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The effects of calcium and boron on apple trees when applied through microjet irrigation

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To the Graduate Council:

I am submitting herewith a thesis written by Christopher G. Milne entitled "The effects of calcium and boron on apple trees when applied through microjet irrigation." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Plant, Soil and Environmental Sciences.

Dennis E. Deyton, Major Professor

We have read this thesis and recommend its acceptance:

D. L. Coffey, J. D. Wolt

Accepted for the Council:
Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

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To the Graduate Council:

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Dennis E. Deyton

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We have read this thesis
and recommend its acceptance:

David L. Coffey

J R Wolt

Accepted for the Council:

Cwminkel

Vice Provost
and Dean of the Graduate School

THE EFFECTS OF CALCIUM AND BORON ON APPLE TREES WHEN APPLIED THROUGH MICROJET IRRIGATION

A Thesis
Presented for the
Master of Science
Degree
The University of Tennessee, Knoxville

Christopher G. Milne
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ABSTRACT

Two experiments were performed to study the effects of calcium (Ca) and boron (B) applied as calcium chloride {$CaCl_2 \cdot 2H_2O$(27% Ca)} and Solubor {$Na_2B_4O_7$(20% B)} through microjet irrigation to young apple trees (*Malus domestica* Borkh). The effects of $CaCl_2$ and Solubor treatments on both soil and foliar nutrient levels were measured when Ca and B were applied in irrigation water with and without foliar applications of Ca as $CaCl_2$ (Exp 1). Additionally, the effects of Ca and B fertilization with and without irrigation were investigated (Exp 2). No differences in foliar or soil test extractable Ca concentrations were found with any $CaCl_2$ treatments for either experiment. Treatments providing 0.25 and 0.50 g/day/tree Solubor (1982) and 0.50 and 0.10 g/day/tree of Solubor (1983) significantly increased both soil and foliar B levels (Exp 1). Applications of 0.50 g/day/tree of Solubor in experiment 2 increased the levels of B in the soil but not in the leaves. No differences were found between the irrigated and non-irrigated treatments. The addition of $CaCl_2$ to irrigation water did not influence volume output but did influence the irrigation spray pattern.

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CHAPTER I

INTRODUCTION

The commercial apple industry in Tennessee is growing substantially each year. There has been a reported 36% increase in the total number of commercial apple orchards since 1978 (76). A survey of these orchards has shown that out of a total of 152,000 apple trees, Red Delicious (39%) and Golden Delicious (32%) were the most common cultivars. Commercial apple growers encounter many problems when producing top quality fruit. Among the most severe, especially on young trees, are physiological disorders such as bitterpit and corkspot which are associated with nutrient imbalances primarily of calcium (Ca) and boron (B) (16, 20, 22, 23, 53, 60, 65, 67, 68, 71, 83). These disorders shorten the storage life of fresh fruit, as well as reduce fruit quality. The relationship between Ca and B and these internal disorders apparently involves a reduction in fruit quality that directly lowers the marketable value (20, 23, 65, 68, 71). Out of this has developed the understanding that if top quality fruit is to be maintained, ways of increasing the levels of Ca in the fruit must be developed.

The objectives of this study were:

1. To evaluate the effects of varying concentrations of Ca and B supplied through low volume microjet irrigation on soil nutrient content and nutrient content of plant tissue;

2. To investigate the effect of Ca and B with and without irrigation; and
3. To evaluate the feasibility of microjet irrigation under Tennessee conditions.

CHAPTER II

LITERATURE REVIEW

1. CALCIUM

Calcium, a member of the Alkaline Earth Family, is essential for plant growth. In the oxide form, it constitutes 5% of the earth's crust (54). Non-calcarious soils usually contain less than 1% Ca. In order for Ca to be taken up by the plant, it must be in solution. This uptake is influenced by many factors: 1) cation exchange capacity (CEC) of the soil, 2) the solubility of soil minerals, 3) the chelation or complexation capacity of a soil, 4) microbial assimilation or excretion, and 5) ion pair formation (54). Calcium that has been solubilized can be lost from the soil by leaching, crop removal, and erosion. More Ca leaches out of the soil under humid conditions than is lost by crop removal. More Ca is generally lost due to soil erosion than by crop removal (54). The supply of Ca can be replenished by acid weathering of minerals and by mircobial activity on organic matter. These processes are not usually fast enough to balance the losses brought about by leaching (54.) Lime and other Ca containing products must be added to the soil in order to make up for these net losses in agricultural soils.

Much of the Ca required to maintain normal growth is transported to the root surfaces by mass flow (54). This movement is in response to the transpirational stream within the plant. The diffusion of ions from areas of high concentrations to low concentrations can also move Ca to root surfaces (3). Root interception also aids in plant Ca uptake by bringing root surfaces into contact with new mineral supplies. The absolute Ca concentration in the soil solution is not as important in controlling Ca uptake as is the relationship of Ca to the total salt concentration, and the proportionate concentration to that of other ions in the solution (66). It has been found in apples that NO_3^- increased Ca uptake and storage in leaves (19) while the uptake of NH_4^+ acidified soils and increased losses of Ca due to leaching while at the same time inhibiting the uptake of the remaining Ca (71). It has also been found, with apples, that autumn applications of NO_3^- improve Ca accumulation in the shoots.

In plants, Ca is absorbed on negatively charged exchange sites present on the walls of the vessels and then is moved upward by a series of exchange reactions in the transpirational stream (4, 6, 25, 57, 84). The xylem is considered to be the major pathway of translocation of Ca in plants. Shear et al. have shown that Ca moves from the roots to the shoots at a rate of 10 cm per day in apple seedlings (69). Calcium has been shown to be relatively mobile in the xylem. Calcium has also been shown to move into the shoots through xylem vessels but only moves into the fruit through phloem vessels. Most of the Ca that reaches apple fruit does so within the first four to five weeks of the growing season. Under deficiency conditions, Ca has been found to increase more in the young leaves than in the older leaves. Stebbins and Dewey (74) reported an increase of ^{45}Ca accumulation with increasing transpiration rates and found that the young leaves accumulated more ^{45}Ca than did the older leaves. A theory developed by Bangerth (2) states that young fruit have a relatively large surface area, a high rate of transportation, and are photosynthetically active. During this period, the fruit have a high water requirement and a relatively low photosynthate need. The water and Ca at this time are supplied through the xylem. As the fruit grow, the transpiration and photosynthesis rate drop and the surface area to volume ratio drops. At this stage, the developing fruit are assimilating more Ca from the leaves than from other portions of the plant. Apparently, the major route of transport shifts from the xylem to the phloem where Ca is relatively immobile (2). It has been found that little or no Ca is retranslocated from old tissue once it has been deposited there (35, 70). Thus fruit tissue, with its high metabolic rate, must depend on a constant supply of Ca.

Concentrations of Ca within the fruit tissue remain relatively constant early in the growing season (35). It was found that Ca concentrations in the leaf tissue increased slightly in a nonlinear fashion when Ca transport shifted from xylem to phloem (17). The rate of Ca uptake through the phloem does not keep pace with the continued growth of the fruit, so the Ca concentration in the fruit declines (2, 84). As the season progresses, a concentration gradient develops within the fruit itself with the skin being the highest, the core being the intermediate region, and the flesh being the lowest (23, 41). As the growing season ends and the leaves senescere, very little Ca is remobilized (33, 52). In the following spring, however, remobilization of Ca from permanent structures, i.e., roots, accounts for 20-25% of the total Ca in the new leaves and fruit.

