitted to go down to 20-30% of the available soil moisture (ASM) and 70-80% ASM in the low and high treatments respectively and then brought back up to field capacity. Delmhorst gypsum blocks (Delmhorst Instrument Co., Boonton, N. J.) were placed at a depth of 6 inches, the readings from which indicated when the plots had dropped to the prescribed moisture level. The salt treatments prevented the moisture blocks from functioning satisfactorily, thus sub-sub-plots were watered according to the requirements of the control plots for each soil moisture level. Metal covers were placed over the plots when rain threatened, enabling soil moisture levels to be controlled. The volume of water applied was recorded.

Ratings of relative wilting were made on days during which wilting occurred on any plot. The mean was calculated by dividing the sum of the wilt rating by the overall number of days ratings were made. Leaf samples were taken on October 2, 1965 for dry matter determinations. Leaves of medium age were cut just below the first node and dried in an oven held at 65 C.

The volume of water transpired per gram of top dry matter was calculated by dividing the volume of water applied to the soil by the relative dry weight of the top of the plant.

The analyses of variance were performed on the resulting data as indicated by Snedecor (43) and mean comparisons made by the method described by Duncan (9).

### Results

The results are presented in Table 1. As reflected by measurements on top growth of plants, the misted plants were not significantly different from the control plants in fresh and dry weight, percentage dry matter, and water transpired per gram of dry matter produced. However, the interaction of environment X soil moisture was significant (Fig. 2). The wilt rating was the same in both low and high soil moisture in the misted plots while there were higher wilt ratings in low than high soil moisture in the control plots.

Of the ion balance treatments the K, Na, and low Ca-Na treatments yielded the highest top fresh weights, followed by the Ca and high Ca-Na treatments and lastly the control (Table 1). The percentages of dry matter followed in approximately the reverse order with the control highest and the K, Na and low and high Ca-Na treatments lowest.

Table 1. Top growth, water use, and wilting of celery plants in relation to environment, ion balance and soil moisture level

|                                |                     | Weight per<br>plant (gm.) |              | Percent-<br>age of<br>dry<br>matter | Volume<br>of water<br>tran-<br>spired<br>per gram<br>dry wt.<br>(ml.) | Visual<br>wilt<br>ratings      |
|--------------------------------|---------------------|---------------------------|--------------|-------------------------------------|-----------------------------------------------------------------------|--------------------------------|
|                                |                     | Total<br>fresh            | Total<br>dry |                                     |                                                                       | 0-no wilt<br>10-severe<br>wilt |
| <u>Environment</u>             |                     |                           |              |                                     |                                                                       |                                |
| 1                              | Mist                | 461 a <sup>1</sup>        | 56 a         | 12.3 a                              | 312 a                                                                 | 0.13 a                         |
| 2                              | Control             | 411 a                     | 52 a         | 12.7 a                              | 362 a                                                                 | 1.19 a                         |
| <u>Ion Balance</u>             |                     |                           |              |                                     |                                                                       |                                |
| 1                              | Control             | 344 d                     | 51 bc        | 15.0 a                              | 348 ab                                                                | 1.12 a                         |
| 2                              | Ca-1500             | 414 bcd                   | 52 bc        | 12.7 b                              | 342 ab                                                                | 0.70 b                         |
| 3                              | K-2190              | 520 a                     | 61 a         | 11.8 bc                             | 292 c                                                                 | 0.69 b                         |
| 4                              | Na-1305             | 501 ab                    | 57 ab        | 11.4 c                              | 315 bc                                                                | 0.57 b                         |
| 5                              | Ca-750,<br>Na-652   | 438 abc                   | 51 bc        | 11.8 bc                             | 355 ab                                                                | 0.55 b                         |
| 6                              | Ca-1500,<br>Na-1305 | 401 cd                    | 48 c         | 12.1 bc                             | 371 a                                                                 | 0.31 b                         |
| <u>Soil Moisture<br/>Level</u> |                     |                           |              |                                     |                                                                       |                                |
| 1                              | 20-30% ASM          | 408 b                     | 50 b         | 12.4 a                              | 349 a                                                                 | 0.76 a                         |
| 2                              | 70-80% ASM          | 464 a                     | 58 a         | 12.5 a                              | 325 a                                                                 | 0.56 b                         |
| <u>Interaction</u>             |                     |                           |              |                                     |                                                                       |                                |
| Environ. X<br>Soil moist.      |                     |                           |              |                                     |                                                                       | **                             |

<sup>1</sup>Values followed by uncommon letters are significantly different at the 5% level.

\*\*Significant at the 1% level.

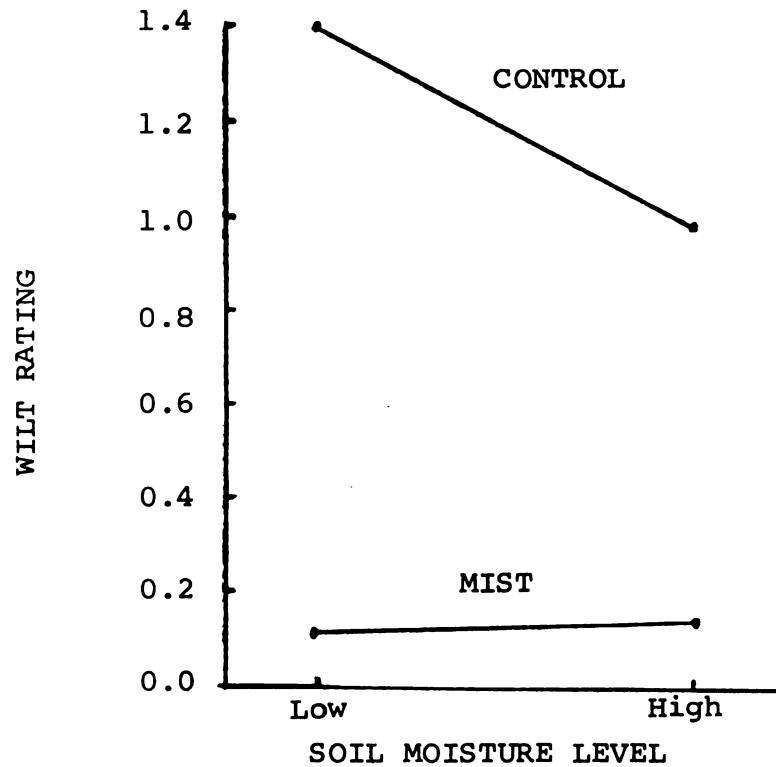


Figure 2. The effect of the interaction of environment and soil moisture level on the degree of wilting of celery plants (0 - no wilt, 10 - severe wilt).

This resulted in the top dry weights being more nearly equal but with the K and Na treated plants highest. The K and Na treatments resulted in the most efficient use of water, using 292 and 315 ml. water per gram of dry matter produced respectively. The high Ca-Na treatment was least efficient as it resulted in 371 ml. per gram. The control plants had a significantly higher degree of wilting than did the salt-treated plants. The high Ca-Na treatment showed the lowest degree of wilting, although it was not significantly lower than that of the other salt treatments.

The high soil moisture level resulted in higher fresh and dry top weights, 464 g. and 58 g. respectively, than those of the low soil moisture level, 408 and 50 g. respectively (Table 1). Table 1 and Fig. 2 indicate that there was a lower degree of wilting in the high than the low moisture plots.

No blackheart symptoms appeared during the course of the experiment.

### Discussion

Misting was effective in reducing the degree of water stress in the plants (Table 1 and Fig. 2). Misted plants tended to be higher than the control plants in fresh and dry weights and lower in percentage dry matter. These differences may be attributed to the reduced degree of plant water stress which is in agreement with the findings of other workers (4, 7, 14, 47, 53).

The K and Na treatments were most efficient in water use and, also, produced the highest fresh and dry weights (Table 1). This was in agreement with Viets (48) who concluded that if a fertilizer treatment increased yield there was generally an accompanying increase in the water-use efficiency. This was also in agreement with Biebl (5) who concluded that plants receiving very high K applications had lowered transpiration rates. The high Ca treatment, on the other hand, did not change the transpiration rate compared to the control, but it did produce a more succulent plant with a lower percentage of dry matter. Eaton (11) reported an increase in water-use efficiency at moderate salinity and a decrease at high levels of salinity. The high Ca-Na treatment showed this trend but the value was not significantly different from that of the control. The lower degree of wilting in the salt treatments compared to the control was in agreement with the findings of Bernstein and Hayward (3). Other workers (10, 11, 28) found that transpiration rate decreased with increasing osmotic pressure and thus a moderate moisture stress may have been maintained throughout the irrigation cycle (3) and may have limited the growth of those plants whose water-use efficiency was not boosted with high K or Na. Thus equal weights of dry matter were produced under high soil moisture tension (control) as under high osmotic tensions (treats. 2, 5, 6). However, the lower

percentage of dry matter in treatments 2, 5, and 6 may have been caused by the different type of moisture stress (39).

The higher fresh and dry weights from high soil moisture compared to those of low soil moisture agreed with the observations of other workers (23, 52). This may be explained by the lower degree of plant water stress as indicated by the lower wilt ratings.

The failure of blackheart symptoms to appear despite the high K and Na, high osmotic concentration and low minimum soil moisture and combinations of these treatments may have been because of a lack of extremely high temperature in late August and September, when the plants were at a stage more susceptible. High temperature may be of primary importance for the development of blackheart symptoms and soil conditions may be secondary. A more vigorous rate of growth than experienced with these treatments may make the plants more susceptible to blackheart.

## II. Effects of Soil and Environmental Treatments on Celery Grown Under Controlled Soil Moisture Conditions (1966)

In the following experiment high N levels and complete nutrient solutions with different Ca/K ratios were used in addition to other treatments in order to avoid any nutrient deficiencies and to promote vigorous growth. A mineral soil was used as blackheart has been reported to be more prevalent on mineral soil than on muck (46).

### Procedure

Utah 52-70 celery seed was sown in vermiculite on March 15, 1966 and later grown on in a one-half muck-one-half sand mixture. On May 28, 1966 these plants were planted in drums as described in the previous experiment. The drums contained Hillsdale sandy loam. Four plants were planted in each drum. A four-foot high snow fence was set up to reduce the force of the prevailing winds. On June 4 and again on June 23, 10-52-17 fertilizer was applied at a rate of 50 pounds per acre.

On July 9, 1966 the following treatments were added in a split-split-split-plot design with two replications:

#### Main plots

- 1 360 lbs. N/A
- 2 720 lbs. N/A

#### Sub-plots

- 1 Mist
- 2 Control

#### Sub-sub-plots

- 1 0 lbs. Ca plus 600 lbs. K/A
- 2 110 lbs. Ca plus 440 lbs. K/A
- 3 220 lbs. Ca plus 280 lbs. K/A

#### Sub-sub-sub-plots

- 1 Low soil moisture (20-30% ASM)
- 2 High soil moisture (70-80% ASM).

The N treatments of the main plots were applied in three equal applications--July 9, August 2, and August 12, totaling the amounts indicated above. The first and third applications were applied in conjunction with the sub-sub-plots as described below. The second application consisted of  $\text{NH}_4\text{NO}_3$  solutions applied at one gallon per plot or drum.

The same misting equipment was used as in the previous experiment. Mist was applied between 10:00 a.m. and 4:00 p.m. on days when the temperature rose above 27 C, except on days of changeable weather, when mist was applied during only part of this 6-hour period. The mist system was operated on 48 days for a total of 246 hours.

The sub-sub-plot treatments were applied in two applications, July 9 and August 12. The first application comprised 3 gallons of Hoaglands No. 1 solution (22) with the Ca, K, and N contents modified to give the desired Ca/K ratios for the sub-sub-plot treatments and the desired N levels for the main plot treatments. The second application was made with only one gallon of solution containing three times the concentration in order to avoid leaching the plots at higher moisture levels.

In order to facilitate the maintenance of the desired soil moisture levels, Delmhorst moisture blocks were placed at a 6-inch depth in each of the non-misted plots in the first replication and in each of the misted plots in both replications. The volume of water applied was recorded.

Blackheart ratings were made at two to four-day intervals after the first symptoms were observed. Ratings of the degree of wilting on days during which wilting occurred on any plot were made and the mean rating calculated by dividing the sum of the ratings by the overall number of days ratings were made.

On several days, air, soil, heart, and leaf temperatures were recorded using thermisters connected to a Telethermometer. The leaf temperatures were recorded by small, flat thermisters taped to the under sides of the leaves.

On September 14, 1966 total top weights were recorded. The plants were then stripped, marketable weights recorded and the length of the outside marketable petioles measured. Medium-aged petioles complete with leaf blades were taken for dry matter determinations. The entire heart consisting of all leaves less than 8 inches in length and cut just above the stem plate was taken from each plant for chemical analysis. The four hearts per plot were combined into one sample. N content was determined by the Kjeldahl procedure, K by a flame photometer, and the other elements by a direct reading photoelectric spectrometer (24).

The analyses of variance and mean comparisons were made by the methods previously indicated. Simple linear correlations of blackheart ratings with all other recorded factors and treatments were also determined.

