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EFFECTS OF MINERAL MICROINJECTION ON DECLINE SYMPTOMS IN SUGAR MAPLE, *ACER SACCHARUM* MARSH.

A Thesis Presented

by

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CHAPTER I

INTRODUCTION

Objective

A two year study was conducted to evaluate the effect of nutrient micro-injection on sugar maple (*Acer saccharum*, Marsh.) decline symptoms. The following morphological plant features: leaf area, leaf color and twig increment growth, were measured over the two year period. Evaluations of foliage density and branch dieback were also conducted throughout the study. These measurements and evaluations were used to determine the trees response to nutrient treatments.

Sugar Maple

Sugar maple is found throughout Eastern U.S. and Canada. It is a valuable tree species throughout its range. Its wood is harvested for timber. Sap is collected annually from some trees for syrup production, and they provide shade and beauty to many New England towns.

Sugar maples have a deep and branched root system. The tree thrives on fertile, moist and well drained soils. Sugar maple is found mostly on podzolic soils but develops the best on loams. Yield and quality increase as fertility and moisture improve. The pH of the soils range from 3.7 to 7.3 with 5.5 to 7.3 being most common (Fowells, 1965).

Sugar maple can reach 300-400 years of age and 20-32 meters in height. The species is tolerant of shade and is most common on north slopes (Fowells, 1965).

Sugar Maple Decline

Decline refers to progressive loss of vigor and health, not attributed to any specific disease or disorder. It is caused by several environmental and biotic factors acting in concert or sequence (Manion, 1981). The key is that decline results from the combined action of stressing factors over periods of years. Populations of sugar maple throughout its natural range have been deteriorating for decades due to the condition known as sugar maple decline. Documentation of this problem dates back to the early part of this century where decline was observed among roadside and shade trees (Westing, 1966).

Investigations into the cause and symptomology were not conducted until the 1950's and 1960's (Manion, 1981). Several symptoms of declining trees were noted in early studies: smaller, paler leaves which may exhibit scorch; premature color change and leaf drop; and terminal twig and branch dieback (Westing, 1966). In more recent years the list of symptoms has been extended to include: reduced foliage density, increased seed production, and reduced twig and diameter growth (Mader and Thompson, 1969). Decline has recently been observed among sugarbush trees (those in maple-syrup orchards) and undisturbed woodlands, as well as among roadside and shade trees.

Many studies have looked for a specific cause of sugar maple decline (e.g. Lacasse and Rich, 1964; Mader and Thompson, 1969; Westing, 1966). No single, primary pathogen is responsible. It is believed that a combination of biotic as well as abiotic factors cause decline (Manion, 1981). Many fungi, nematodes and other microorganisms may be associated with declining trees but are thought to be secondary pathogens and not causal agents. Insect defoliation, drought, road salt, air pollution and poor site conditions (soil compaction, improper drainage, nutrient deficient soil) have all been implicated (e.g. Houston, 1981; Lacasse and Rich, 1964; Westing, 1966). Compaction due to human traffic, construction, etc., and soil alteration are common stresses for shade trees. Trees along roadsides may be adversely affected by salt and vehicle exhaust. Cattle are commonly found grazing in the sugarbush. This can compact soil, and may cause physical damage to the roots and boles of trees. These stresses can result in the tree's susceptibility to nonaggressive pathogens (Schoeneweiss, 1981).

The stresses mentioned above can also affect a tree's ability to absorb or translocate the proper nutrients for growth in a number of ways. 1) Drought, compaction, defoliation, etc., can cause a reduction in the number of nonwoody absorbing roots. This reduction in nonwoody absorbing roots inhibits the uptake of nutrients and the maintenance of vigor (Teskey and Hinckley, 1986). 2) Spitko, Tattar and Rohde (1978) found that mycorrhizal infection of sugar maple roots decreased with increased tree decline. Reduction in mycorrhizal associations can interfere with absorption of water and nutrients. The endomycorrhizal relationship that sugar maple has may enable it to compete more successfully with other plants.

A reduction in the uptake of nutrients can then in turn affect a tree's energy reserves. Carroll (1981) found a relationship between root starch and crown condition. Depletion of root starch reserves reduces tree vigor. Mader and Thompson (1969) have noted low foliar nitrogen and reduced growth rates in stands exhibiting decline symptoms.

Mineral Nutrient Deficiency

Symptoms of decline, namely chlorotic leaves, reduced growth and smaller leaves, are also symptoms of most mineral deficiencies. A reduction in mineral supply can manifest itself in many ways in trees. Research done on mineral deficiency and mineral cycles has been conducted on agricultural crops and herbaceous plants. Little information is available on mineral nutrient physiology in trees. Inferences based on research done on non-woody crops must be used when discussing mineral cycles in trees.

The amount of **nitrogen** found in plants exceeds the amount of any other soil mineral element. A limited nitrogen supply decreases the rate and extent of amino acid formation and protein synthesis. Amino acids are the fundamental building blocks of virtually all biological systems, and are used in cell walls, chromosomes, nucleic acids, ATP, chlorophyll, cytochromes and as enzymes (Hewitt, 1963).