2. BORON

Boron is one of the only two nonmetals among the micronutrients. Agricultural soils usually contain B in a range of 20-200 mg/kg (56). Most soil B is unavailable to plants; however, the available (hot water soluble) B in soil usually ranges from 0.4 to 5.0 mg/kg (30, 56). It is widely accepted that the soluble B found in soils is in the form of boric acid (H_3BO_3) (25, 56, 76) which is not dissociated (deprotonated) at normal soil pH. Therefore, B is primarily present in the nonionized form in soil solution, and because of this, B is easily leached from soils. Gupta and Cutcliffe (30) found that 60% of applied B was not recovered in the upper layer of podzolic soil five months after application. Hobbs (36) found that on Indiana soils, the supply of available B in the surface soil should be adequate for plant growth, but the amount of available B decreased with increasing depth. Boron deficiencies are not only due to low B, but may also be influenced by low soil moisture (37, 83). Hobbs (36) noted that applications of B fertilizer did not increase the supply of B as long as the soil was dry.

Boron adsorption is depressed as soil pH decreases, with maximum adsorption occurring at pH 9.0 (56). Because of this, overtiming can induce B deficiencies. Parfitt (63) noted that B does not act as a proton but instead acts as a Lewis base accepting OH^-. Boron adsorption in the soil may be a consequence of ligand exchange in which the OH^- is replaced by $B(OH)_4^-$ on the adsorbing surface. Boron can be held by organic matter since the carboxyl acids of the humic colloids may condense with boric acid. It has been suggested by Russel (66) that because this bond is stronger than the bonds between borate and sesquioxides under acid or neutral conditions, humic colloids are probably the principal reservoir for B in many agricultural soils. The increase of B adsorption with increasing pH accounts for the low B availability in soils with a high pH.

Boron is thought to be taken up by plants in the undisassociated form. There is still a controversy as to whether it is an active or passive process (25, 56, 75, 77). Boron is relatively immobile in plants and has been found to increase in concentration from the lower to the upper part of the plant with highest concentrations in the upper portion (18). Michael et al. (59) found that in tobacco, the transpiration rate of the plant had a decisive influence on the upward movement of B. This suggests that B is mainly transported in the xylem. Since transpiration affects movement, high concentrations of B are found in the leaf tips (39); consequently, boron deficiency always begins at the growing points. This is similar to Ca movement in that both Ca and B are virtually absent from the phloem sap.

3. Ca AND B SOURCE EFFECTS ON MINERAL LEVELS

The interactions of various nutrients within plant tissues must be considered when evaluating problems involving Ca and B as well as other nutrients.

Boron has been known to affect the uptake and solubility of Ca (67). The effectiveness of B in reducing the corking disorders in apples was thought to be through the correction of B deficiency (67). Cain (12) reported in 1958 that both magnesium and potassium levels in apple leaf tissue decreased as a result of Ca applications to the soil. They also found that each cation increased as its supply increased. It was found that leaf Ca levels could be increased, but not significantly, by putting 1.13 kg of lime ($CaCO_3$) in the planting holes. Work by Boynton et al. on McIntosh apple trees revealed that applications of 45.3 kg/tree of hydrated lime {$Ca(OH)_2$} did not significantly increase leaf Ca levels. The application did increase the available Ca, but no mention was made of the extent of the increase (5). Neilsen et al. (61) observed significant increases in Ca content of apple leaves with soil applications of $CaSO_4 \cdot 2H_2O$ (gypsum) above 3,000 kg/ha. They also reported that treatments of 12,000 kg/ha of gypsum significantly reduced leaf levels of Mg. They noted that gypsum applications decreased exchangeable Mg and K in the soil but caused only a limited increase of exchangeable Ca in the root zone. Only negligible soil Ca accumulation occurred below the 10 cm depth for any of the treatments (3,000, 6,000, and 12,000 kg/ha), and only with 6,000 kg/ha gypsum was exchangeable Ca in the top 10 cm significantly increased. Boon et al. (79) reported in 1966 that applications of gypsum to the soil significantly lowered the percentages of Mg in the soil. The levels of K were also reduced in the soil, but not significantly. Boon et al. (79) also noted that applications of calcium carbonate and gypsum led to only slight reductions of N, P, and K and slight increases of Ca in apple trees. Himelrick and Ingle (34) found that foliar sprays of $CaCl_2$ early in the season did not significantly increase Ca levels in the leaf tissue. Van Goor (80) reported in 1971 that the levels of Ca in the leaf tissue could be increased by 0.05% with foliar sprays of $Ca(NO_3)_2$, although no mention was made as to whether this increase was significant. Dixon et al. (20), working with various treatments including $CaNO_3$ and Solubor ($Na_2B_4O_7$) sprays, reported that sprays of calcium nitrate (1% w/v) had no effect on the foliar levels of Ca, B, Mg, P, N, or K in the first season of treatment. During the second season of treatment, they noted that the levels of Ca were the lowest in the trees that received calcium nitrate, but no B. The B content of the leaves was found to increase with all treatments. Individual treatments with B sprays (0.15% and 0.25% w/v) at petal fall were found to be the most effective ($P = 0.001$). Work in British Columbia revealed that leaf B content of Barcelona Filbert (Corylus avellana) trees could be increased with applications of B to the soil (42). Other studies found that applications of agricultural grade borax ($Na_2B_4O_7$) increased leaf B content significantly (62). Follow-up work revealed that 0.44 lbs borax/tree significantly increased B content of the leaf tissue. Gupta (30) reported that band applications of B increased foliar B content. He also noted that liming decreased foliar concentration of B.

4. IRRIGATION

For many years, irrigation has been used to relieve water stress in crops and enhance crop growth. Cripps (18) noted that irrigation intensified biennial bearing and increased shoot growth and trunk expansion of apple trees. Increases in fruit yield in irrigated areas have been reported to be due to increases in fruit number and in vegetative growth (1, 8, 11, 28, 44). Magness et al. (51) reported a 50% yield increase of Rome Beauty due to an increase in fruit size as a result of irrigation. Burell (10) found that irrigation decreased the incidence of corkspot, a Ca related disorder in apples, while also increasing the size of the fruits.

There are many types of irrigation used to deliver water to crops. Irrigation types differ in labor and energy requirements, as well as the quantities of water which they deliver. Some methods include border check-flood irrigation, furrow irrigation, conventional and overhead sprinkler systems, permanent set, trickle or drip, and microjet. Border check-flood and furrow irrigation are low cost and high quantity delivery surface irrigation systems. These systems can deliver approximately 568 and 164 lps, respectively, depending on the number of laborers involved (78). Sprinkler systems are used where surface systems are impractical for reasons such as hilly terrain. Advantages of this type of system are frost protection, heat protection by evaporative cooling, and rapid water replacement. Major disadvantages are their high initial investment cost, high energy consumption, and large water supply requirements.

Trickle or drip irrigation is based on the principle of supplying a near continuous supply of moisture to a particular part of the root system (77). Some advantages of trickle or drip irrigation are: 1) greatly reduced water consumption, 2) easier operation of equipment, 3) easier weed control, 4) low initial cost, 5) lower energy operation, and 6) less water loss by run-off and evaporation. One major disadvantage of the system is that it cannot be used for frost protection.

Microjet irrigation is a type of low volume irrigation that has a sprinkler output ranging from 15.5 to 181.3 lpm depending on the system. This is between the outputs of trickle (37.5 lph) and sprinkler (11,340 lph). Microjet systems wet a wider strip of the soil than do trickle systems, thus encouraging a slightly larger root volume (59). Relative to trickle irrigation, microjet may delay cropping and encourage vegetative growth and be less suited for high density plantings (47). It has been found that microjet caused greater annual increase in TCA (truck cross-sectional area) but fewer and larger apple fruit over a three-year period than did trickle (59). Bredell (7) reported that microjet reduced problems often associated with trickle such as the difficulty of delivering insoluble fertilizers into the root zone and resulted in less accumulation of salts in the rhizosphere. The problem of salt accumulation was reduced because the accumulation was beyond the depth of the feeder roots (7). It has been reported (73) that wetting only 25% of the rhizosphere is sufficient for normal growth, but microjet enables wetting the entire rhizosphere. Microjets will carry relatively insoluble fertilizers into the soil within a short period of time, making it easier to correct deficiencies (7).