### Results

The N treatments did not result in any significant differences in total, marketable and dry weight of top nor in percentage of top dry matter, water use or wilting (Table 2). However, there was a significant interaction between N level and environment for total top fresh weight (Fig. 3)

Table 2. Top growth, water use and wilting of celery plants in relation to nutrition, environment and soil moisture level

|                                |                    |              |      |                          | Volume<br>of water<br>tran-<br>spired<br>per gram<br>dry<br>matter<br>(ml.) | Visual<br>wilt<br>ratings      |
|--------------------------------|--------------------|--------------|------|--------------------------|-----------------------------------------------------------------------------|--------------------------------|
| Weight per plant<br>(grams)    |                    |              |      | Percent<br>dry<br>matter |                                                                             | 0-no wilt<br>10-severe<br>wilt |
| Total<br>fresh                 | Market-<br>able    | Total<br>dry |      |                          |                                                                             |                                |
| <u>Nitrogen Level</u>          |                    |              |      |                          |                                                                             |                                |
| 1 N-360                        | 988 a <sup>1</sup> | 640 a        | 95 a | 9.6 a                    | 491 a                                                                       | 0.6 a                          |
| 2 N-720                        | 1002 a             | 216 a        | 91 a | 9.1 a                    | 464 a                                                                       | 0.9 a                          |
| <u>Environment</u>             |                    |              |      |                          |                                                                             |                                |
| 1 Mist                         | 1044 a             | 665 a        | 96 a | 9.2 a                    | 428 a                                                                       | 0.3 a                          |
| 2 Control                      | 945 b              | 587 a        | 90 b | 9.5 a                    | 526 a                                                                       | 1.1 a                          |
| <u>Ca/K Ratio</u>              |                    |              |      |                          |                                                                             |                                |
| 1 Ca-O,<br>K-600               | 1065 a             | 681 a        | 97 a | 9.1 a                    | 477 a                                                                       | 0.8 a                          |
| 2 Ca-110,<br>K-440             | 1007 a             | 628 ab       | 93 a | 9.3 a                    | 471 a                                                                       | 0.7 a                          |
| 3 Ca-220,<br>K-280             | 912 b              | 569 b        | 88 a | 9.7 a                    | 483 a                                                                       | 0.7 a                          |
| <u>Soil Moisture<br/>Level</u> |                    |              |      |                          |                                                                             |                                |
| 1 20-30% ASM                   | 877 b              | 546 b        | 87 b | 9.9 a                    | 463 a                                                                       | 1.1 a                          |
| 2 70-80% ASM                   | 1112 a             | 706 a        | 98 a | 8.8 b                    | 492 a                                                                       | 0.4 b                          |
| <u>Interactions</u>            |                    |              |      |                          |                                                                             |                                |
| N level X<br>Envir.            | **                 |              |      |                          |                                                                             |                                |
| N level X<br>Soil Moist.       | **                 |              |      |                          |                                                                             |                                |
| Envir. X<br>Soil Moist.        | *                  |              |      |                          |                                                                             |                                |
| Ca/K X Soil<br>Moist.          | **                 |              |      |                          |                                                                             |                                |

<sup>1</sup>Values followed by uncommon letters are significantly different at the 5% level.

\*Significant at the 5% level.

\*\*Significant at the 1% level.

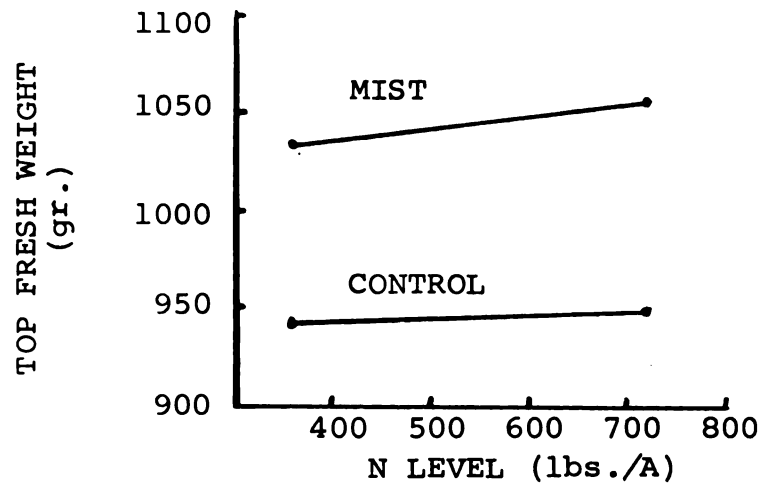


Figure 3. The effect of the interaction of environment and N level on top fresh weight of celery plants.

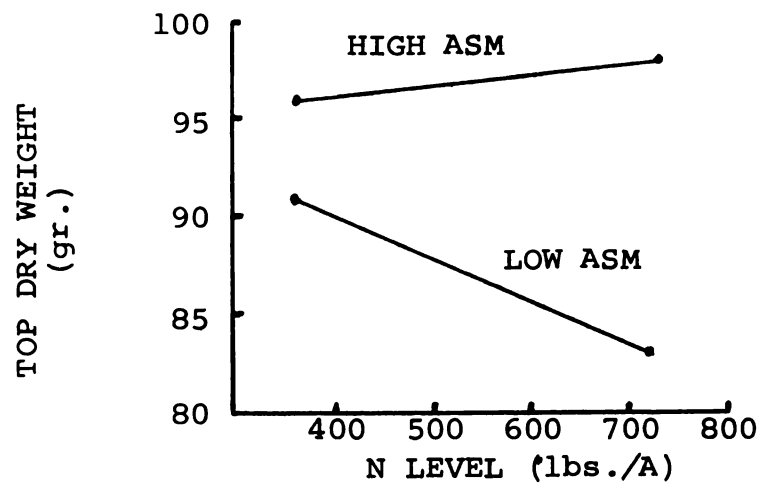


Figure 4. The effect of the interaction of N and available soil moisture (ASM) on the dry weight of celery top growth.

indicating that misted plants gave a greater increase in yield for increasing N level than did the control plants. The interaction of N level X soil moisture (Fig. 4) shows that top dry weight decreased from the low to the high N level under low soil moisture but increased under high moisture.

The misted plants were higher than the control in total top fresh weight (Table 2 and Fig. 3). The interaction of environment X soil moisture (Fig. 5) shows that the increase in top dry weight from low to high soil moisture levels was greater in misted plots than in the controls.

The data in Table 2 further indicate that total and marketable fresh weight decreased with increasing Ca/K ratio in the soil. The significant interaction of Ca/K ratio X soil moisture level (Fig. 6) pointed out a greater decrease in marketable weight from the low to the medium Ca/K ratio at the high soil moisture level than at the low level and an approximately equal decrease from the medium to the high Ca/K ratio. No significant differences in the wilting ratings were attributable to the Ca/K ratios in the soil. The interaction of Ca/K ratio X soil moisture level for transpiration was significant (Fig. 7). This interaction showed that at high soil moisture, the transpiration rate decreased from the low to the medium Ca/K ratio and was about similar at the medium and high Ca/K ratios, while at low soil moisture, transpiration increased slightly from the low to the

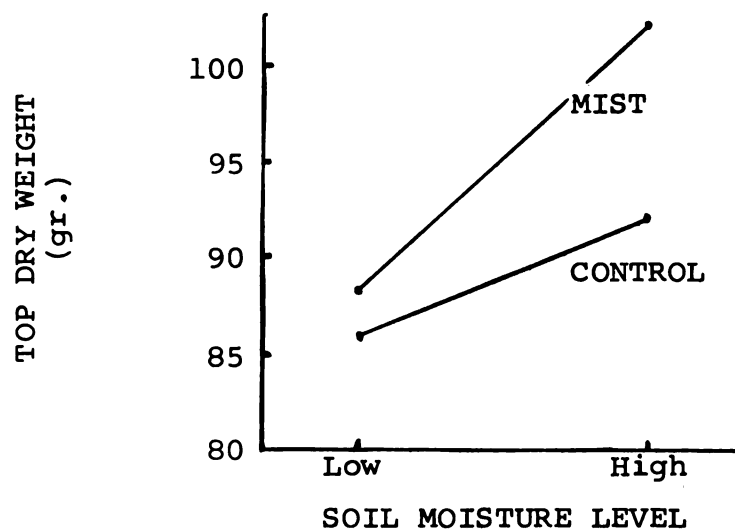


Figure 5. The effect of the interaction of soil moisture level and environment on the dry weight of the celery top growth.

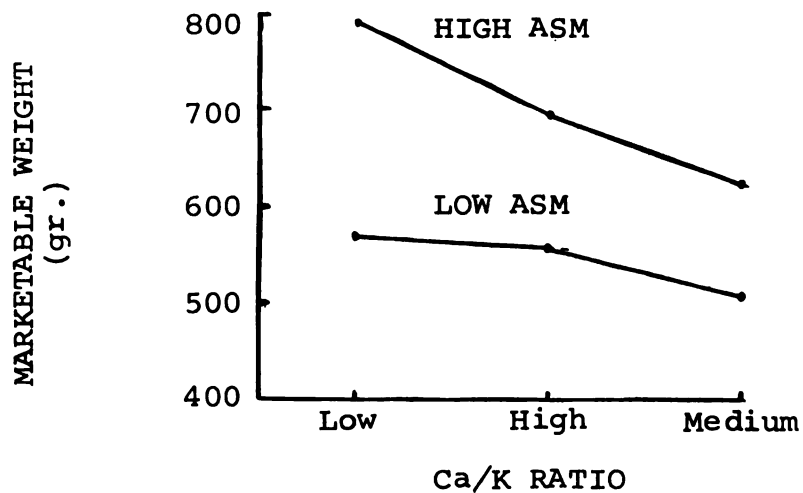


Figure 6. The effect of the interaction of Ca/K ratio and soil moisture level on marketable weight of celery.

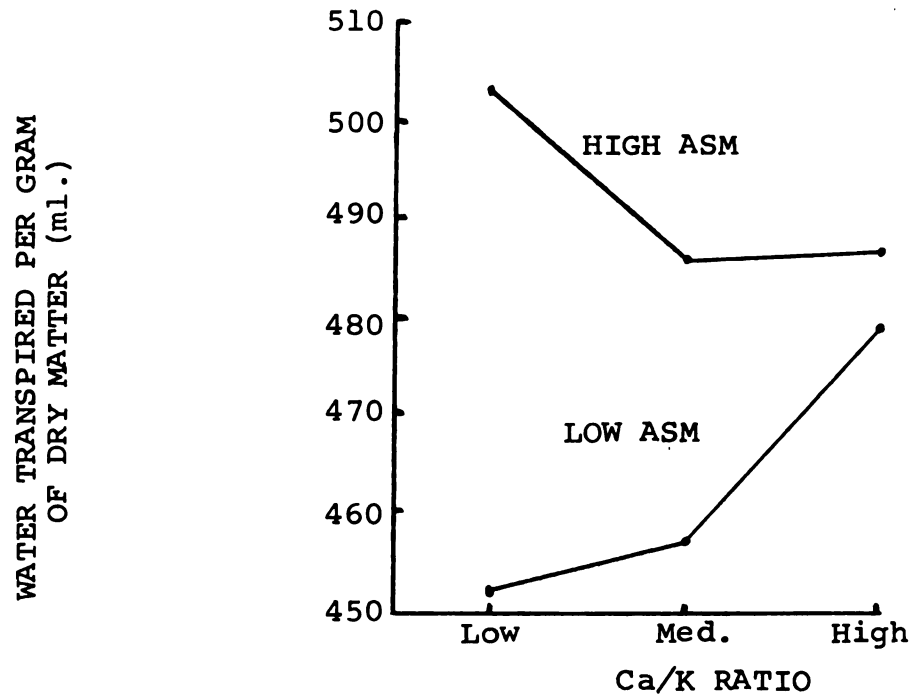


Figure 7. The effect of the interaction of Ca/K ratio and soil moisture level on the volume of water transpired per gram of dry matter produced by celery.

medium Ca/K ratio and increased greatly from the medium to the high Ca/K ratio.

High soil moisture resulted in a higher total top fresh weight (Table 2), a higher marketable weight (Table 2, Fig. 6), a higher top dry weight (Table 2, Fig. 5), and a lower percentage top dry matter (Table 2) than in the low soil moisture. It also resulted in a lower degree of wilting (Table 2).

The only significant difference in petiole length resulted from the soil moisture treatments. Petiole length averaged 19.6 cm. in the low soil moisture and 21.4 cm. in the high. Means of the other treatments varied from 20.1 to 20.8 cm.

The results of the chemical analyses for those elements that were significant at the 5% level are presented in Table 3. There were no significant differences due to soil N level. However, there was a significant interaction between soil N level and soil Ca/K ratio for P content of the heart tissues (Fig. 8). At the high N level the P content increased with increasing Ca/K ratio while at the low N level it decreased from the low to the medium Ca/K ratio and then increased to the high Ca/K ratio. There was also a significant interaction between soil N level and soil moisture level for Ca/K ratio in the heart tissue (Fig. 9). This interaction indicated that at the low soil moisture level the Ca/K ratio in the heart tissue was lower at the

Table 3. Mineral content of celery heart tissues related to nutrition, environment and soil moisture level

|                            | Ca<br>%             | P<br>%  | B<br>ppm | Ca/K<br>ratio |
|----------------------------|---------------------|---------|----------|---------------|
| <u>Nitrogen Level</u>      |                     |         |          |               |
| 1 N-360                    | .410 a <sup>1</sup> | .898 a  | 72.7 a   | .086 a        |
| 2 N-720                    | .464 a              | .872 a  | 59.8 a   | .100 a        |
| <u>Environment</u>         |                     |         |          |               |
| 1 Mist                     | .411 b              | .898 a  | 65.9 a   | .088 a        |
| 2 Control                  | .463 a              | .872 a  | 66.7 a   | .098 a        |
| <u>Ca/K Ratio</u>          |                     |         |          |               |
| 1 Ca-O, K-600              | .418 a              | .879 ab | 65.4 b   | .084 b        |
| 2 Ca-110, K-440            | .416 a              | .857 b  | 63.6 b   | .086 b        |
| 3 Ca-220, K-280            | .477 a              | .919 a  | 69.8 a   | .108 a        |
| <u>Soil Moisture Level</u> |                     |         |          |               |
| 1 20-30% ASM               | .438 a              | .838 b  | 65.6 a   | .094 a        |
| 2 70-80% ASM               | .436 a              | .931 a  | 67.0 a   | .092 a        |
| <u>Interactions</u>        |                     |         |          |               |
| N level X Ca/K ratio       |                     | *       |          |               |
| Envir. X Ca/K ratio        |                     |         | **       |               |
| N level X Soil moist.      |                     |         |          | **            |

<sup>1</sup>Values followed by uncommon letters are significantly different at the 5% level.

\*Significant at the 5% level.

\*\*Significant at the 1% level.