The application of fertilizers and other chemicals through irrigation can be beneficial. Childers (15) reported that 0.91 kg of Carbaryl/378 l of water applied at blossom fall through over-tree sprinkler irrigation should remove all unwanted fruit. Phene and Sanders (64) reported that trickle irrigation containing a nutrient solution improved the quality and yield of potato tubers. Smith et al. (72) found that the use of trickle irrigation has allowed reduction in the rates of N by 50% in fruit trees. It was also noted that the rate of water had an influence on both the distribution of N and the amount of N accumulated in the tree.

5. IRRIGATION VERSUS NON-IRRIGATION

Water plays an important role in the movement and uptake of minerals in and by the plant (3, 14, 26). The effects of irrigated plants versus non-irrigated plants have been studied to determine to what extent water will affect mineral levels (8, 11, 24, 28, 29, 31). Levin et al. (44, 45) found there to be no significant differences in the levels of K, Mg, and Ca in the leaf tissue due to irrigation when using sprinkler irrigation. In a follow-up study, they found that irrigation caused a significant increase in K levels and a significant decrease in Mg levels. Smith and Kenworthy (71), working with Golden Delicious apples, did not see an increase in the nutrient levels of leaf tissue due to the irrigation. Work by Fieldstein and Childers (24) reported an increase of 0.1% in Ca levels in peach leaf samples due to irrigation and an increase of 0.02% in the P levels with the irrigation. This work does not agree with work done by Chesness (14), who reported significant increases in leaf Ca levels due to irrigation. These differences could be due to varying rates of irrigation.

CHAPTER III

MATERIALS AND METHODS

1. PLOT SITE AND TREATMENT TECHNIQUES

Experiments were established on a Sequoia silt loam soil at The University of Tennessee Plant Science Field Laboratory near Knoxville, Tennessee. Experiment 1 comprised a randomized complete block design of nine single tree plots in four replications. Treatments in experiment 1 were applied to three-year-old Smoothee on MM106 rootstocks in 1982 and repeated in 1983. The treatments consisted of calcium chloride {$CaCl_2 \cdot 2H_2O$(27% Ca)} and Solubor {$Na_2B_4O_7$(20% B)} at varying levels applied through a simulated microjet system to the soil, and of $CaCl_2$ applied to the trees as a foliar spray. The individual treatments and rates of application of Ca and B are shown in Table 1. Treatments were applied using a compressed CO_2 delivery system regulated at 103.4 kPa and devised to simulate actual application through the microjet irrigation system (Appendix A). A 30.5 cm riser with a 360° x 15 hole nozzle and 0.08 cm orifice terminated the boom. The delivery rate of the nozzle at the desired pressure and concentration of fertilizer in the tank were used to calculate the period of time required to deliver the desired amount of fertilizer to each tree. Thus, each tree was sprayed individually when applying treatments. Calcium chloride and Solubor were mixed at 433.3 gm/l and 20.3 gm/l, respectively, to

Table 1. Rates of application of $CaCl_2$, Ca, Solubor, and B for experiment 1.

	Microjet Application (g/day/tree)				Foliar Application (kg/100 l H_2O)	
Treatment	$CaCl_2$	Ca	Solubor	B	$CaCl_2$	Ca
1	0	0.00	0.00	0.00	0.00	0.00
2	4	1.08	0.00	0.00	0.00	0.00
3	8	2.16	0.00	0.00	0.00	0.00
4	12	3.24	0.00	0.00	0.00	0.00
5	8	2.16	0.25	0.05	0.00	0.00
6	8	2.16	0.50	0.10	0.00	0.00
7	8	2.16	0.00	0.00	0.91	0.24
8	8	2.16	0.00	0.00	1.35	0.36
9	8	2.16	0.50	0.10	0.00	0.00

prepare stock solutions for the soil applications. Foliar applications were mixed at 9.1 gm/l and 13.6 gm/l, respectively, of $CaCl_2$ and sprayed until run-off using the compressed CO_2 sprayer at 310.3 kPa through conventional hollow cone nozzles. Following fertilizer application, the microjet system was operated for a time interval calculated to provide sufficient water based on pan evaporation (Appendix B). Treatments were applied at two-week intervals starting May 12 and continuing through June 22 in 1982 and May 22 through June 27 in 1983 (Appendices C and D).

Experiment 2 was designed to evaluate Ca treatments, as well as irrigation effects on apple trees. A randomized complete block with split block array of treatments and four replications was used. Each replication contained 10 single tree plots of Redchief on seedling rootstocks. Main plot treatments were irrigated versus non-irrgated. Subplot treatments were varying concentrations of Ca and B that corresponded to selected treatments from experiment 1. These treatments were applied in the same manner as in experiment 1.

In 1983, application rates for experiment 1 were doubled. To accommodate for this, a second riser was added to the spray boom. The treatments are shown in Table 2.

2. IRRIGATION SYSTEM

A low volume microjet irrigation system was used for these experiments. Polyvinyl chloride pipe (PVC) (20.57 mm I.D.) supplied water to each replication while polyethylene tubing (15.71 mm I.D.) supplied water within a replication to each tree. There was a

Table 2. Rates of application of $CaCl_2$, Ca, Solubor, and B for both irrigated and non-irrigated plots in experiment 2 in 1983.

Treatment	Application Rate (g/day/tree)			
	$CaCl_2$	Ca	Solubor	B
1	0	0.00	0.0	0.0
2	8	2.16	0.0	0.0
3	16	4.32	0.0	0.0
4	24	6.48	0.0	0.0
5	16	4.32	0.5	0.1

pressure reducer for each replication to regulate the pressure of the water to 103.4 kPa. In determining the length of time for the system to run, weekly pan evaporation and weekly rainfall were determining factors (Appendix B). Accumulative rainfall, pan evaporation, and amount of irrigation per tree at each treatment date for 1982 and 1983 are shown in Appendices E and F.

3. HARVEST TECHNIQUES

Leaf samples were collected the second week of July in both 1982 and 1983. Fifty leaves from midshoot areas were collected at random from each tree in a sampling method described by Lockwood (48). Soil samples were also taken at approximately the same time. Core samples were taken at four points 91 cm from the tree to a depth of 15 cm. These four samples were then mixed together to form a collective sample for each tree.

4. LABORATORY ANALYSIS

Both leaf samples and soil samples were analyzed for Ca, Mg, B, and K. The leaf samples were dried in a forced-air oven at 70°C and then ground using a UD Corporation Cyclone Sample-Mill with a 20 mesh screen. The samples were then dry ashed using the procedure described by Johnson and Ulrich (38). Calcium, Mg, and K were measured via atomic absorption using a Perkin Elmer 5000 Atomic Absorption Spectrophotometer. Boron was determined spectrophotometrically using the method described by M. L. Jackson (37), with the exception that in 1983, 0.5 gm of leaf sample was used instead of 1.0 gm.

Soil samples were analyzed for Mehlich I (0.05 N HCL + 0.025 N H_2SO_4) extractable nutrients (55). Boron was determined using the method described by M. L. Jackson (37) with the exception that the soil samples were refluxed for eight minutes instead of five minutes; 2 N $CaCl_2$ was used instead of 1 N $CaCl_2$ before cooling; and all water during the procedure was replaced with 0.1 N $CaCl_2$.

Spray patterns for the microjet risers were evaluated using the CO_2 delivery system developed to apply fertilizer treatments. Petri dishes were layed out such that a row of 25 plates lay in each quadrant around the riser. Thus, the water delivery pattern was determined in four directions. Both water and Ca solutions were sprayed out the same type of emitters used in the field, and the solutions collected were measured for volume distribution.

5. DATA ANALYSIS

Analysis of variance as a randomized complete block design and linear regression (5% level) were performed to evaluate treatment effects on variable means. Regression equations were developed to describe distribution patterns for emitters used in the experiment.

CHAPTER IV

RESULTS

1. EXPERIMENT 1, 1982, 1983

Nutrient Levels in Leaf Tissue

None of the levels of $CaCl_2$ (4, 8, or 12 g/day/tree) supplied through the microjet irrigation system in 1982 significantly affected the foliar levels of Ca, Mg, or K in Smoothee apple trees (Table 3). The Ca and Mg found throughout the experiment were generally within their acceptable ranges (Appendix G) as described by Chapman (14), Donahue (22), and Childers (16). A trend existed for Mg to be reduced by the Ca treatments in 1982, but the results were not significant at the 5% level. Potassium levels were lower than those previously reported (14, 16, 22), but no deficiency symptoms were evident on the trees. Although $CaCl_2$ levels applied in 1983 (8, 16, and 24 g/day/tree) were double those in 1982, the treatments had no significant effect on levels of Ca, Mg, or K in leaf tissue (Table 3). All of the levels found were within the acceptable ranges for each mineral. Potassium levels within the leaf tissue tended to increase with increasing calcium concentrations with the 24 g $CaCl_2$ treatment having 38% more K than the control.

Solubor levels of 0.25 g/day/tree supplied through irrigation in 1982 did not significantly alter the foliar levels of Ca, Mg, or K (Table 4). Regression analysis indicated a significant positive

Table 3. The effects of microjet applied $CaCl_2$ on levels of foliar nutrient content of Smoothee apple trees and soil test (Mehlich I) extractable nutrients in 1982 and 1983.

	Leaf Nutrient Concentrations (% dry wt)						Soil Test Extractable Nutrients (mg/kg)					
	1982			1983			1982			1983		
$CaCl_2$ Rate (g/day/tree)	Ca	Mg	K	Ca	Mg	K	Ca	Mg	K	Ca	Mg	K
0	1.49	0.30	0.88	1.41	0.33	1.25	860	225	175	1,390	220	120
4	1.39	0.20	0.91	----	----	----	940	260	175	----	---	---
8	1.44	0.27	0.95	1.42	0.32	1.31	1,050	210	180	1,435	170	110
12	1.18	0.22	0.92	----	----	----	960	235	200	----	---	---
16	----	----	----	1.41	0.32	1.32	----	---	---	1,665	220	110
24	----	----	----	1.63	0.41	1.73	----	---	---	1,315	170	100
F test	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

^{NS}Not significant at the 5% level by F test.

Table 4. The effects of microjet applied Solubor on levels of foliar nutrient content of Smoothee apple trees and soil test (Mehlich I) extractable nutrients in 1982 and 1983.

	Leaf Nutrient Concentrations								Soil Test Extractable Nutrients (mg/kg)							
	1982				1983				1982				1983			
Solubor Rate (g/day/tree)	Ca (%)	Mg (%)	K (%)	B (mg/kg)	Ca (%)	Mg (%)	K (%)	B (mg/kg)	Ca	Mg	K	B	Ca	Mg	K	B
0.00	1.49	0.30	0.88	28	1.41	0.33	1.25	24	860	225	160	0.9	1,390	220	120	1.2
0.25	1.44	0.27	0.99	38	----	----	----	--	760	210	180	2.5	----	---	---	---
0.50	1.40	0.28	0.93	51	1.49	0.35	1.44	36	1,110	270	145	3.7	1,460	160	130	2.8
1.00	----	----	----	--	1.29	0.29	1.27	46	----	---	---	---	1,655	210	125	3.2
F test	NS	NS	NS	*	NS	NS	NS	*	NS	NS	NS	*	NS	NS	NS	*

NS Not significant at 5% level by F test.

*Significant at 5% level.

increase in leaf B values with increasing Solubor concentrations. All of the values were within their desired ranges except K, which appeared somewhat lower than commonly reported values (14, 16, 22).

Applications of Solubor through the microjet system in 1983 did not significantly affect the foliar levels of Ca, Mg, or K (Table 4). Values of these minerals remained within their respective sufficiency ranges regardless of Solubor treatments. Solubor applied at 0.5 g/day/tree again significantly increased elemental leaf concentration of B. Increasing the Solubor rate to 1.0 g/day/tree resulted in an 82% increase in B over the control with resulting concentrations being in the upper sufficiency range (Appendix G).

Foliar applications of $CaCl_2$ of 9.1 and 13.6 g/l had no effect on the concentration of Ca, Mg, and K in apple leaves in 1982 or 1983 (Table 5). Again, both Ca and Mg were found to be near or below the lower end of their recommended ranges (Appendix G).

Soil Test Extractable Nutrients

The four levels of $CaCl_2$ applied through microjet irrigation did not alter soil test Ca, Mg, or K levels in 1982 or 1983 (Table 3). Potassium showed a positive trend with increasing levels of Ca application in 1982, but these values were not significant at the 5% level. Although higher rates of $CaCl_2$ were applied in 1983 than in 1982, rates as high as 24 g/day/tree applied through microjet sprinklers had no effect on soil test levels of Ca, Mg, and K (Table 3). Contrary to the trend in 1982, there was a slight trend for $CaCl_2$ to result in reduced K levels in 1983. It should be noted that the soil

Table 5. The effects of foliar applications of $CaCl_2$ on the foliar nutrient content of Smoothee apples in 1982 and 1983.

Foliar Spray Concentration (g/l)	Leaf Nutrient Concentrations (% dry wt)					
	1982			1983		
	Ca	Mg	K	Ca	Mg	K
0.0	1.44	0.27	0.95	1.41	0.32	1.32
9.1	1.45	0.25	1.02	1.44	0.31	1.31
13.6	1.35	0.25	0.97	1.46	0.33	1.29
F test	NS	NS	NS	NS	NS	NS

[NS] Not significant at 5% level by F test.

test Ca values were generally higher and K values generally lower at sampling time in 1983 than in 1982.

Rates of 0.25 g/day/tree and 0.50 g/day/tree of Solubor supplied through irrigation in 1982 did not affect the soil concentrations of Ca, Mg, and K (Table 4). The Solubor treatments in 1982 and 1983 did significantly increase soil B levels in a linear fashion (Table 4). In 1983, rates of 0.50 and 1.0 g/day/tree of Solubor applied did not significantly affect the soil test levels of Ca, Mg, or K (Table 4). All of these values remained within their respective concentration ranges.

2. EXPERIMENT 2, 1983

Irrigation

An analysis of irrigated versus non-irrigated trees on the level of Ca, Mg, and K showed no significant differences (Table 6). Non-irrigated trees, however, tended to have higher leaf B levels than did the irrigated trees (Table 6). Irrigation seemed to have little or no effect on levels of soil test extractable Ca, Mg, K, or B (Table 6). A trend might be noted that Ca was slightly less in the foliar tissue for irrigated trees compared to non-irrigated.

Nutrient Levels in Leaf Tissue

There were no significant effects of applications of $CaCl_2$ ($\leq$ 24 g/day/tree) on levels of Ca, Mg, and K in leaf tissue (Table 7). This confirms the results found in experiment 1. In contrast to

Table 6. The effects of irrigation on the foliar nutrient content of Redchief apple trees and soil test (Mehlich I) extractable nutrients in 1983.