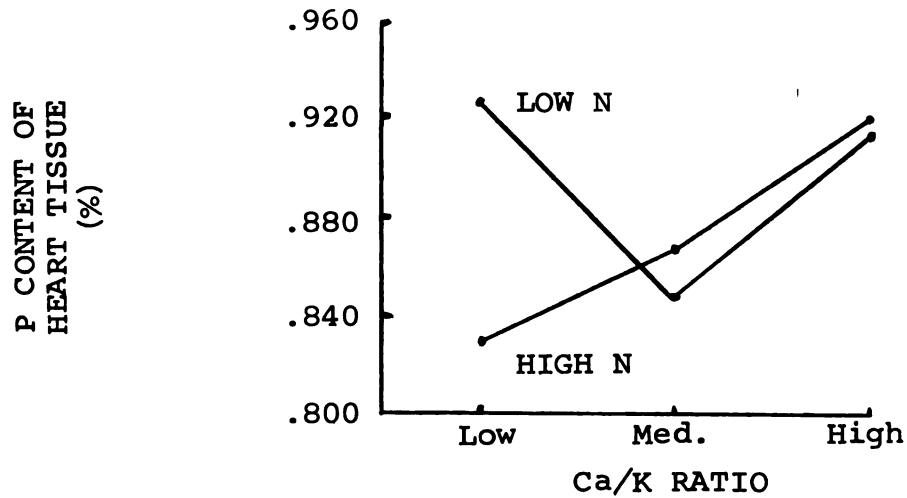


Figure 8. The effects of the interaction of Ca/K ratio and N on the P content of celery heart tissue.

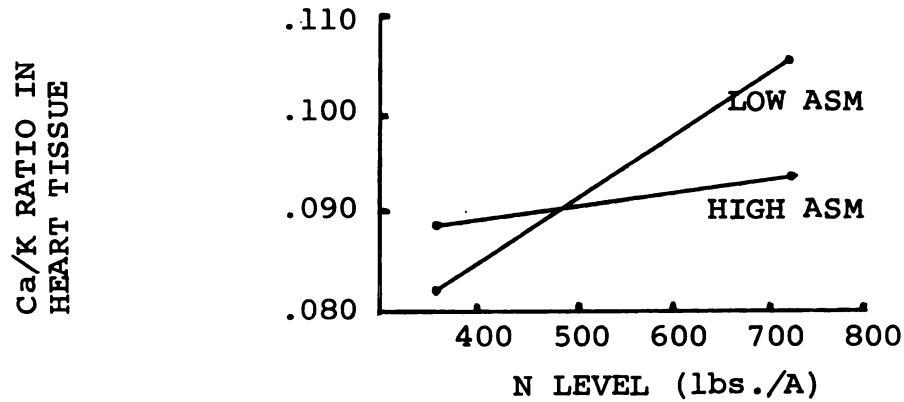


Figure 9. The effects of the interaction of N level and soil moisture on the Ca/K ratio in celery heart tissue.

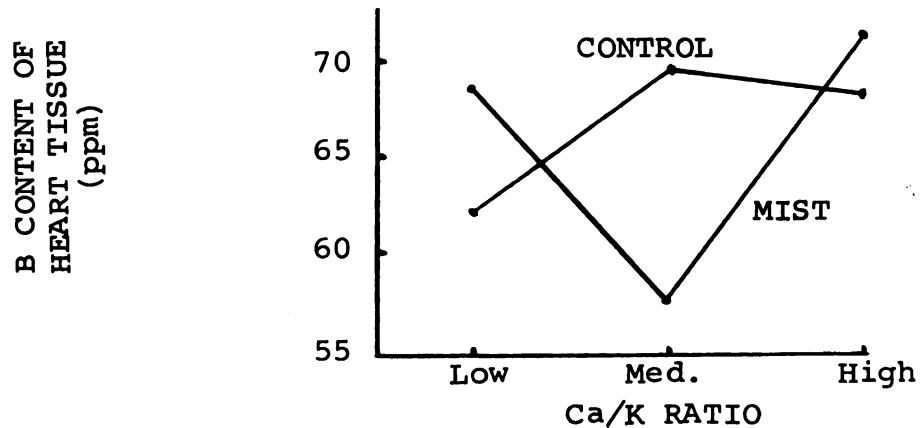


Figure 10. The effects of the interaction of Ca/K ratio and environment on the B content of celery heart tissue.

low soil N than it was at the high soil moisture level, but higher at the high soil N level.

In the environmental treatments, the Ca content of the heart tissue was higher in the control than in the misted plants (Table 3). The interaction of environment X soil Ca/K ratio was significant for B content of the heart tissues (Fig. 10) indicating that in the misted plants the B content decreased from the low soil Ca/K ratio to the medium and increased from the medium to the high, while in the control plants the B content increased from the low soil Ca/K ratio to the medium and slightly decreased from the medium to the high.

The soil Ca/K treatments showed a higher P content in the celery heart tissue at the highest ratio than at the medium but was not different significantly from that of the low (Table 3, Fig. 8). The B content of the celery heart in relation to the soil Ca/K ratio is explained above in the interaction of environment X Ca/K (Fig. 10). The Ca/K in the heart tissues showed no difference due to the two lower soil Ca/K ratios. Both, however, were lower than the value resulting from the high soil Ca/K ratio (Table 3).

The high soil moisture level resulted in a higher P content of the heart tissue of the plants than that found in plants at low soil moisture (Table 3).

Midday soil, air and leaf temperatures are presented in Table 4 for mist and control plants. During the seven-day period of August 27 to September 2 the midday soil temperature was 0.7 C lower at the 3-inch depth and 0.8 C lower at the 1/4-inch depth in the misted plots than in the controls. The air temperature in the canopy was 2.2 C lower and the leaf temperature was 5.5 C lower in the misted plants than in the controls. Leaf and canopy temperatures in control and misted plots are shown plotted at two-minute intervals in Fig. 11. The leaf temperatures of the misted plants dropped sharply as the mist was applied. After the mist had ceased the temperature of the leaves gradually rose as the leaf surface dried, then dropped when the next mist application was made. This cycle was repeated continuously as the leaves were saturated about to the point of runoff followed by evaporation of water from the leaf surface almost to the point of dryness.

Very mild blackheart symptoms in some plants were observed from September 2 until September 9. Statistical analysis of the results showed no significant differences attributable to any of the treatments. Simple linear correlations of blackheart ratings with treatment and other recorded data indicated significant correlations between the following factors: wilt rating ( $r = -.329$ ), P content of heart tissue ( $r = +.434$ ), and Mg content of heart tissue ( $r = +.333$ ).

Table 4. Mid-day soil, air and leaf temperatures in mist and control plots. Mean of seven days during which mist was applied (August 27 to September 2, 1966)

|                            | Mean<br>(C) | Difference<br>(C) |
|----------------------------|-------------|-------------------|
| <u>Soil 3-inch depth</u>   |             |                   |
| 1 Mist                     | 22.2        | 0.7               |
| 2 Control                  | 22.9        |                   |
| <u>Soil 1/4-inch depth</u> |             |                   |
| 1 Mist                     | 23.3        | 0.8               |
| 2 Control                  | 24.1        |                   |
| <u>Air in canopy</u>       |             |                   |
| 1 Mist                     | 26.8        | 2.2               |
| 2 Control                  | 29.0        |                   |
| <u>Leaf</u>                |             |                   |
| 1 Mist                     | 27.1        | 5.5               |
| 2 Control                  | 32.6        |                   |

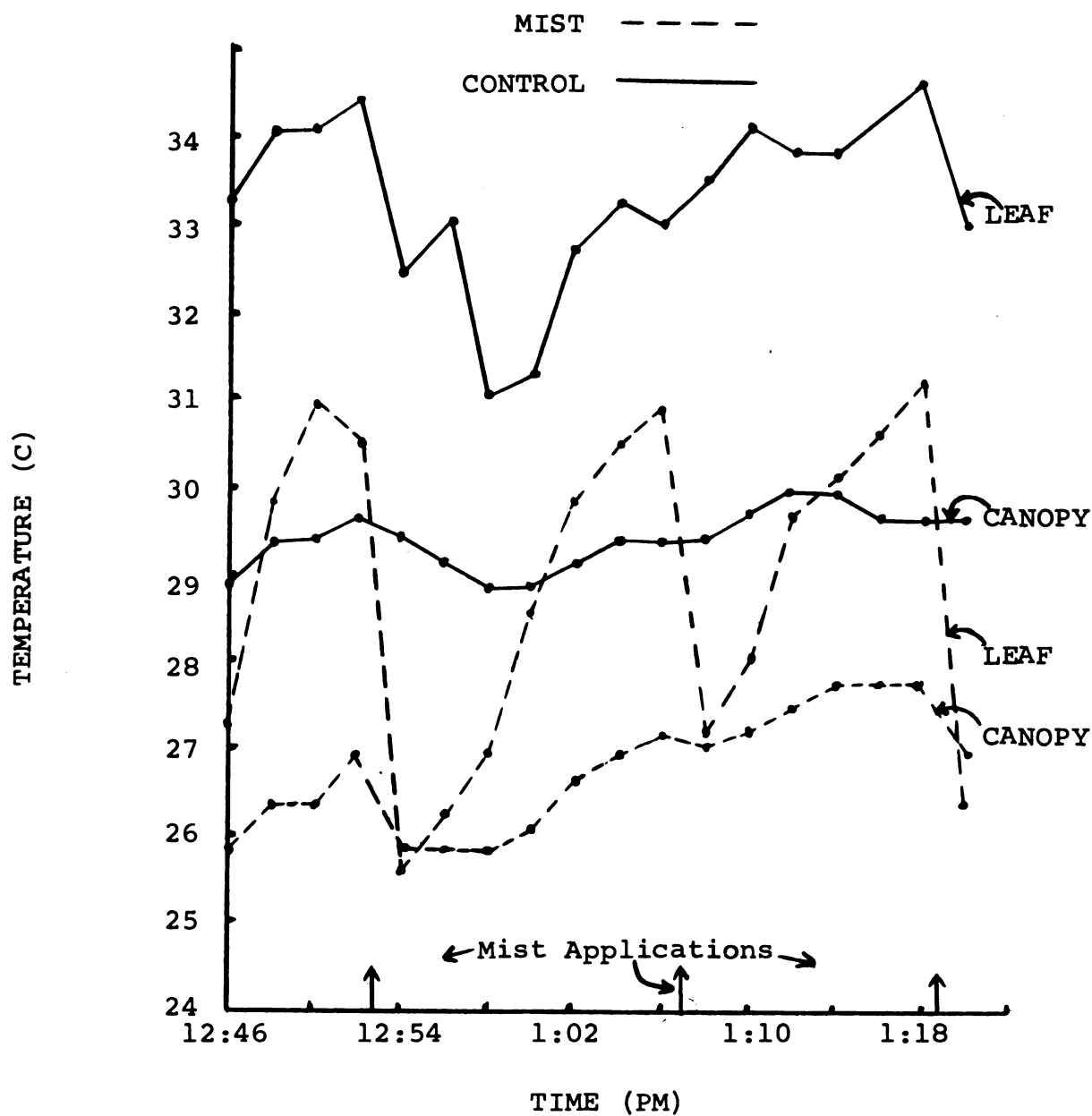


Figure 11. The effect of mist on leaf and canopy temperatures on a typical hot day (August 28, 1966). Maximum air temperature was 29.4 C: relative humidity, 41%; pan evaporation, 4.57 mm.; wind travel, 56 Km.; sky, mostly sunny. Mist duration was approximately 60 sec. per application.

## Discussion

Misted plants showed the same trends as in the previous experiment when compared to the control plants for plant weights, percentage dry matter, water transpired and wilting. The interaction of environment X soil moisture level indicates that mist was more effective at high than low soil moisture in increasing dry matter production (Fig. 5). The interaction of environment X N level indicates that mist was more effective in increasing top fresh weight at the high than the low N level (Fig. 3). Although the mist applications reduced the volume of water transpired per gram of dry matter produced, the Ca/K ratio in the heart tissues indicated no significant difference from that of the control. Freeland (13) had reported higher Ca/K ratios in bean and corn plants due to reduced transpiration rates.

The fresh weights recorded (Table 2) showed a decrease with increasing Ca/K ratio in the soil. This was in agreement with the results of Geraldson (18), Landry (29) and Bergman (2) in their studies using nutrient solutions. Although the top fresh weight decreased with increasing Ca/K ratio, the top percentage of dry matter tended to increase resulting in no significant difference in top dry weight.

The volume of water transpired at high soil moisture per gram of dry matter produced declined with increasing Ca/K ratio from the lowest to the medium level and was about the same at the medium and high levels, while at low soil

moisture transpiration rate increased with increasing Ca/K ratio (Fig. 7). This was in agreement with Wostmann's findings (54) that if the Ca/K ratio was varied the transpiration rate decreased with decreasing K. However, under conditions an unbalance such as a water shortage, the water loss of Ca-treated plants exceeded that of K-treated plants.

Although the Ca and K content of the celery heart tissue was not significantly altered by the different Ca/K ratios applied to the soil, the Ca/K ratio in the heart tissue increased with increasing Ca/K ratio. This was in agreement with the observations of Geraldson (18).

The higher fresh and dry weights resulting from the high soil moisture treatment compared to the low (Table 2) were in agreement with the findings of Janes (23) and Wheaton et al. (52). Also, the lower percentage of dry matter at high soil moisture indicated a more succulent growth. The interaction of soil moisture level X N level (Fig. 9) indicates that Ca/K ratio increased to a greater degree from the low to the high N level in the low soil moisture plots than it did in the high soil moisture plots. This resulted in a high Ca/K ratio occurring in the low soil moisture-high N plots in this experiment. The higher Ca/K ratio would tend to decrease the incidence of blackheart, yet, blackheart has been reported to be more severe at low soil moisture and high N levels (1, 6, 46, 49). This higher Ca/K ratio may be over balanced by other factors in

the ultimate occurrence of blackheart, or, it is possible that the relationship of moisture level and N to Ca/K ratio may change under higher temperature conditions. Cannel et al. (6) found that leaf Ca, Mg, and Mn increased while P, Mo and B decreased at lower soil moisture treatments. The values in Table 3 for P agree with Cannel but the values for Ca, B and all of the other elements determined showed no change due to soil moisture level.

The blackheart symptoms that developed in the latter part of the growing season were very mild and showed no significant differences between any of the treatments. There was a significant negative correlation of blackheart rating with wilting ( $r = -.329$ ). This is opposite to the observations of other workers (46) who reported blackheart symptoms increased by drought. However, the treatments that resulted in lower degrees of wilting (mist and high soil moisture level) achieved more vigorous growth which has been associated with more severe blackheart symptoms (2, 18, 46). Furthermore, the low soil moisture-high N plants had higher Ca/K ratios (Fig. 9) associated with the higher degree of wilting (Table 2). Since high Ca/K ratio and drought are opposing factors in the development of blackheart symptoms, the higher Ca/K ratio may have been the deciding factor in blackheart occurrence in this instance. The higher Ca/K ratios in the higher N plots are contrary to the findings of Takatori et al. (45) using nutrient solutions.

### III. Effects of Soil and Environmental Treatments on Celery Grown Under Field Conditions (1965)

Celery is grown primarily on muck soil in Michigan. It was desirable, therefore, to determine the effect of the soil and atmospheric treatments on the plant water balance and the occurrence of blackheart in celery grown under field conditions without any restriction of root development.

#### Procedure

Utah 52-70 celery seed was sown in muck soil. At the end of May the plants were transplanted to the field at the Michigan State University Muck Farm in Houghton muck. Row spacing was 32 inches with plants 7 inches apart in the rows. Soon after planting,  $\text{KNO}_3$  was side-dressed at 75 pounds and  $\text{NH}_4\text{NO}_3$  at 75 pounds per acre.

Treatments were applied as outlined below using a split-split-plot design with three replications.

#### Main plots

- 1 Mist
- 2 Control

#### Sub-plots

- 1 Control
- 2 140 lbs. N/A as  $\text{NH}_4\text{NO}_3$

#### Sub-sub-plots

- 1 Control
- 2 3000 lbs. Ca/A as  $\text{CaCl}_2$
- 3 4380 lbs. K/A as  $\text{KCl}$
- 4 1500 lbs. Ca plus 2190 lbs. K/A as Cl salts.

Misting was begun on the main plots in mid-June using a sequamatic irrigation system which applied .07 inches of water per hour between the hours of 10:00 a.m. and 4:00 p.m. on days when the temperature rose above 29 C. The sprinklers in the sequamatic system had 5/32 inch nozzles regulated by valves with each of the three sprinklers on a line operating five minutes out of twenty in a sequencing cycle. The mist system was operated on 23 days. The moisture level on all plots was maintained above 50% of the available soil moisture.

The N treatment of the sub-plots was side-dressed in two applications, August 6 and August 12, totaling 140 pounds per acre.

The salt treatments of the sub-sub-plots were applied broadcast over the entire plot surface and worked into the surface inch of soil. These treatments were calculated to result in equal osmotic concentrations and were applied in three applications, August 6, 12 and September 2, totaling the amounts indicated above. Two-row plots 7 feet long were used.

On October 2, 1965 leaves of intermediate age were cut just below the second node and percent dry matter determined. On this same date the plants were harvested. Records of total top weight and marketable weight were made on 14 plants from the center of each plot.

Statistical analyses were made by the methods previously indicated.

### Results

Growth of the celery plants during the season was good with the average plant weight in excess of 2000 g. The season was cool, with only 8 days on which the temperature was above 32 C. Total top fresh weight, marketable weight and percentage of dry matter are presented in Table 5. The differences between means were not significant at the 5% level. No blackheart symptoms were observed during the course of the experiment.

### Discussion

The mist application showed a tendency to have decreased the yield compared to the control (Table 5). This may have resulted from a lowering of the plant temperature below the optimum on several days throughout the season, thus nullifying the beneficial effects on yield that could have taken place due to misting on the hotter days.

The failure of blackheart symptoms to appear may have been due to the lack of periods of sufficiently high temperatures during the growing season. Furthermore, the unbalance of nutrients may not have been severe enough to cause blackheart to develop.

Table 5. The effect of environment and nutrition on the growth of celery plants (1965)

|                       | Weight per plant<br>(grams) |            | Top percent<br>dry matter |
|-----------------------|-----------------------------|------------|---------------------------|
|                       | Total top                   | Marketable |                           |
| <u>Environment</u>    |                             |            |                           |
| 1 Mist                | 2075                        | 1376       | 6.69                      |
| 2 Control             | 2215                        | 1485       | 6.81                      |
| <u>Nitrogen Level</u> |                             |            |                           |
| 1 Control             | 2125                        | 1416       | 6.64                      |
| 2 N - 140             | 2165                        | 1444       | 6.86                      |
| <u>Ion Balance</u>    |                             |            |                           |
| 1 Control             | 2093                        | 1430       | 7.10                      |
| 2 Ca - 3000           | 2107                        | 1403       | 6.70                      |
| 3 K - 4380            | 2193                        | 1444       | 6.79                      |
| 4 Ca-1500, K-2190     | 2193                        | 1439       | 6.42                      |

IV. Effects of Soil and Environmental  
Treatments on Celery Grown Under  
Field Conditions (1966)

In order to encourage the development of blackheart, high N and K levels were included in the treatments in the following experiment carried out on muck soil in the same manner as the previous experiment.

Procedure

Utah 52-70 seedlings were grown in muck and transplanted to the field at the Michigan State University Muck Farm on May 27, 1966. Rows were spaced 32 inches apart and plants were set 7 inches apart in the rows. Before planting, 5-10-30 plus 2% Mn was broadcast at the rate of 800 pounds per acre.

Treatments were applied as indicated below using a split-plot design with 4 replications.

Main plots

- 1 Mist
- 2 Control

Sub-plots

|   |     |      |     |    |                                 |      |      |      |     |    |     |
|---|-----|------|-----|----|---------------------------------|------|------|------|-----|----|-----|
| 1 | 300 | lbs. | N/A | as | NH <sub>4</sub> NO <sub>3</sub> | plus | 1000 | lbs. | K/A | as | KCl |
| 2 | 300 | "    | "   | "  | "                               | "    | 2000 | "    | "   | "  | "   |
| 3 | 300 | "    | "   | "  | "                               | "    | 4000 | "    | "   | "  | "   |
| 4 | 600 | "    | "   | "  | "                               | "    | 1000 | "    | "   | "  | "   |
| 5 | 600 | "    | "   | "  | "                               | "    | 2000 | "    | "   | "  | "   |
| 6 | 600 | "    | "   | "  | "                               | "    | 4000 | "    | "   | "  | "   |

Misting was begun in mid-June using the same method and apparatus as described in the previous experiment. The mist system was operated on 35 days.

The N treatments were applied in three applications, July 16, August 1, and August 12, while the K treatments were applied in two applications, July 16, and August 12, totaling the amounts indicated above. These salts were broadcast uniformly over the surface area of the plots. Two-row plots 10 feet long were used. The soil moisture level on all plots was maintained above 50% of the available soil moisture.

Five plants from each plot were harvested on October 3. Total weight, marketable weight and average petiole length were recorded.

Statistical analyses were made by the methods previously indicated.

### Results

Growth during the season was very rapid with the average plant total fresh weight of top exceeding 4000 grams. There were 11 days during which the temperature rose above 32 C. Total plant top fresh weight, marketable weight and petiole length are presented in Table 6. No significant differences at the 5% level were shown between the treatment means. No blackheart symptoms developed during the course of the experiment.

Table 6. The effect of environment and nutrition on the growth of celery plants (1966)

|                        |          | <u>Weight per plant (grams)</u> |                   | <u>Petiole<br/>length<br/>(cm.)</u> |
|------------------------|----------|---------------------------------|-------------------|-------------------------------------|
|                        |          | <u>Total top</u>                | <u>Marketable</u> |                                     |
| <u>Environment</u>     |          |                                 |                   |                                     |
| 1                      | Mist     | 4339                            | 2140              | 25.0                                |
| 2                      | Control  | 4202                            | 2036              | 24.2                                |
| <u>Nitrogen Level</u>  |          |                                 |                   |                                     |
| 1                      | N - 300  | 4220                            | 2143              | 24.7                                |
| 2                      | N - 600  | 4322                            | 2033              | 24.5                                |
| <u>Potassium Level</u> |          |                                 |                   |                                     |
| 1                      | K - 1000 | 4296                            | 2092              | 25.0                                |
| 2                      | K - 2000 | 4256                            | 2094              | 24.6                                |
| 3                      | K - 4000 | 4261                            | 2079              | 24.2                                |

### Discussion

In this experiment plant growth on all plots was extremely vigorous, with misted plants showing a tendency to be larger than those of the control. This increase may be attributed to the decreased plant water stress on the hotter days.

The high exchange capacity of the muck soil may have prevented the N and K treatments from having a more pronounced effect on the plants.

The failure of blackheart to occur in this experiment may have been due to two possible conditions: (1) the failure of periods of extreme temperatures to occur, and (2) the maintenance of the soil moisture level too near the optimum. It is possible that the effect of the two conditions is accumulative in the development of symptoms. That is, blackheart may not develop unless the soil moisture level is low at the same time that the temperatures are high for a prolonged period of time.

## GREENHOUSE EXPERIMENTS

Two greenhouse experiments were conducted using solution culture to avoid the effects of soil moisture fluctuations. With soil culture the water in the soil is depleted at a rate dependent upon the amount of moisture stress on the plant top and the plant size, resulting in different soil moisture contents in plots of different treatments at a given time. Differences in plant response or in the development of blackheart symptoms occurring between plots during a two or three-day hot period could be attributed to the soil moisture level during that period as readily as to the treatment effects. The use of solutions instead of soil would allow uniform root conditions, permitting observed differences to be attributed to the various treatments applied.

### I. Effects of Ca/K Ratio and Environmental Conditions on Celery Grown in Nutrient Solutions

To determine the effect of plant water balance on celery response and on the development of blackheart symptoms, atmospheric stress was modified in this experiment by applying mist to decrease stress and by applying infrared radiation to increase stress, with normal greenhouse

atmosphere between these two extremes. Different Ca/K ratios were used in the nutrient solution to further affect the plant water balance and to promote the development of blackheart symptoms to different degrees of intensity.

### Procedure

Celery seed of the variety Utah 52-70 was sown in muck and the seedlings were grown to transplanting size. On April 2, 1966 these plants were transferred to half-strength Hoaglands No. 2 nutrient solution (22) in two-gallon crocks on greenhouse benches. Solutions were changed each week.

On May 13, 1966 the following treatments were put on in a split-plot design with four replications:

#### Main plots

- 1 Mist
- 2 Control
- 3 Heat lamps

#### Sub-plots

- 1 50 ppm Ca/235 ppm K
- 2 100 ppm Ca/176 ppm K
- 3 150 ppm Ca/117 ppm K
- 4 200 ppm Ca/59 ppm K

The treatments of the main plots were applied every day between the hours of 9:00 a.m. and 4:00 p.m. Mist was applied intermittently from fine mist nozzles using deionized water. A timeclock was adjusted to turn the mist on for 2 seconds every 3 or 6 minutes depending on the atmospheric conditions so as to keep the leaves moist, but with no appreciable runoff. Polyethylene sheets were placed across

the bench on two sides of each plot extending 12 inches above the top of the foliage to limit the mist to the appropriate plots. The control consisted of normal greenhouse conditions. In the plots receiving increased radiation, 250 watt infrared heat lamps were placed 14 inches above the foliage with one lamp supplying heat radiation to two plants. Reflectors were used to prevent radiation from striking plants of adjacent plots.

The sub-plot treatments consisted of Hoaglands No. 1 solution (22) with the Ca and K contents modified as indicated above by altering the amounts of  $\text{Ca}(\text{NO}_3)_2$  and  $\text{KNO}_3$  added. These Ca/K ratios resulted in solutions with very nearly equal osmotic concentrations (0.6 atm.).  $\text{NH}_4\text{NO}_3$  was added to correct the N levels resulting from the omission of portions of the  $\text{Ca}(\text{NO}_3)_2$  and/or  $\text{KNO}_3$ . The pH of the solutions was adjusted to 6.0. Deionized water was used throughout. The solutions were changed each week.

Each day the volume of water used was measured in each plot by determining the amount of deionized water required to bring the solution level back up to a wire marker.

Periodically the plants were lifted out of the solutions, allowed to drain for a few seconds and then weighed. Ratings of the severity of blackheart symptoms were also made periodically.

Final records were made on June 17, 1966. Weights of total top, root, suckers and marketable stalk were recorded. The entire heart consisting of all leaves less than 8 inches in length and cut just above the stem plate was taken from each plant as a sample for chemical analyses. Nitrogen was determined by the Kjeldahl procedure, potassium with a flame photometer, and the other elements by a direct reading photoelectric spectrometer (24). The root and the remainder of the top from each plot was dried in a forced-air oven at 65 C for the determination of the dry matter content.

The volume of water transpired per gram of dry matter (DM) produced was determined by the following formula:

$$\text{ml. water/g. DM} = \frac{\text{ml. water transpired from May 14 to June 16}}{(\text{fresh wt. June 16} - \text{fresh wt. May 14}) \times \% \text{DM}}$$

Analysis of variance was performed on the resulting data as indicated by Snedecor (43) and mean comparisons made by the method described by Duncan (9). Simple linear correlations of blackheart ratings with all other recorded data and with treatment were run. Correlations were also run of nutrient solution Ca/K ratio and environmental treatments with all of the recorded factors.

## Results

Data on the growth of the celery plants are presented in Table 7 for those measurements that were significant at the 5% level. Misting increased the weight of suckers per plant and decreased the percentage of dry matter in the top compared to the control and heat lamp treatments. The interaction of environment X Ca/K ratio was significant for total top fresh weight per plant (Fig. 12). This interaction indicates that in misted plots the top fresh weight decreased with increasing Ca/K ratio, while it increased from the 50/235 to the 100/176 ratios, then decreased to the 200/59 ratio in the control plots. The heat lamp treatment resulted in similar values for the 50/235 and 100/176 ratios then decreased to the 200/59 ratio. The interaction of environment X Ca/K ratio was also significant for root fresh weight (Fig. 13). In this interaction the misted plants showed equal root weights at the 100/176 and 150/117 ratios, but a higher weight at the 50/235 ratio and a lower weight at the 200/59 ratio, while the roots of the control plant increased in weight from the 50/235 to the 100/176 ratio, decreased to the 150/117 ratio, then remained the same to the 200/59 ratio. Root weights of the plants given additional radiation with heat lamps were the same at the 50/235 and 100/176 ratios, then decreased to the 150/117 ratio.