	Leaf Nutrient Concentrations				Soil Test Extractable Nutrients (mg/kg)			
Treatment	Ca (%)	Mg (%)	K (%)	B (mg/kg)	Ca	Mg	K	B
Irrigated	1.26	0.33	1.27	53	1,430	265	110	1.6
Non-Irrigated	1.23	0.34	1.27	56	1,180	230	100	1.2
F test	NS	NS	NS	NS	NS	NS	NS	NS

NS Not significant at 5% level by F test.

Table 7. The effects of microjet applied $CaCl_2$ on foliar nutrient content of Redchief apple trees and soil test (Mehlich I) extractable nutrients in 1983.

$CaCl_2$ Rate (g/day/tree)	Leaf Nutrient Concentrations (% dry wt)			Soil Test Extractable Nutrients (mg/kg)		
	Ca	Mg	K	Ca	Mg	K
0	1.22	0.33	1.30	1,260	235	110
8	1.26	0.34	1.25	1,245	250	110
16	1.28	0.34	1.31	1,350	260	110
24	1.31	0.37	1.16	1,480	270	100
F test	NS	NS	NS	NS	NS	NS

^{NS}Not significant at 5% level by F test.

experiment 1, there was no effect of Solubor applications on foliar B concentrations (Table 8).

Soil Test Extractable Nutrients

Applications of $CaCl_2$ ($\leq$ 24 g/day/tree) through the microjet sprinklers did not affect soil test extractable Ca, Mg, or K (Table 7). Solubor applied at 0.50 g/day/tree resulted in an increase in soil B of 64% in experiment 2, but the effect was not significant (Table 8).

3. APPLICATION METHOD

Several points should be made about the application method and system used in these experiments. By using a compressed CO_2 sprayer, it was found that accurate applications of soluble fertilizers through the delivery system could be made which simulated delivery through the irrigation system. This system allowed a high degree of control when applying both high and low levels of fertilizers. The improved ability, over application through the irrigation system, to turn on and off the spray enables one to achieve very accurate applications. It is felt that the CO_2 system is very useful for research work in the area of fertilizers. A drawback is that by using the time calculation method for each treatment, the process of applying the treatments becomes very time consuming.

An analysis comparing the volume output and irrigation spray patterns of $CaCl_2$ solutions and water revealed no significant differences between the volume outputs of the two at the 5% level (Figures 1 and 2). There were significant differences between the patterns of

Table 8. The effects of microjet applied Solubor on the foliar nutrient content of Redchief apple trees and soil test (Mehlich I) extractable nutrients in 1983.

Solubor Rate (g/day/tree)	Leaf Nutrient Concentrations Ca (%)	Leaf Nutrient Concentrations Mg (%)	Leaf Nutrient Concentrations K (%)	Leaf Nutrient Concentrations B (mg/kg)	Soil Test Extractable Nutrients (mg/kg) Ca	Soil Test Extractable Nutrients (mg/kg) Mg	Soil Test Extractable Nutrients (mg/kg) K	Soil Test Extractable Nutrients (mg/kg) B
0.00	1.21	0.33	1.30	54	1,260	235	110	1.1
0.50	1.67	0.31	1.33	55	1,450	290	90	1.8
F test	NS	NS	NS	NS	NS	NS	NS	NS

[NS] Not significant at 5% level by F test.

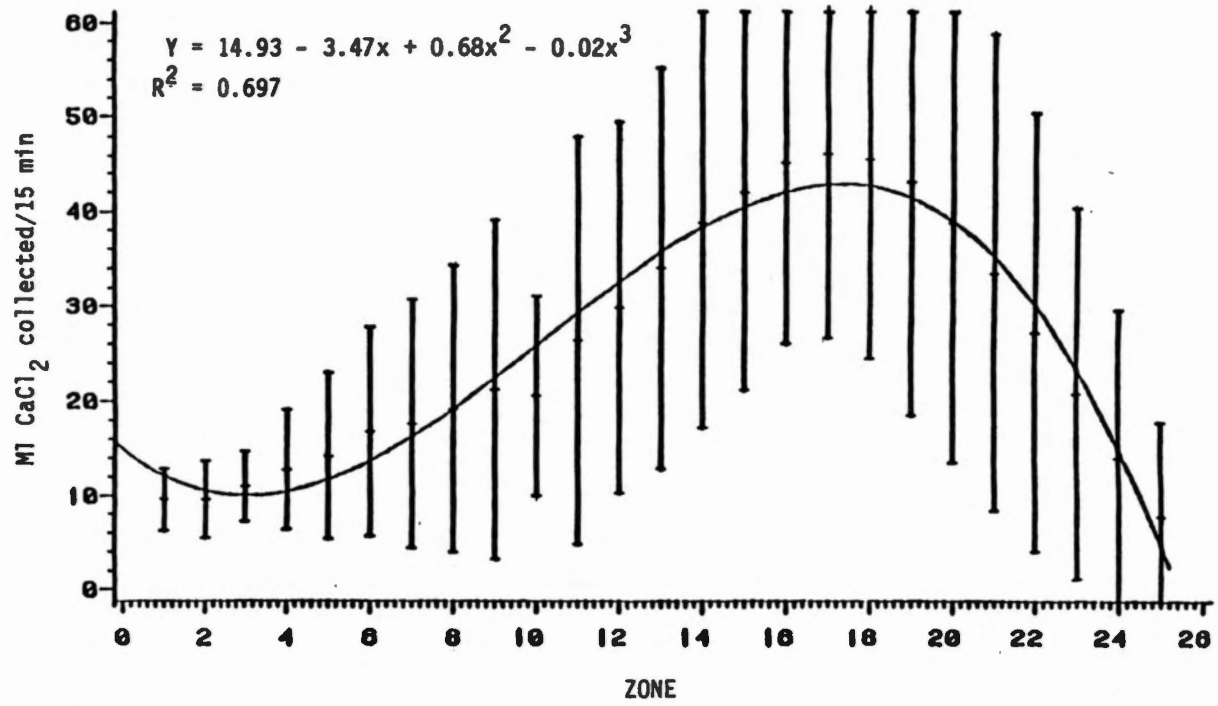

Figure 1. Volume of $CaCl_2$ solution at various distances from microjet emitter. Each point represents the mean of 5 replications. Vertical bars represent 1 SD. Each zone represents 1 62.07 cm^2 petri dish having a diameter of 8.89 cm.