Table 7. Growth of celery plants related to environment and nutrient solution Ca/K ratio

|                        |            | Fresh weight per plant<br>(grams) |        |       | Root<br>dry<br>weight<br>per<br>plant<br>(gr.) | Percent dry<br>matter |       |
|------------------------|------------|-----------------------------------|--------|-------|------------------------------------------------|-----------------------|-------|
|                        |            | Total<br>top                      | Sucker | Root  |                                                | Top                   | Root  |
| <u>Environment</u>     |            |                                   |        |       |                                                |                       |       |
| 1                      | Mist       | 1277 a <sup>1</sup>               | 555 a  | 143 a | 9.7 a                                          | 9.5 b                 | 6.8 a |
| 2                      | Control    | 1132 a                            | 406 b  | 126 a | 9.0 a                                          | 10.3 a                | 7.1 a |
| 3                      | Heat lamps | 1148 a                            | 434 b  | 136 a | 9.8 a                                          | 10.2 a                | 7.2 a |
| <u>Ca/K Ratio</u>      |            |                                   |        |       |                                                |                       |       |
| 1                      | 50/235     | 1285 a                            | 550 a  | 150 a | 9.9 ab                                         | 9.3 c                 | 6.6 b |
| 2                      | 100/176    | 1311 a                            | 609 a  | 157 a | 10.5 a                                         | 9.4 c                 | 6.7 b |
| 3                      | 150/117    | 1123 b                            | 395 b  | 123 b | 9.1 bc                                         | 10.2 b                | 7.4 a |
| 4                      | 200/59     | 1025 c                            | 307 b  | 111 b | 8.6 c                                          | 11.2 a                | 7.7 a |
| <u>Interactions</u>    |            |                                   |        |       |                                                |                       |       |
| Envir. X Ca/K<br>ratio |            | *                                 |        |       | *                                              |                       |       |

<sup>1</sup>Values followed by uncommon letters are significantly different at the 5% level.

\*Significant at the 5% level.

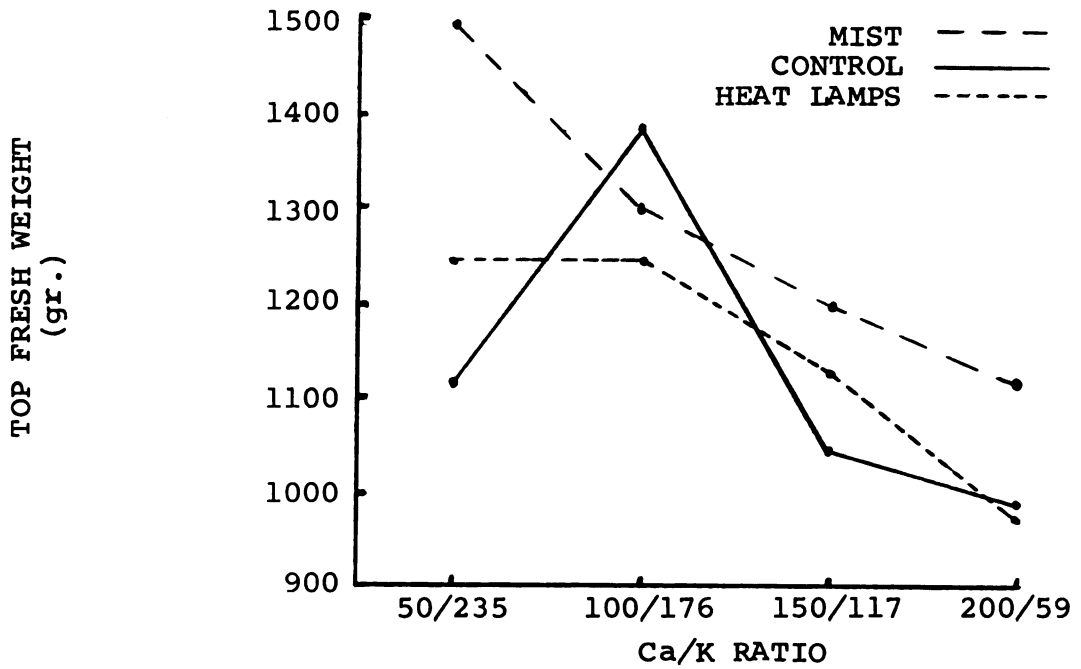


Figure 12. The effects of the interaction of Ca/K ratio and environment on the top fresh weight of celery grown in nutrient solutions in the greenhouse.

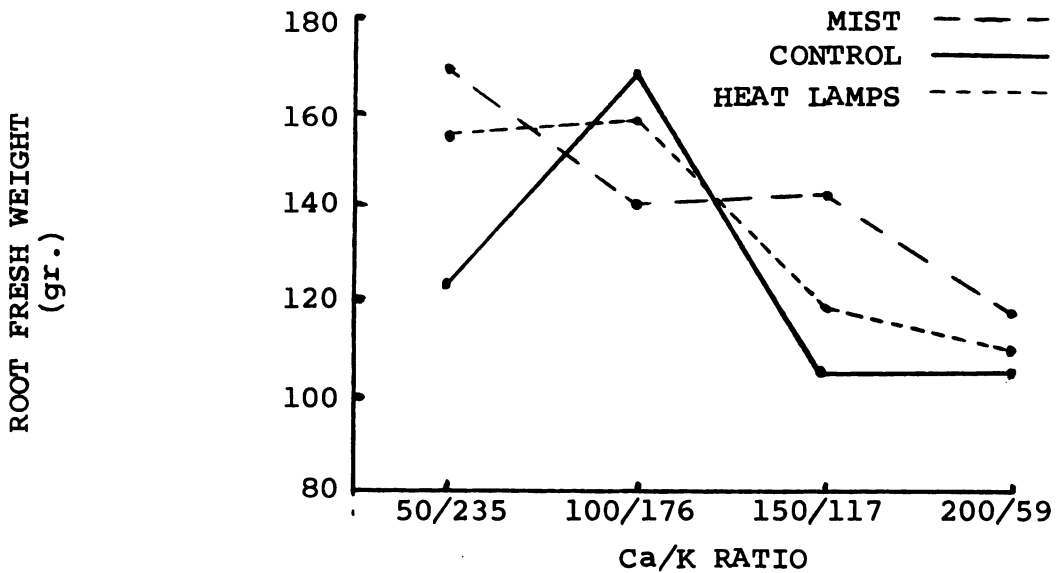


Figure 13. The effect of the interaction of Ca/K ratio and environment on the fresh weight of celery roots grown in nutrient solutions in the greenhouse.

Table 7 further points out that the 50/235 and 100/176 ratios resulted in higher sucker weights per plant than did the 150/117 and 200/59 ratios. Root dry weight was highest at the 50/235 and 100/176 Ca/K ratios, and lowest at the 150/117 and 200/59 ratios with no significant difference between the 50/235 and 150/117 ratios. Top and root percentages of dry matter increased with increasing Ca/K ratio with no difference between the two low ratios in top and root values and no difference between the two high ratios for root values.

In the last 28 days of the experiment (May 20 to June 17) the misted plants increased in fresh weight 1019 g. in 50/235 Ca/K solution; 822 g. in 100/176; 737 g. in 150/117; and 608 g. in 200/59 solution. The increases during the same period of time for plants in normal greenhouse environment (control) were 733 g. in 50/235; 879 g. in 100/176; 643 g. in 150/117; and 531 g. in 200/59 Ca/K solution.

Results of the chemical analyses of the celery heart tissues are presented in Table 8 for those elements that showed significant differences between treatment means. In the environment treatments the only significant difference was a lower value for Al in the control plots than in either the mist or heat lamp plots.

Table 8. Mineral content of celery heart tissue in relation to environment and nutrient solution Ca/K ratio

|                    | K<br>%              | Ca<br>% | Mg<br>% | Mn<br>ppm. | B<br>ppm. | Al<br>ppm. |
|--------------------|---------------------|---------|---------|------------|-----------|------------|
| <u>Environment</u> |                     |         |         |            |           |            |
| 1 Mist             | 4.71 a <sup>1</sup> | .160 a  | .196 a  | 20.1 a     | 62.8 a    | 29.2 a     |
| 2 Control          | 4.91 a              | .147 a  | .200 a  | 20.8 a     | 61.6 a    | 23.4 b     |
| 3 Heat lamps       | 4.69 a              | .184 a  | .210 a  | 23.9 a     | 69.8 a    | 28.3 a     |
| <u>Ca/K Ratio</u>  |                     |         |         |            |           |            |
| 1 50/235           | 5.60 a              | .099 c  | .230 a  | 25.2 a     | 49.9 c    | 26.5 ab    |
| 2 100/176          | 5.07 b              | .181 ab | .209 b  | 23.2 ab    | 52.5 bc   | 27.7 ab    |
| 3 150/117          | 4.57 c              | .160 b  | .186 c  | 18.3 c     | 64.1 b    | 21.6 b     |
| 4 200/59           | 3.83 d              | .215 a  | .183 c  | 19.7 bc    | 92.4 a    | 32.2 a     |

<sup>1</sup>Values followed by uncommon letters are significantly different at the 5% level.

K and Mg content of heart tissue decreased with increasing Ca/K of the nutrient solution while Ca and B generally increased. Mn decreased from the 50/235 ratio to the 150/117 ratio and was not different at the 150/117 and 200/59 ratios. Al was lowest at the 150/117, highest at the 200/59 and intermediate at the 50/235 and 100/176 ratios (Table 8).

Blackheart ratings, transpiration and Ca/K ratios in the celery heart tissues are presented in Table 9. There were no significant differences in the severity of blackheart symptoms and Ca/K ratios in heart tissues between the means of the environment treatments. The misted plants transpired less water per gram of dry matter produced than did the control plants, and plants of the heat lamp treatment transpired more than the control plants.

With increasing Ca/K ratio in the nutrient solution the severity of blackheart symptoms decreased, the volume of water transpired per gram of dry matter produced increased and the Ca/K ratio of the heart tissue increased (Table 9).

Table 10 contains the simple linear correlation coefficients that were significant between blackheart symptoms and other factors recorded and the corresponding coefficients between treatments and the same factors.

Table 9. Blackheart ratings, transpiration and Ca/K ratio in celery heart tissue related to environment and nutrient solution Ca/K ratio

|                    | Blackheart<br>rating <sup>1</sup> | Water<br>transpired<br>per gram<br>dry matter<br>(ml.) | Ca/K ratio<br>in heart<br>tissue |
|--------------------|-----------------------------------|--------------------------------------------------------|----------------------------------|
| <u>Environment</u> |                                   |                                                        |                                  |
| 1 Mist             | 4.34 a <sup>2</sup>               | 287 c                                                  | .036 a                           |
| 2 Control          | 4.28 a                            | 360 b                                                  | .031 a                           |
| 3 Heat lamps       | 4.09 a                            | 417 a                                                  | .041 a                           |
| <u>Ca/K Ratio</u>  |                                   |                                                        |                                  |
| 1 50/235           | 5.31 a                            | 326 c                                                  | .018 c                           |
| 2 100/176          | 4.48 ab                           | 344 b                                                  | .036 b                           |
| 3 150/117          | 4.17 b                            | 348 b                                                  | .035 b                           |
| 4 200/59           | 3.00 c                            | 403 a                                                  | .056 a                           |

<sup>1</sup>1-no symptoms; 9-severe symptoms.

<sup>2</sup>Values followed by uncommon letters are significantly different at the 5% level.

Table 10. The relationship of blackheart ratings and nutrient solution Ca/K ratio to celery plant characteristics (simple linear correlation coefficients)

|                                  | Blackheart<br>rating | Ca/K ratio<br>in nutrient<br>solution |
|----------------------------------|----------------------|---------------------------------------|
| Top fresh weight                 | + .351 *             | - .584 **                             |
| Top percent dry matter           | - .416 **            | + .682 **                             |
| Transpiration (dry weight basis) | - .336 *             | + .413 **                             |
| Sucker weight                    | + .384 **            | - .595 **                             |
| Ca content in heart              | - .693 **            | + .490 **                             |
| K content in heart               | + .557 **            | - .824 **                             |
| B content in heart               | - .491 **            | + .682 **                             |
| Ca/K ratio in heart              | - .719 **            | + .654 **                             |
| Ca/K ratio in nutrient solutions | - .560 **            |                                       |

\*Significant at the 5% level.

\*\*Significant at the 1% level.

Blackheart severity increased with increasing top fresh weight, sucker weight and K content in the heart, while symptoms decreased in severity with increasing top percentage dry matter, transpiration rate, Ca and B content in the hearts, Ca/K ratio in the hearts and Ca/K ratio in the nutrient solutions. In each case the correlation with Ca/K ratio in the nutrient solutions showed a significant, but opposite relationship. For example, with increasing top fresh weight, blackheart symptoms increased, but top fresh weight decreased with increasing Ca/K in the nutrient solution.

The correlation of environmental treatment with blackheart ratings was not significant at the 5% level ( $r = -0.070$ ).

### Discussion

With the exception of the values at the 100/176 Ca/K ratio, the values of the top and root fresh weights were higher in the misted plots than in the control and the heat lamp plots (Figs. 12, 13). However, the percentage of dry matter in the tops of the control was higher, resulting in no significant differences in the dry weights of tops and roots between the plants of the environmental treatments (Table 7). The increase in fresh weight in the misted plants was in agreement with the results of other workers (4, 7, 14, 47, 53) who found increased growth due to reduced plant moisture stress. The significant increase in sucker

weight by the mist applications compared to the control (Table 7) resulted in a marketable weight not significantly different from that of the control.

The reduction in the volume of water transpired per gram of dry matter produced by the mist applications compared to the control (Table 9) was in agreement with McMillan and Burgy (32) who found that transpiration was reduced proportionally to the evaporation of the sprinkled water. The reduction in transpiration was not accompanied by a reduction in the uptake of nutrients into the heart tissues (Table 8), nor by a change in the Ca/K ratio in the heart tissues (Table 9). This did not agree with the findings of Freeland (13) in which he observed that higher transpiration caused corn and bean plants to take up relatively less Ca and more K. Michael and Marschner (35) also found that ion uptake was affected by reduced transpiration rates but their transpiration rates were reduced much more than they were in this experiment.

The only notable effect of the infrared heat lamps was to increase the volume of water transpired per gram of dry matter produced (Table 9). However, as for the mist application, the altered transpiration rate did not result in a marked altering of the mineral uptake.

The lower Ca/K ratios in the nutrient solutions yielded higher fresh weights but lower percentages of dry matter (Table 7), resulting in no significant differences

in dry matter produced compared to the higher Ca/K ratios. Similarly the sucker weights were higher, resulting in no significant differences in marketable weight. As the Ca/K ratio increased in the nutrient solutions, the K content in the heart tissues decreased and the Ca content increased, resulting in an increasing Ca/K ratio in the hearts (Tables 8, 9). This was in agreement with observations of Geraldson (18). Also, the decrease in severity of blackheart symptoms with increasing Ca/K ratio in the nutrient solution (Table 9) was in agreement with the observations of other workers (2, 18, 29).

The volume of water transpired per gram of dry matter produced was lowest in the lowest Ca/K ratio solution and highest in the highest Ca/K ratio and approximately equal in the medium ratio solutions (Table 9). Wostmann (54) found transpiration to decrease with increasing Ca/K ratio in solutions. However, Wostmann (54) and Biebl (5) found that highly unbalanced K applications caused reduced transpiration which may have been the case in the low Ca/K ratio solution. On the other hand, low K could have caused an increase in transpiration (48, 54). This may have been the case in the high Ca/K ratio solution.

The simple linear correlation coefficients (Table 10) indicate that blackheart increased in intensity with increasing top fresh weight, increasing sucker weight and decreasing

percentage of dry matter. Since these three factors are associated with succulence or increased vigor, then it follows that blackheart increased in severity with increased vigor. This has been reported by many workers (1, 2, 18, 46, 49). The correlation coefficients also show that blackheart was related to Ca, K, B and Ca/K ratio in the heart tissue. These same trends were pointed out in Table 8 and were discussed previously. While each of the factors mentioned above was related to blackheart, each was related in the opposite direction to the Ca/K ratio in the nutrient solution. The environmental treatments, with increasing atmospheric stress from mist to control to heat lamps, showed no significant correlation with blackheart. Thus, in this experiment the Ca/K ratio in the nutrient solution appeared to have been the dominant factor affecting the severity of blackheart symptoms.

## II. Effects of Ca/K Ratio, Solution Concentration and Environmental Conditions on Celery Grown in Nutrient Solutions

In the previous greenhouse experiment the use of infrared heat lamps to increase plant water stress caused an increase in transpiration but did not significantly alter any of the other characteristics recorded. In order to have a more effective means of increasing plant water stress, different levels of osmotic concentrations of the nutrient

solutions were employed in the following experiment in conjunction with Ca/K ratios and mist applications.

### Procedure

Utah 52-70 celery seed was sown in vermiculite and the seedlings grown to transplanting size in a one-half muck/one-half sand mixture. On June 25, 1966 these plants were placed in half-strength Hoaglands No. 2 nutrient solution (22) in 2-gallon crocks. Blackheart symptoms began appearing on July 5. To reduce the intensity of the symptoms the  $\text{Ca}(\text{NO}_3)_2$  content in the nutrient solutions was doubled and the  $\text{KNO}_3$  halved when the solutions were changed on July 6 and again on July 20.

On July 29, 1966 the following treatments were put into effect according to a split-split-plot design with two replications:

#### Main plots

- 1 100 ppm. Ca/176 ppm. K
- 2 200 ppm. Ca/59 ppm. K

#### Sub-plots

- 1 Mist
- 2 Control

#### Sub-sub-plots

- 1 0.3 atm. concentration
- 2 1.2 atm. concentration
- 3 4.8 atm. concentration.

Main plot and sub-plot treatments were carried out as described in the previous experiment.

In the sub-sub-plots the osmotic concentrations were adjusted to 0.3, 1.2, and 4.8 atm. by altering the content of each element in the solutions while maintaining the same balance between the elements. The pH of the solutions was adjusted to 6.0.

Records were taken during the course of the experiment as indicated in the previous experiment. In addition, a 16-point strip-chart recorder was set up to record temperatures by means of copper-constantan thermocouples constructed of 24-guage wire in the air, solutions and plant hearts, and by means of thermocouples a 40-guage wire inserted into leaf veins.

On several days transpiration values were recorded throughout the day by noting the volume of water lost from inverted containers that fed water into the crocks as it was taken up by the plants, thereby keeping the level in the crocks constant.

On September 24, 1966 the plants were harvested and final records were made and statistically analyzed as indicated for the previous experiment.

### Results

Data recorded on celery growth is summarized in Table 11. The 200/59 Ca/K ratio nutrient solution resulted in significantly lower total top and root fresh weights than those in the 100/176 ratio solution. The interaction of

Ca/K ratio X solution concentration on marketable weight was significant (Fig. 14), indicating that the marketable weight was higher in the 200/59 ratio solutions than in the 100/176 ratio solutions at the 1.2 and 4.8 atm. solution concentrations but lower at the 0.3 atm. The interaction of Ca/K ratio X solution concentration was also significant for root dry weight. It may be explained in the same terms as the previous interaction. There was also a significant interaction of Ca/K ratio X solution concentration on root percentage dry matter (Fig. 15). In this case, the root percentage of dry matter showed a greater increase from the 100/176 ratio to the 200/59 ratio the higher the solution concentration.

Misting resulted in a significant increase in the total top fresh weight per plant above that of the control (Table 11).

The 1.2 atm. solution yielded higher total top fresh weight, sucker fresh weights, top dry weight and lower percent dry matter in the tops and roots than either the 0.3 atm. or 4.8 atm. (Table 11). In these measurements the 0.3 atm. and the 4.8 atm. solutions were not significantly different from each other except in root percentage dry matter in which case the former was lower than the latter. Root fresh weight was lower in the 4.8 atm. nutrient solutions than in the 0.3 and 1.2 atm. (Table 11). Marketable weight was lower in the 4.8 atm. than in the 1.2 atm. but not

Table 11. Growth of celery plants related to environment, nutrient solution Ca/K ratio and concentration

|                          | Fresh weight per plant (grams) |          |        | Dry weight per plant (grams) |        | Percent dry matter |        |
|--------------------------|--------------------------------|----------|--------|------------------------------|--------|--------------------|--------|
|                          | Total top                      | Mkt. top | Sucker | Root                         | Top    | Root               | Top    |
| <u>Ca/K Ratio</u>        |                                |          |        |                              |        |                    |        |
| 1 100/176                | 1036 a <sup>1</sup>            | 450 a    | 309 a  | 99 a                         | 90.4 a | 6.1 a              | 8.7 a  |
| 2 200/59                 | 900 b                          | 476 a    | 181 a  | 89 b                         | 85.0 a | 6.4 a              | 9.5 a  |
| <u>Environment</u>       |                                |          |        |                              |        |                    |        |
| 1 Mist                   | 1052 a                         | 501 a    | 285 a  | 96 a                         | 91.6 a | 6.3 a              | 8.7 a  |
| 2 Control                | 885 b                          | 425 a    | 205 a  | 92 a                         | 83.8 a | 6.2 a              | 9.5 a  |
| <u>Solution Conc.</u>    |                                |          |        |                              |        |                    |        |
| 1 0.3 Atm.               | 799 b                          | 438 ab   | 137 b  | 97 a                         | 79.3 b | 6.8 a              | 9.9 a  |
| 2 1.2 Atm.               | 1144 a                         | 515 a    | 352 a  | 107 a                        | 98.3 a | 6.5 ab             | 8.6 b  |
| 3 4.8 Atm.               | 713 b                          | 345 b    | 134 b  | 65 b                         | 72.8 b | 5.6 b              | 10.2 a |
| <u>Interaction</u>       |                                |          |        |                              |        |                    |        |
| Ca/K ratio X soln. conc. |                                | **       |        |                              |        | *                  | **     |

<sup>1</sup>Values followed by uncommon letters are significantly different at the 5% level.

\*Significant at the 5% level.

\*\*Significant at the 1% level.

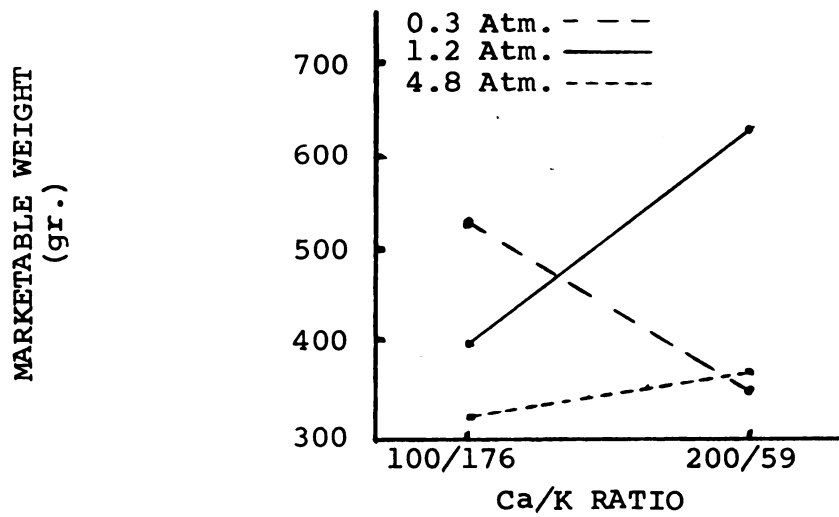


Figure 14. The effect of the interaction of Ca/K ratio and nutrient solution concentration on marketable weight of celery.

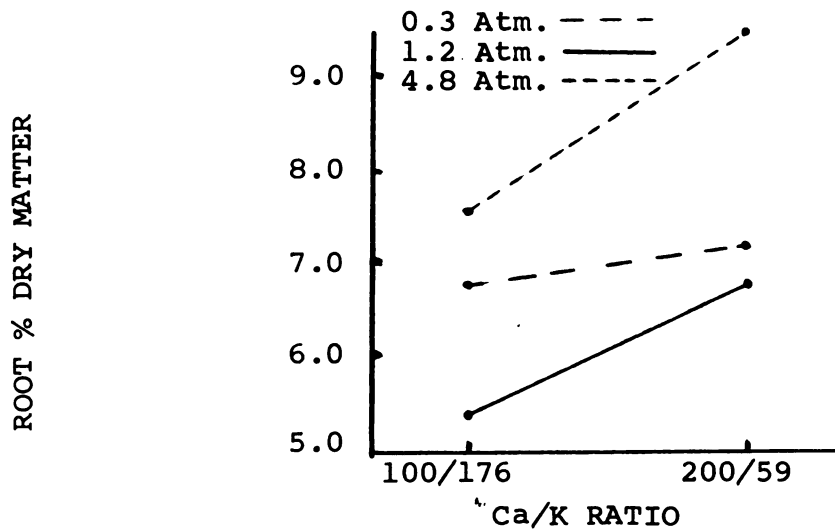


Figure 15. The effect of the interaction of Ca/K ratio and nutrient solution concentration on the percentage of dry matter in celery roots.

significantly different from that in the 0.3 atm. solutions. Root dry weight was lower in the 4.8 atm. solutions than in the 0.3 atm. but not significantly different from that in the 1.2 atm.

In the last 28 days of the experiment (August 26 to September 24) the misted plants in the 1.2 atm. solutions increased in fresh weight 552 g. in 100/176 Ca/K ratio solution and 590 g. in 200/59 solutions. The increases for control plants were 482 g. in 100/176, and 524 g. in 200/59 Ca/K ratio solution.

The mineral content of celery heart tissue is presented in Table 12 for elements that showed significant differences between means. The 100/176 Ca/K ratio in the nutrient solution resulted in a higher K content in the heart tissue than did the 200/59 ratio solution. However, the interaction of Ca/K ratio X solution concentration was significant (Fig. 16) for K content. This interaction showed a smaller decrease in K content from the 100/176 to the 200/59 ratio at the 4.8 atm. solution concentration than at the 0.3 or 1.2 atm. concentrations.

The mist treatment resulted in a lower B content of heart tissue than did the control (Table 12).

From Table 12 K content of the heart tissues was lower and Mg content was higher in the plants grown in the 0.3 atm. solutions than in the 1.2 and 4.8 atm. solutions.

Table 12. Mineral content of celery heart tissue related to environment, nutrient solution Ca/K ratio and concentration

|                               |          | K<br>%              | Mg<br>% | P<br>% | B<br>ppm |
|-------------------------------|----------|---------------------|---------|--------|----------|
| <u>Ca/K Ratio</u>             |          |                     |         |        |          |
| 1                             | 100/176  | 5.43 a <sup>1</sup> | .314 a  | 1.63 a | 187 a    |
| 2                             | 200/59   | 4.51 b              | .247 a  | 1.44 a | 223 a    |
| <u>Environment</u>            |          |                     |         |        |          |
| 1                             | Mist     | 4.87 a              | .256 a  | 1.57 a | 195 b    |
| 2                             | Control  | 5.07 a              | .306 a  | 1.50 a | 215 a    |
| <u>Solution Concentration</u> |          |                     |         |        |          |
| 1                             | 0.3 Atm. | 4.21 c              | .400 a  | 1.44 b | 238 a    |
| 2                             | 1.2 Atm. | 5.57 a              | .264 b  | 1.66 a | 167 b    |
| 3                             | 4.8 Atm. | 5.12 b              | .230 b  | 1.40 b | 268 a    |
| <u>Interaction</u>            |          |                     |         |        |          |
| Ca/K ratio X Soln. conc.      |          | **                  |         |        |          |

<sup>1</sup>Values followed by uncommon letters are significantly different at the 5% level.

\*\*Significant at the 1% level.

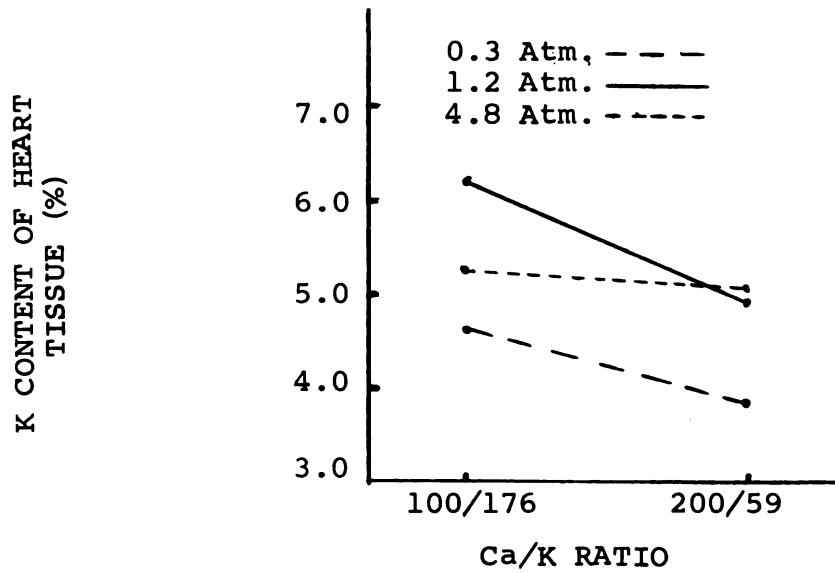


Figure 16. The effect of the interaction of Ca/K ratio and nutrient solution concentration on the K content of celery heart tissue.