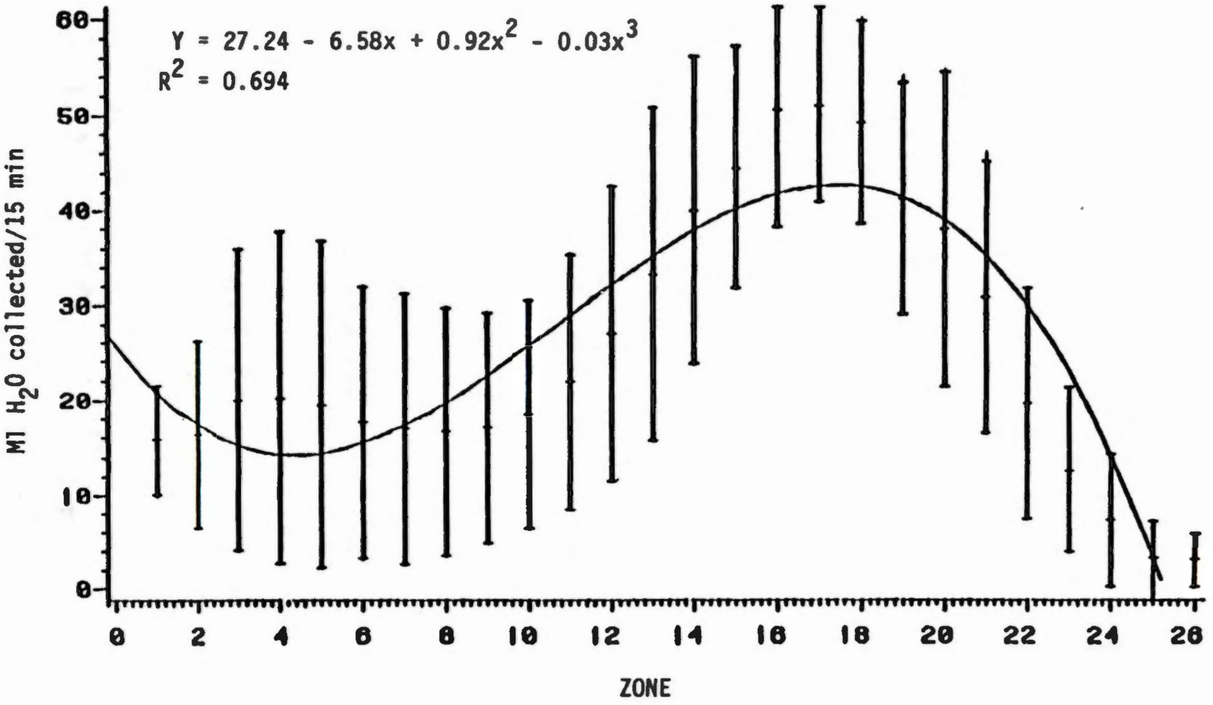

Figure 2. Volume of H_2O solution at various distances from microjet emitter. Each point represents the mean of 5 replications. Vertical bars represent 1 SD. Each zone represents 1 62.07 cm^2 petri dish having a diameter of 8.89 cm.

the two solutions at the 5% level (Figure 3). These solutions were tested for differences in both density and viscosity using an Ainsworth 300 electronic balance and a Brookfield viscometer, respectively, but no differences were found with the accuracy of the equipment used. Because of this, no reason is offered for the differences between patterns.

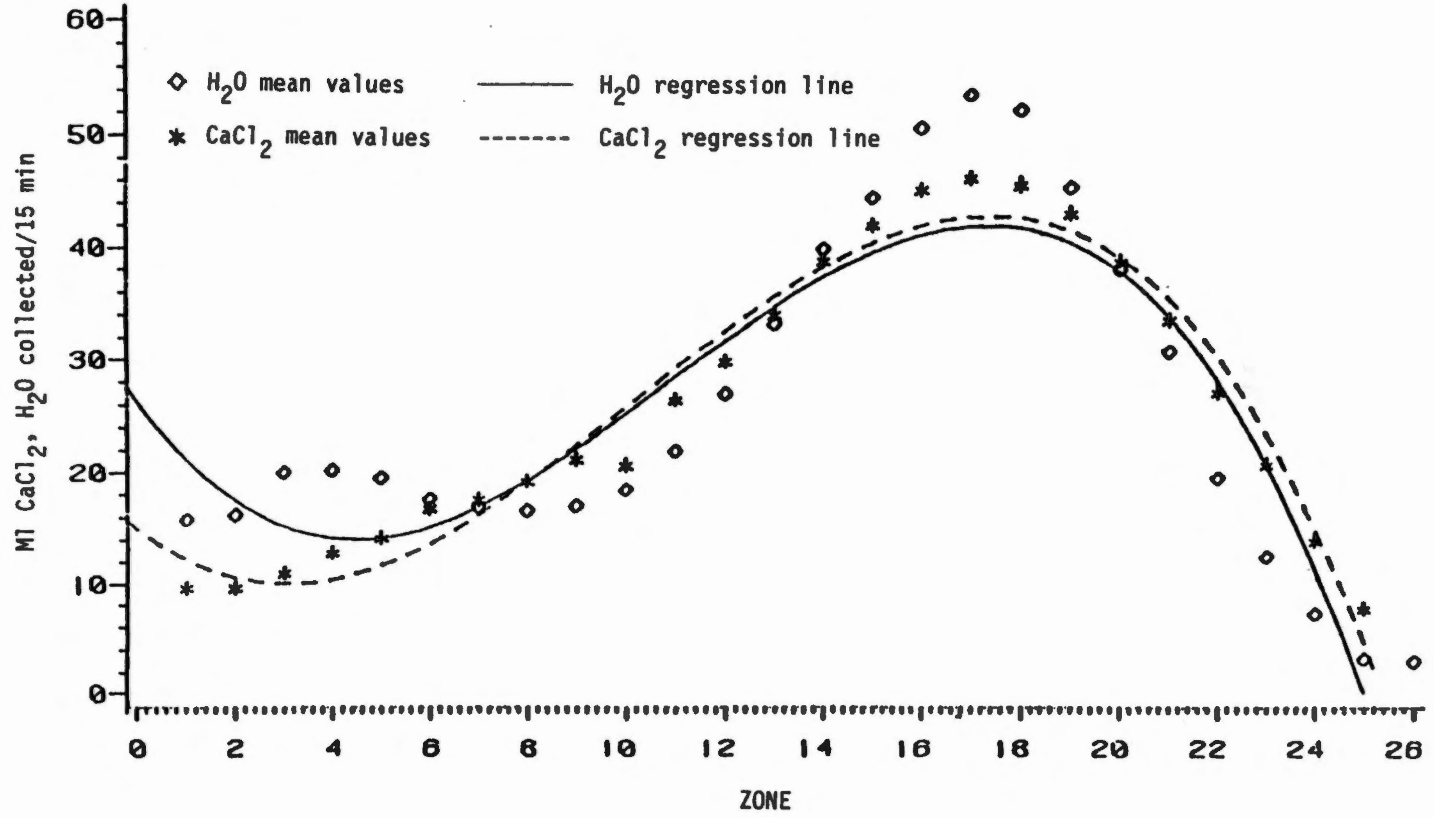

Figure 3. Comparison of mean values for volume output and regression equations for H_2O and $CaCl_2$ solutions. Each zone represents 1 62.07 cm^2 petri dish having a diameter of 8.89 cm.

CHAPTER V

DISCUSSION

The findings in 1982 and 1983 concerning the effects of CaCl applied to the soil on the leaf nutrient concentrations coincided with Boon (79), who found only slight increase in leaf Ca levels when Ca sources (gypsum and calcium carbonate) were applied to soil. These results also agree with work done by Lord (5) and Boynton (49), who found no significant increase in leaf Ca level due to application of lime to the planting holes and soil respectively. The leaf calcium results did not agree with Neilsen (61), who found increases in leaf Ca with applications of $CaSO_4$ above the 3,000 kg/ha level. A major difference in these experiments was that the treatments applied were already in solution at application time and represent substantially lower amounts of total Ca application than used by previous researchers. No increases were found in the soil test Ca concentration because the amounts of Ca in solution were slight compared to the dry applications of lime and CaSO (gypsum) in previous studies. The amounts applied in this experiment were too small to alter the large pool of Ca already present in the soil. It is possible, however, that these low levels of Ca application may have increased soil solution Ca for short periods after application.

Recommended rates for Tennessee of foliar $CaCl_2$ had no effect on foliar levels of Ca in either 1982 or 1983. These results were contrary to work reported by Van Goor (81), indicating that $Ca(NO_3)$ foliar sprays increased Ca levels in leaves, but were similar to the work by Dixon et al. (20) which indicated sprays of $Ca(NO_3)$ did not increase leaf Ca levels during the first two seasons of application. The results presented here also confirmed the work done by Himelrick et al. (34) which indicated no change in apple leaf nutrient levels following foliar sprays containing Ca.