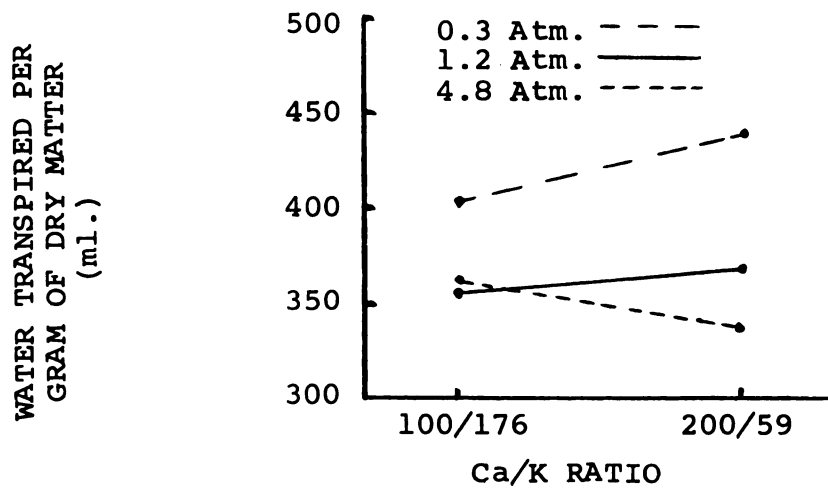


Figure 17. The effect of the interaction of Ca/K ratio and nutrient solution concentration on the volume of water transpired per gram of dry matter produced.

The values in Table 12 also indicate that P content was higher and B content lower at 1.2 atm. than at either the 0.3 or 4.8 atm. concentration.

Ca contents in the plant hearts showed no significant differences between treatments. Treatment mean values ranged from 0.331 to 0.477% Ca. Ratings of blackheart symptoms, volume of water transpired per gram of dry matter produced and Ca/K ratio in heart tissues are summarized in Table 13. Although there were no significant differences attributable to Ca/K ratio of the nutrient solutions in these respects, the interaction of Ca/K ratio in the solutions X solution concentration for transpiration was significant (Fig. 17). Transpiration was higher in the 200/59 Ca/K ratio solutions than in the 100/176 Ca/K ratio solutions for the 0.3 and 1.2 atm. concentrations but lower for the 4.8 atm.

The mist treatment resulted in a lower volume of water transpired per gram of dry matter than did the control (Table 13).

The 1.2 atm. concentration resulted in a higher degree of blackheart symptoms than did the 4.8 atm. solution, but not significantly different from the 0.3 atm. (Table 13). There was a higher rate of transpiration and a higher Ca/K ratio in the heart tissue in plants grown in the 0.3 atm. solutions than in either the 1.2 or 4.8 atm. (Table 13, Fig. 17).

Table 13. Blackheart ratings, transpiration and Ca/K ratio in celery heart tissue related to environment, nutrient solution Ca/K ratio and concentration

|                               |          | Blackheart<br>ratings<br>1-no symptoms<br>9-severe<br>symptoms | Water<br>transpired<br>per gram<br>dry matter<br>(ml.) | Ca/K ratio<br>in heart<br>tissue |
|-------------------------------|----------|----------------------------------------------------------------|--------------------------------------------------------|----------------------------------|
| <u>Ca/K Ratio</u>             |          |                                                                |                                                        |                                  |
| 1                             | 100/176  | 2.9 a <sup>1</sup>                                             | 365 a                                                  | .062 a                           |
| 2                             | 200/59   | 1.6 a                                                          | 384 a                                                  | .108 a                           |
| <u>Environment</u>            |          |                                                                |                                                        |                                  |
| 1                             | Mist     | 2.0 a                                                          | 316 b                                                  | .083 a                           |
| 2                             | Control  | 2.5 a                                                          | 433 a                                                  | .087 a                           |
| <u>Solution Concentration</u> |          |                                                                |                                                        |                                  |
| 1                             | 0.3 Atm. | 1.9 ab                                                         | 421 a                                                  | .115 a                           |
| 2                             | 1.2 Atm. | 2.6 a                                                          | 362 b                                                  | .082 b                           |
| 3                             | 4.8 Atm. | 1.5 b                                                          | 347 b                                                  | .078 b                           |
| <u>Interaction</u>            |          |                                                                |                                                        |                                  |
| Ca/K ratio X Soln.<br>conc.   |          |                                                                | *                                                      |                                  |

<sup>1</sup>Values followed by uncommon letters are significantly different at the 5% level.

\*Significant at the 5% level.

Table 14 contains the simple linear correlation coefficients that were significant between blackheart symptoms and other factors in the experiment and the corresponding coefficients between treatments and the same factors. The values indicate that blackheart severity increased with increasing sucker weight and K and P content in the heart tissues, while symptoms decreased in severity with increasing top percentage of dry matter, Ca, B and Ca/K ratio in heart tissues, and Ca/K ratio in the nutrient solutions. In each case the correlation with Ca/K ratio in the nutrient solutions showed the opposite relationship.

The correlation of environmental treatments with blackheart ratings was not significant at the 5% level ( $r = +0.199$ ).

The effects of misting on temperature are summarized in Table 15. Recordings made at 8:00 a.m. prior to starting the mist indicate that leaf temperatures were 0.2 C lower in the misted plots than in the control while heart temperatures were 0.3 C lower, air in canopy 0.9 C lower and nutrient solutions 1.0 C lower. The 2:00 p.m. recordings when the mist was in operation indicated that leaf temperatures were 2.4 C lower, hearts 1.2 lower, air in canopy 2.6 lower and nutrient solutions 1.8 lower in the misted than in the control plots.

Table 14. Relationship of blackheart rating and nutrient solution Ca/K ratio to celery plant characteristics (simple linear correlation coefficients)

|                                  | Blackheart<br>rating | Ca/K ratio<br>in nutrient<br>solutions |
|----------------------------------|----------------------|----------------------------------------|
| Top percent dry matter           | -.434 *              | +.306                                  |
| Sucker weight                    | +.518 **             | -.408 *                                |
| Ca content in heart              | -.436 *              | +.575 **                               |
| K content in heart               | +.534 **             | -.597 **                               |
| P content in heart               | +.600 **             | -.490 **                               |
| B content in heart               | -.547 **             | +.287                                  |
| Ca/K ratio in heart              | -.543 **             | +.656 **                               |
| Ca/K ratio in nutrient solutions | -.539 **             |                                        |

\*Significant at the 5% level.

\*\*Significant at the 1% level.

Table 15. Mean daily 8:30 a.m. and 2:00 p.m. leaf, heart, air and solution temperatures (C) between August 25 and September 5, 1966

|                          |         | 8:30 a.m.        |                                              | 2:00 p.m.        |                                              |
|--------------------------|---------|------------------|----------------------------------------------|------------------|----------------------------------------------|
|                          |         | Temper-<br>ature | Difference<br>between<br>mist and<br>control | Temper-<br>ature | Difference<br>between<br>mist and<br>control |
| <u>Leaf</u>              |         |                  |                                              |                  |                                              |
| 1                        | Mist    | 23.4             | ...                                          | 27.2             | ...                                          |
| 2                        | Control | 23.6             | 0.2                                          | 29.6             | 2.4                                          |
| <u>Heart</u>             |         |                  |                                              |                  |                                              |
| 1                        | Mist    | 23.1             | ...                                          | 28.2             | ...                                          |
| 2                        | Control | 23.4             | 0.3                                          | 29.4             | 1.2                                          |
| <u>Air in canopy</u>     |         |                  |                                              |                  |                                              |
| 1                        | Mist    | 22.9             | ...                                          | 27.9             | ...                                          |
| 2                        | Control | 23.8             | 0.9                                          | 30.5             | 2.6                                          |
| <u>Nutrient solution</u> |         |                  |                                              |                  |                                              |
| 1                        | Mist    | 23.2             | ...                                          | 28.2             | ...                                          |
| 2                        | Control | 24.2             | 1.0                                          | 30.0             | 1.8                                          |

Figure 18 shows the effect of misting on the rate of transpiration of the celery plants. Before the misting started the transpiration rates were approximately equal at about 30 cc./hour. As environmental stress increased, the control plants increased in transpiration rate more rapidly than did the misted plants and reached a rate of approximately 33 cc./hour higher than plants in the misted plots. After misting ceased the difference gradually disappeared.

Values for daily transpiration, blackheart ratings and growth rates are plotted for the period between August 17 and September 18, 1966 in Figure 19. Comparing the blackheart values to those of transpiration there was an indication that where transpiration was low, blackheart symptoms tended to decline and where transpiration was high, blackheart symptoms either remained relatively constant or increased.

In comparing the growth rate to the transpiration rate (Fig. 19), during periods of high transpiration the growth rate in the misted plots appeared to exceed that of the control plots, while during periods of low transpiration growth rate in misted plots was as low as or lower than that of the control plots. In like manner there was a suggested relationship between growth rate and blackheart symptoms--symptoms increasing in severity during periods of greater difference between growth rates of misted plants and control plants and decreasing during periods of smaller differences.

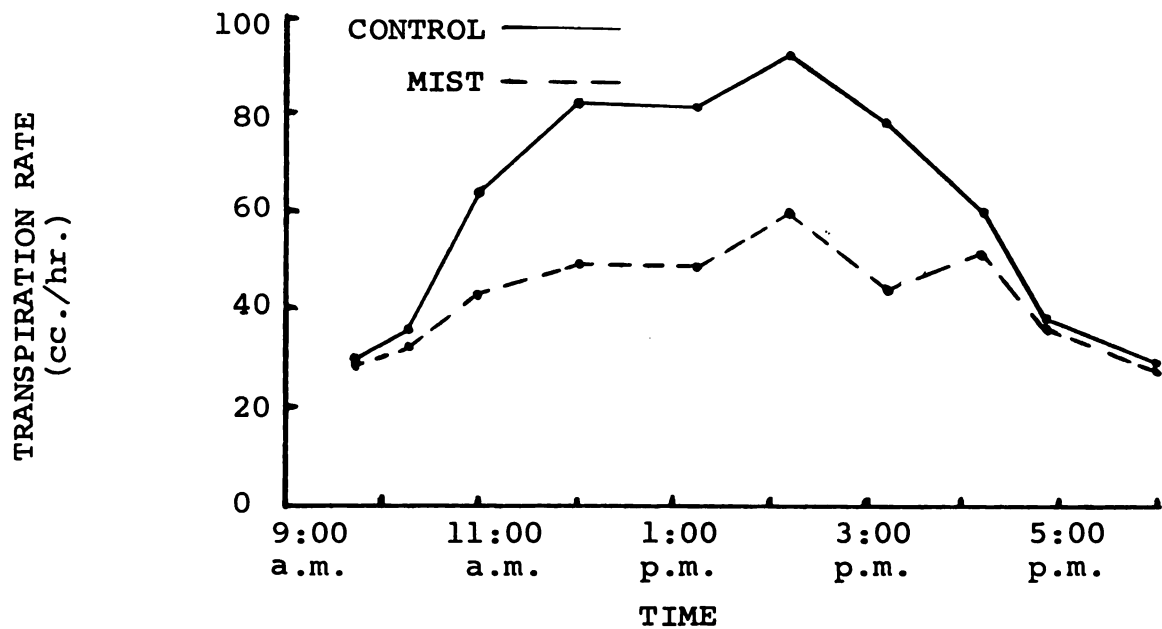


Figure 18. The effect of mist on transpiration rate on a typical hot day (August 26, 1966) with some cumulus cloud. Mist was in operation from 9:00 a.m. until 4:00 p.m.

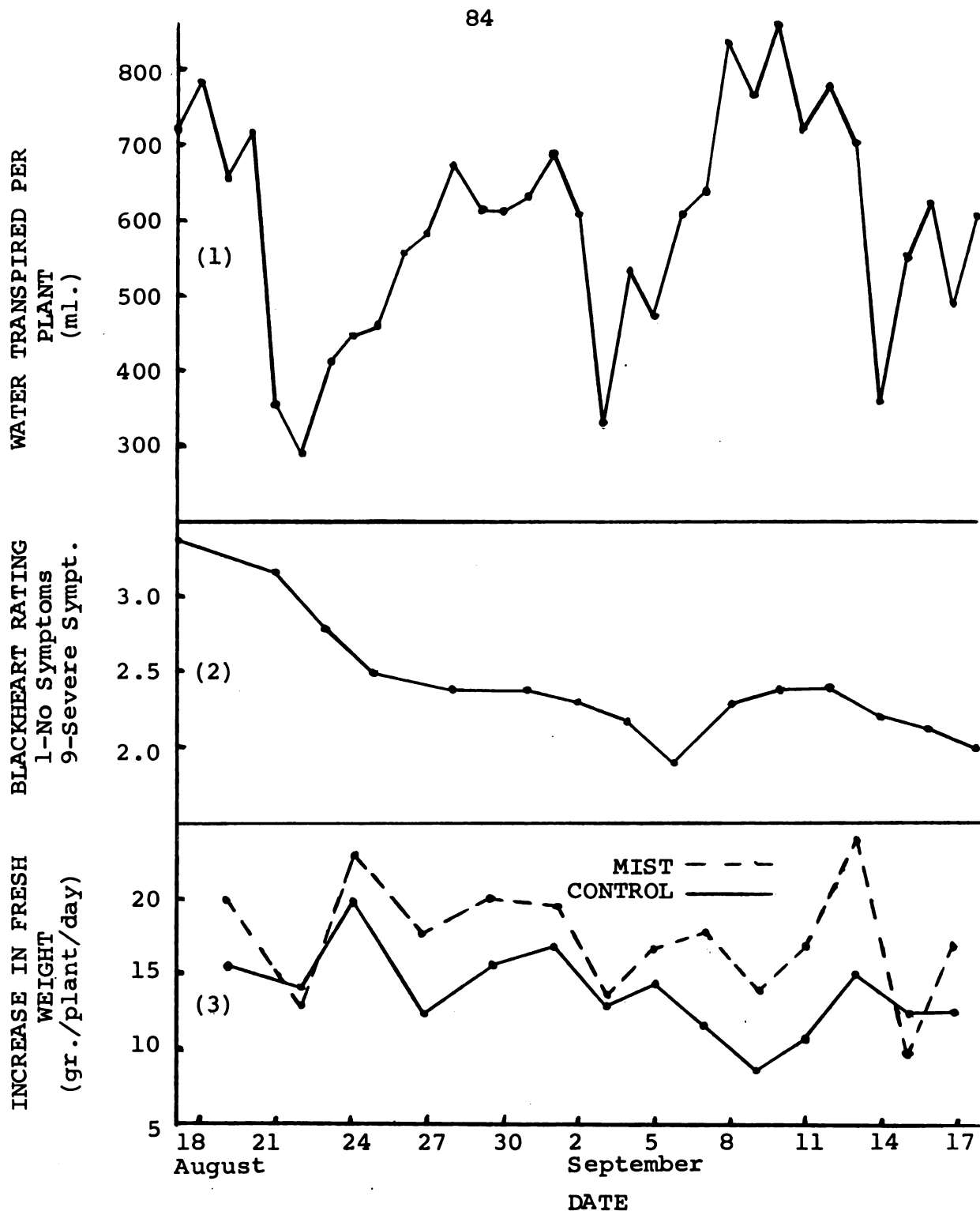


Figure 19. The relationship between transpiration, blackheart rating and growth rate from August 17 to September 18, 1966. (1) Mean daily transpiration; (2) Mean blackheart rating; (3) Mean growth rates.

## Discussion

The effects of the Ca/K ratios in the nutrient solutions and the effects of the environmental treatments (Tables 11, 12, 13) generally follow the same trends as in the previous experiment.

The 1.2 atm. solution resulted in higher plant top weights than those of the 0.3 atm. treatment (Table 11). This could have been caused by a depletion of one or more elements to deficiency levels in the 0.3 atm. solutions between the weekly solution changes. The plant top weights at 4.8 atm. were also lower than those at 1.2 atm. (Table 11). This could have resulted from a reduction of growth due to plant moisture stress as has been reported by other workers (11, 21, 39).

The K content of the heart tissues was lower in the 4.8 atm. treatment compared to the 1.2 atm. treatment but the Ca contents and the Ca/K ratios were not significantly different (Tables 12, 13). This, plus a lower vigor may explain why the blackheart symptoms were not as severe in the 4.8 atm. solution as in the 1.2 atm. solution (Table 13). Geraldson recorded similar results in nutrient solutions but in the field he observed blackheart to be more severe in plants grown under high soil osmotic conditions with resultant lower Ca/K ratio in the heart tissues (17, 18).

The low osmotic concentration treatment (0.3 atm.) resulted in a lower K content and a higher Ca/K ratio in the heart tissues than was found in plants of the 1.2 atm. concentration treatment (Tables 12, 13). This condition together with the lower vigor may explain the trend to lower blackheart ratings in the 0.3 atm. as compared to the 1.2 atm. solutions.

The correlations presented in Table 14 show generally the same relationship as found in the previous experiment (Table 10) in that plant vigor, plant Ca, K, B and Ca/K ratio are closely related to blackheart symptoms but that they are also closely related to the Ca/K ratio of the nutrient solutions. P showed a significant correlation with blackheart in this experiment and in outdoor experiment II but not in the previous greenhouse experiment.

The temperature values presented in Table 15 indicate that there was a small carryover effect of the mist treatments to the following day. The lower 2:00 p.m. temperatures in the misted plots could account in part for the decrease in transpiration rate as shown in Figure 18. This reduction in temperature and transpiration rate helps explain the higher growth rate of misted plants compared to the control plants during the periods of higher temperatures (Fig. 19). The high points in transpiration values were associated with high temperatures and appeared to coincide with the greatest differences in growth rate between control

and misted plants while the low points in transpiration coincided with the smallest difference in growth rate.

Although the blackheart curve in Figure 19 appeared to show some relationship to the transpiration curve, the trends were somewhat weak. The periods of high and low stress were possibly too short to show marked rises and falls in symptom ratings. Thus, the symptoms may have maintained a middle path between extremes that could have resulted with longer atmospheric cycles.

## GENERAL DISCUSSION

The purpose of this investigation was to study celery plant characteristics and the development of black-heart under various conditions of plant water balance as affected by altered atmospheric conditions, soil moisture levels, osmotic concentrations and ion balances.

Misting generally resulted in an increase in total fresh weight with a relatively smaller increase in dry weight because of a lower percentage of dry matter. Sucker weight was also increased by mist applications resulting in no significant gain in marketable weight attributable to misting. The increased succulence associated with the lower percentage of dry matter may indicate a quality improvement in celery due to misting.

Since no guide-lines were available marking the point where plant moisture stress begins in celery, it is possible that mist was applied during the course of the outdoor experiments when the combination of temperature, solar radiation intensity, relative humidity, wind speed and root medium stress did not add up to a detrimental plant water stress. In such occasions misting may have caused a reduction in net photosynthesis as is indicated by the growth rates during periods of low transpiration shown in Figure 19.

It is possible that greater benefits could have been gained from misting in the outdoor experiments had the critical point for plant stress been known. Furthermore, the higher the temperature during the growing season, the greater might have been the potential benefit from misting.

Misting did not cause any marked effect on nutrient uptake. Based on the dry matter produced, misting reduced transpiration 14 and 19% in the outdoor experiments I and II respectively and 20 and 27% in greenhouse experiments I and II respectively. The decrease was lower outdoors because mist was applied only on high temperature days while it was applied every day in the greenhouse. These reductions in transpiration may not have been great enough to cause marked changes in nutrient uptake as reported by other workers (13, 35, 40). It is possible that by reducing transpiration rate for only six hours per day, ample time remained for the plant to regain its nutrient equilibrium.

The low soil moisture level resulted in considerably lower fresh and dry weights compared to high soil moisture (Tables 1, 2). This may be attributed to the higher degree of plant water stress as indicated by the higher wilt ratings. This was in agreement with the observations of other investigators (7, 8, 14, 23, 27, 41, 52, 53). The higher percentage of dry matter in the plants with low soil moisture may be associated with lower quality in celery and as such would be in agreement with the observations of Janes (23).

In soil culture, the osmotic effect of the applications of 3000 pounds of Ca per acre and 4380 of K to muck soil was not sufficient to cause any marked plant response compared to the control. The high exchange capacity of the colloids in the muck may have minimized the effects of the salt applications. High salt applications in a predominately mineral soil, however, resulted in increased water-use efficiency and increased fresh and dry weights with 2190 pounds of K per acre and 1305 of Na. This was in agreement with Viets (48). The application of 1500 pounds of Ca per acre and combinations of 750 Ca plus 652 Na and 1500 Ca plus 1305 Na resulted in the same weight of dry matter as in control plots but higher fresh weights due to lower percentages of dry matter being produced. Despite the fact that equal volumes of water were applied to salt-treated plots and control plots, the control plants wilted the most severely. This was in agreement with other workers (3, 10, 11, 28) who believed that a moderate stress, but no wilting, is maintained throughout the irrigation cycle limiting growth of the plants. From this it appears that the osmotic stress from Ca and Na caused as much plant water stress as the soil moisture tension in the control plot resulting in equal dry matter production but the different type of stress as described by Slatyer (39) for high osmotic concentrations of the soil solution resulted in a higher succulence.

In nutrient solutions, 0.3 atm. and 4.8 atm. concentrations with equal nutrient balance resulted in inferior growth compared to 1.2 atm. Deficiencies of some elements could have occurred because of low supply due to depletion in the 0.3 atm. solutions. This could also explain the reduced water-use efficiency of this treatment. The high osmotic concentration could have resulted in lower growth because of a plant moisture stress as has been reported by other workers (3, 10, 11, 38).

Celery plant fresh weight decreased with increasing Ca/K ratio, with the exception of the lowest Ca/K ratio where low Ca may have been a limiting factor. However, since the percentage of dry matter increased with increasing Ca/K ratio, the net weight of dry matter produced was not generally affected significantly by Ca/K ratio, but tended to be somewhat lower at the high Ca/K ratio. Water-use efficiency was approximately similar at the intermediate Ca/K ratios but was lower at the high ratio possibly due to low K, and higher in the low ratio possibly due to high K. The low K situation follows the thinking of Viets (48) in that any fertilizer that increases yield also generally increases water-use efficiency. The high K effect agreed with the findings of Wostmann (54) and Biebl (5) who found that with highly unbalanced K applications to the soil, transpiration rates were lower due to the K. However, it

was contrary to Wostmann's (54) findings that transpiration rate increased with decreasing Ca/K ratio in solutions.

Blackheart symptoms were not significantly different on misted and control plants. Nevertheless, the mist applications prevented an increase in the severity of the symptoms that should have been associated with the increase in plant fresh weight and succulence resulting from the mist treatment.

Blackheart was most markedly affected by the Ca/K ratios in the nutrient solutions. Symptoms decreased with increasing Ca/K ratio. Also, blackheart was positively correlated with top fresh weight, sucker weight, K content in the heart tissues, and negatively correlated with top percentage of dry matter, Ca, B and Ca/K ratio in the heart tissues. Yet, each of these plant characteristics was correlated with the Ca/K ratios supplied in the nutrient solutions. Therefore, the nutrient solution Ca/K ratio appeared to have been the dominating factor in blackheart expression.

Geraldson (17, 18) found the Ca levels in young leaves of plants with blackheart symptoms to be from 0.1 to 0.4% while levels were 0.5 to 1.0% in young leaves from healthy plants. In greenhouse experiment I, carried out between May 13 and June 17, 1966 the Ca contents of the celery heart tissues varied from means of 0.099 to 0.215% (Table 8). Blackheart symptoms were present in most of the

plants and to a greater degree than in the other experiments. In greenhouse experiment II carried out between July 29 and September 24, 1966 the Ca contents varied from means of 0.331 to 0.477% and blackheart symptoms were not as pronounced as in greenhouse experiment I. In field experiment II carried out between May 28 and September 14, 1966 the Ca contents varied from means of 0.410 to 0.477% (Table 3). These Ca values agree closely with Geraldson's values given above, showing that in greenhouse experiment I Ca contents were conducive to blackheart, in greenhouse experiment II Ca contents were borderline and in field experiment II Ca contents were just above the values conducive to blackheart.

One reason for the difference in Ca content of heart tissue and associated blackheart symptoms between the two greenhouse experiments could be the difference in growth rates. In the last 28 days of greenhouse experiment I plant fresh weight in the control increased 879 g. while in experiment II in the same length of time and with reasonably comparable treatments the increase in weight was only 482 g. Thus the higher blackheart ratings of experiment I could have been due to a more rapid rate of growth with Ca uptake falling behind the demands of the plant to a greater extent. This was a reason suggested by Geraldson (20) for blackheart development.

Higher greenhouse minimum and maximum air and root medium temperatures may explain the presence of blackheart symptoms in the greenhouse and virtual absence in the field. Geraldson (17, 18) found that the Ca content in the young tips of tomato and celery plants varied inversely with the temperature.

Blackheart occurrence may depend on the additive effects of temperature, soil moisture level and nutritional status. In outdoor experiments III and IV with plants grown in muck soil, the adequate soil moisture level may have prevented blackheart from developing. Geraldson (20) was of the opinion that low soil moisture could bring about a decreased Ca uptake. However, in outdoor experiments I and II with plants grown in predominantly mineral soils, the soil moisture levels did fluctuate widely and plants did wilt, but the one or two days at high soil moisture stress may not have been a sufficiently long period for the plant Ca level in the heart tissues to be exhausted to the critical level. On the other hand, with a continuously adequate soil moisture level or with short fluctuating cycles, a prolonged period of higher than usual air and soil temperatures may be necessary for blackheart development.

## CONCLUSIONS

The application of low rates of irrigation (misting) to reduce plant water stress resulted in an increase in total fresh weight of celery plants compared to the control and a relatively smaller increase in total dry weight. Sucker weight was higher in the misted plants than in the control resulting in no significant gain in marketable weight but the marketable product was more succulent. Misting during periods of low temperature resulted in decreased rate of growth. Misting reduced transpiration from 14 to 27% but did not appreciably alter nutrient uptake.

Increased radiation by means of infrared heat lamps increased transpiration but did not markedly alter any other conditions of the plant.

Low minimum soil moisture (20-30% ASM) resulted in lower fresh and dry weights of celery and a higher percentage of dry matter compared to high moisture (70-80% ASM). Water-use efficiency was not consistently affected by soil moisture.

The application of Ca plus Na to mineral soil to increase the soil solution osmotic concentration resulted in higher fresh weights, lower percentages of dry matter, similar dry weights and water-use efficiencies and lower degrees

of wilting than the control using the same amount of water. High (4.8 atm.) and low (0.3 atm.) osmotic concentrations in nutrient solutions generally resulted in lower plant fresh and dry weights but higher percentages of dry matter compared to those of intermediate osmotic concentration (1.2 atm.). Water-use efficiency was lowest at the low concentration but not different at the intermediate and high.

In soil and nutrient solutions fresh weight generally increased with decreasing Ca/K ratio and dry weight increased to a relatively smaller degree. The large increase in fresh weight with decreasing Ca/K ratio was offset by a large increase in the sucker weight, which resulted in no difference in marketable weight. In soil and solution culture very low Ca/K ratios resulted in a higher water-use efficiency, while moderate Ca/K ratios resulted in no differences. High Ca/K ratios in nutrient solutions resulted in lower efficiency.

Blackheart symptoms increased in severity with increasing plant top fresh weight, sucker weight, and K content of heart tissue, but decreased with increasing percentage of dry matter, Ca, B and Ca/K ratio in heart tissue.

Blackheart severity was the same in misted as in control plants. However, the greater fresh weight and succulence of the misted plants was not accompanied by an increase in blackheart severity.

Blackheart symptoms were highest in 1.2 atm. concentration solutions compared to 0.3 and 4.8 atm. solutions with the same nutrient balance, and were not different at the latter two concentrations.

The symptoms of blackheart increased in severity with decreasing Ca/K ratio in the nutrient solutions.

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