Solubor applied through microjet irrigation caused increased foliar B levels similar to increases in plant tissue following application of borate to the soil as reported by Gupta (30). The results from this experiment also confirm work done by Kowalenko and Painter (42), who found increases in leaf B levels with various B applications to the soil. These results also agreed with Dixon et al., who found increased B levels with soil applications of Solubor (20).

The results of the leaf and soil analysis of experiment 2 for Ca content parallel those from experiment 1. The leaf B values for experiment 2 do not agree with previous work cited (20, 30, 42) or those in experiment 1. This may be due to changes in soil characteristics, variety differences, or only having one year of data in experiment 2. Soil B levels were found to be significantly increased by the Solubor treatments, also confirming work done by Kowalenko and Painter (42). The nutrient levels in both the leaf and soil samples for both experiments in 1982 and 1983 were, for the most part, within their predicted (13, 15, 21) sufficiency ranges (Appendix G). These values can now be used as a basis of comparison for other fruit workers in Tennessee (Appendix H).

The results from the comparison of irrigated versus non-irrigated treatments have shown no significant differences between the two. These results agree with those found by Levin et al. (43) and Smith and Kenworthy (73), who saw no significant changes in leaf nutrient values between irrigated and non-irrigated apple trees.

The use of the compressed CO_2 application system was found to work very well for applying fertilizer treatments. The ability to stop and start the applications with precision enables one to apply very accurate amounts of fertilizer to the soil. The microjet system as a unit did a very good job irrigating the soil. It was felt that the system had potential for use as irrigation equipment in many crops in addition to apples. The system is versatile enough that patterns and volume output, depending on crop, can be adjusted by changing emitter caps and orifice sizes.

Certain changes would have to be made to enable the irrigation system to be used to apply fertilizers for research purposes. Some sort of control mechanism for rapid starting and stopping would have to be incorporated to ensure the accuracy needed for research. If it is to be used for the application of fertilizers on a commercial basis where slight amounts of drainage are not critical, the system would work well.

CHAPTER VI

CONCLUSION

This experiment was undertaken with the idea of examining three points:

1. The effects of varying $CaCl_2$ levels on both soil and foliar nutrient content;
2. The effects of varying Solubor levels on both soil and foliar nutrient content; and
3. The effects of irrigation versus non-irrigation on the $CaCl_2$ and Solubor treatments.

The results concluded there were no significant differences among Ca treatments for both leaf tissue and soil samples. There were no significant changes in Mg or K in either the soil or leaf samples in any of the experiments. The boron treatments significantly increased both soil and foliar B levels without influencing Ca, Mg, or K.

From the irrigation study in 1983, it was concluded that irrigation did not significantly affect soil or foliar nutrient levels. These results agree with previous work in this area, but from the review of the literature, it is obvious that more work is needed to be conclusive in this field of study.

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LITERATURE CITED

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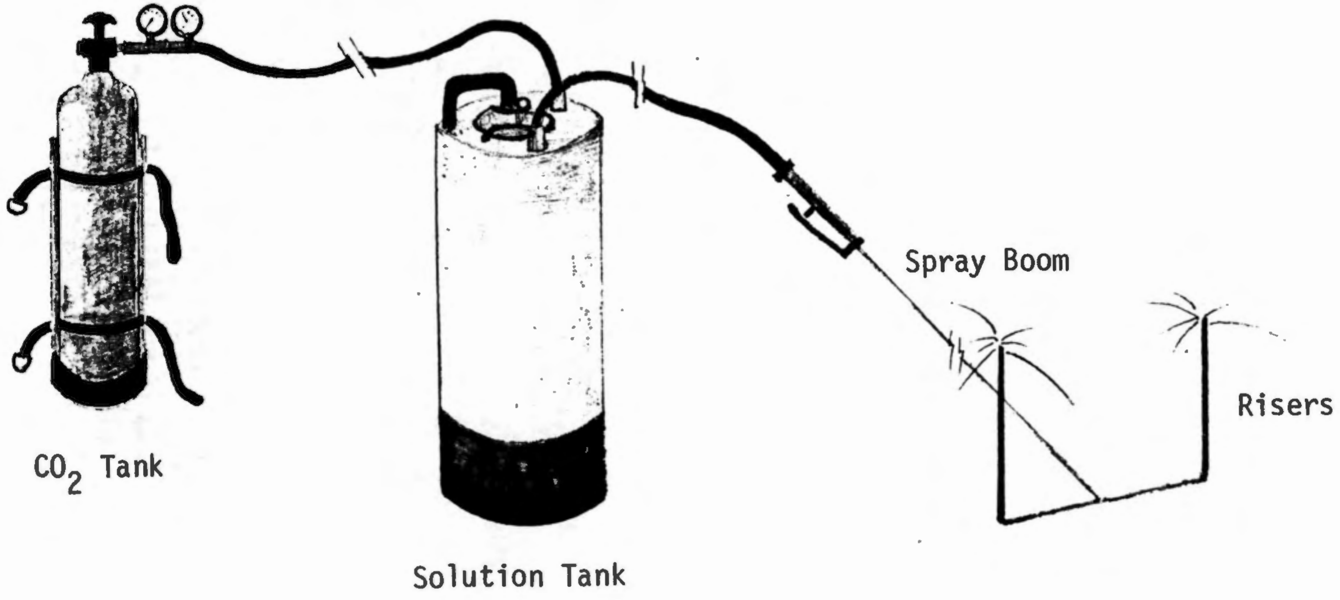
APPENDICES

APPENDIX A

SCHEMATIC DIAGRAM OF COMPRESSED CO_2 APPLICATION EQUIPMENT



APPENDIX B

ASSUMPTIONS AND FORMULAE FOR CALCULATING WATER NEED REQUIREMENTS IN 1982, 1983

Assumptions:

1. Net water loss = pan evaporation = inches evaporation - inches of rainfall.
2. Assume need to replace 75% of net water loss.
3. Assume plants cover 7%[z] of ground area in 1982 and 1983.
4. One acre inch of water = 252,531 1 = (27,000 gallons).
5. Emitter yields 460 ml/min or 27.6 1/hr.[y]
6. Plants = 215.2/Ha (87.12[x]/Ac)

Water need formula: (Standard)

1. ________________ in. net water loss x 27,000 gal./A

$$\frac{\text{X.75 replacement X.07 coverage}}{\text{8.12 plants/A}} = \text{gallons/plant needed}$$

2. ________________ gallons/plant needed x $\frac{\text{3,785 ml/gal}}{\text{460 ml/min}}$

_______ = minutes system should run

Water need formula: (Metric)

1. _______ cm. net water loss x 252,531 1/A

$$\frac{\text{X.75 replacement X.07 coverage}}{\text{215.2 plants/Ha}} = \text{1/plants needed}$$

2. _______ 1/plant needed x $\frac{\text{1000 ml/1}}{\text{460 ml/min}}$ = minutes system should run

---

[z] Varies depending on the planting system used.

[y] Depends on emitter system and pressure used to run system.

[x] Varies depending on size and age of trees.

APPENDIX C

TREATMENT DATES AND IRRIGATION CALCULATION VALUES, 1982

Treatment and Irrigation Dates	Net Loss[z] (in)	Liters/Plant	Time Irrigation Run (min)
5/12	6.63	100.9	220
5/26	0.97	59.7	129
6/9	-4.3	----	30
6/22	0.86	52.9	115

---

[z] Calculated as sum net loss over time period between treatments.

APPENDIX D

TREATMENT DATES AND IRRIGATION CALCULATION VALUES, 1983

Treatment and Irrigation Dates	Exp	Net Loss[z] (in)	Liters/Plant	Time Irrigation Run (min)
5/30	1	-2.37	-146.7	30.0
	2	-2.37	-146.1	30.0
6/8	1	1.33	82.7	180.0
	2	1.43	88.6	192.7
6/27	2	1.52	93.6	203.0
6/29	1	1.03	63.3	137.8
7/12	1	1.71	105.2	228.0
	2	1.71	105.2	228.0
7/26	2	0.53	32.6	70.9
7/27	1	1.10	67.7	147.0

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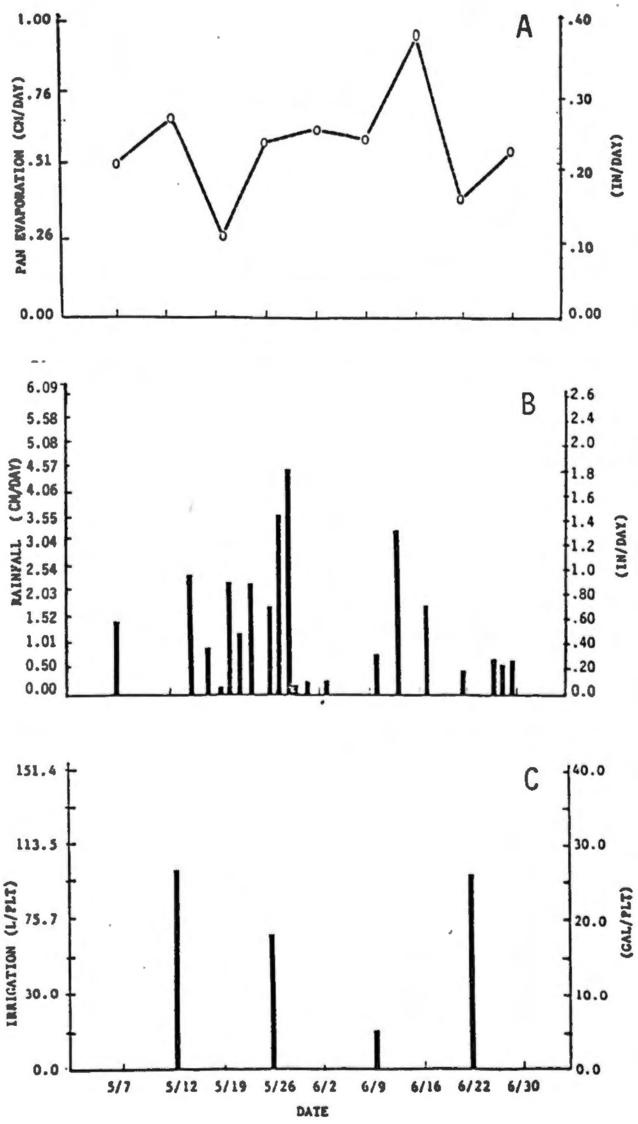
[z] Calculated as sum net loss over time period between treatments.

APPENDIX E

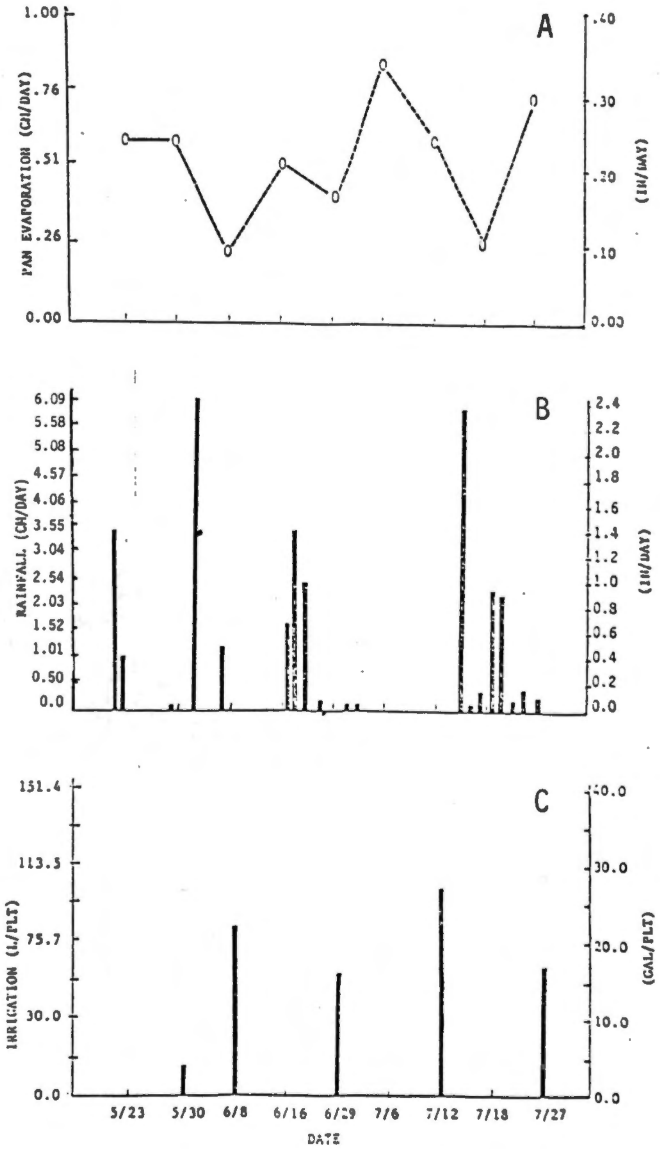
PAN EVAPORATION, RAINFALL, AND IRRIGATION APPLIED AFTER TREATMENTS FOR THE TREATMENT SEASON 1982



A: Pan evaporation (cm/day)
B: Rainfall (cm/day)
C: Irrigation applied after treatments

APPENDIX F

PAN EVAPORATION, RAINFALL, AND IRRIGATION APPLIED AFTER TREATMENTS FOR THE TREATMENT SEASON 1983



A: Pan evaporation (cm/day)
B: Rainfall (cm/day)
C: Irrigation applied after treatments

APPENDIX G

CUMULATION OF THE EXPECTED RANGES FOR MINERAL SUFFICIENCY FOR THE APPLE LEAF TISSUE BY VARIOUS AUTHORS CITED IN THIS MANUSCRIPT

Source	Expected Range of Sufficiency			
	Ca (%)	Mg (%)	K (%)	B (mg/kg)
(13)	1.0 - 1.25	0.20 - 0.50	1.00 - 2.00	20 - 50
(21)	1.0 - 2.00	0.20 - 0.50	1.25 - 3.00	20 - 60
(15)	1.5 - 2.00	0.20 - 0.50	1.20 - 1.95	30 - 40
Ranges Used	1.0 - 2.0	0.20 - 0.50	1.00 - 3.00	20 - 60

APPENDIX H

RANGES FOR MINERAL LEVELS FOUND IN SMOOTHEE AND REDCHIEF APPLES IN KNOXVILLE, TN IN 1982 AND 1983

	Soil		Leaf	
Minerals	Low	High	Low	High
Ca	860	1,665 (mg/kg)	1.18	1.63 (%)
Mg	215	290 (mg/kg)	0.208	0.410 (%)
K	92	200 (mg/kg)	0.887	1.73 (%)
B	0.92	3.74 (mg/kg)	24.5	55.4 (mg/kg)

VITA

Christopher G. Milne was born August 29, 1960 in Hackensack, New Jersey. He attended public schools in Blairstown, New Jersey and in 1978 graduated from Blair Academy, Blairstown, New Jersey. He entered Lycoming College, Williamsport, Pennsylvania in 1978 and received his Bachelor of Arts degree in 1982. He entered The University of Tennessee in the fall of 1982 and became a Graduate Research Assistant that winter. He received his Master of Science degree in March 1984. He is also a member of the American Society of Horticultural Science.

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