Reduced nitrogen also causes cell expansion and cell division to become limited. Prolonged dormancy, as well as a delay in normal swelling and opening of buds occurs. This delay is often accompanied by early senescence, premature leaf fall and premature maturation of stem tissues. These problems would result from early differentiation of meristematic tissue, abscission layers, xylem and parenchyma tissue, respectively (Hewitt, 1963).

Reduced nitrogen also decreases chlorophyll content causing leaves to be pale green. Chloroplasts decrease in size and number, therefore, reducing photosynthesis. Photosynthesis is required for the assimilation of CO_2 into organic cellular components needed for the growth and maintenance of the plant. A reduction in CO_2 assimilation will limit growth.

Visible symptoms of **phosphorus** deficiency such as prolonged dormancy and premature leaf fall, reflect nitrogen deficiency. This is not surprising because nitrogen and phosphorus are parts of many of the same cell components. A decrease in phosphorus content would reduce the formation of

ATP, ADP, nucleic acids (DNA and RNA) as well as phospholipids (Hewitt, 1963).

A reduction in ATP formation due to a limited supply of phosphorus can slow down plant metabolism. There would be a shortage of energy needed to carry on normal plant functions and therefore reduced growth.

As with nitrogen and phosphorus, **potassium** deficiency causes reduced growth and chlorosis. Leaves may also show browning at tips, on margins and interveinal areas. Foliage becomes sparse on the tree as a whole and shoots dieback (Sinclair, Lyon and Johnson, 1987). Potassium deficiency also increases sensitivity to freezing.

Copper (Cu), iron (Fe), manganese (Mn) and zinc (Zn) are considered **micro-nutrients** or trace elements because they are needed by plants in small amounts. These and other micro-nutrients are essential for the proper function and growth of plants. Deficiencies of trace elements can resemble those of macro-nutrients.

Iron deficient plants develop interveinal chlorosis which occurs first in young leaves. Iron deficiency also decreases cell division and decreases chloroplast size. Manganese deficiency also is characterized by interveinal chlorosis but may be found on both young and old leaves. Necrotic lesions may also develop on leaves of manganese deficient plants. Zinc deficiency reduces growth of young leaves and stem internodes. Leaf margins may become distorted and puckered. Copper deficiency may cause young leaves to become dark green. Leaves may also be twisted and may exhibit necrotic spots. Copper deficiency also causes decreased leaf size and reduces internodal length (Salisbury and Ross, 1985).

Many mineral deficiency symptoms resemble decline symptoms in trees (Table 1).

TABLE 1. Comparison of mineral deficiency symptoms and decline symptoms.

Nutrient Deficiency Symptom	Associated Mineral	Decline Symptom
chlorosis	N,P,K Mn,Fe	chlorosis
reduced growth	N,P,K Zn,Cu	reduced leaf area reduced twig growth
crown thinning	N,P,K Zn,Cu	reduced foliage density
dieback of shoots	K	branch dieback

Application of Mineral Nutrients

Broadcast fertilization of both urea (224 g/hectare of N) and 10-10-10 (224g/hectare of N) have shown a positive effect on declining sugar maples in western Massachusetts by increasing foliar nitrogen content and producing darker leaves (Mader and Thompson, 1969). Kielbaso and Ottman (1976) found improved leaf color of sugar maples with manganese (manganese chelate with 28% of Mn as manganese sulfate) treatments in Michigan. Funk and Peterson (1980) noted significant improvement in leaf color and increased nutrient levels in leaves of sugar maples treated with Arbor Green (30-10-7) soil injection and manganese trunk injection in Michigan. These studies did not note the response of other decline symptoms. We know that decline symptoms resemble nutrient deficiency symptoms (Table 1) and that there is an increase in foliar nutrient content after fertilization, but does this cause any of the decline symptoms to change?

In disturbed sites, broadcast fertilization may not be economical. Soil compaction, slope, and drainage reduce effective penetration of broadcast fertilizers through the soil. Reduction in mycorrhizae and feeder roots can reduce effective absorption of nutrients by the tree. A more direct method of fertilizer application may be more economical and result in a higher percentage of nutrients entering the target tree.

Systemic Injection of Minerals

Trunk injection is a more direct method of mineral application. Microinjection of minerals has been used for many years by arborists (Kielbaso and Ottman, 1976; Funk and Peterson, 1980). A 6 mm diameter hole is drilled through the bark and into the outer xylem of the tree exposing cut vessel ends. A pressurized (1 atm) capsule containing a liquid mixture of nitrogen, phosphorus, potassium, copper, iron, manganese and zinc is attached to a plastic tube which is fitted into the hole. The liquid is absorbed and translocated by the tree. The drill allows the technician to control the depth of the wound and to also observe the health and composition of the tissues into which the bit penetrates. In years following drought or defoliation, when nutrients are depleted, injection could supply minerals the tree needs to overcome these stresses. Shigo et. al (1977) found that the wound made by Mauget (J.J. Mauget Co., Inc., Los Angeles, CA) injection causes little injury. The treatment, however, causes some discoloration and compartmentalization in living xylem tissue, but it is assumed that the healthier a tree is, the more likely it is to overcome the small injury.

Because mineral nutrients have improved symptoms of sugar maple decline and because micro-injection may be an effective method for delivering these minerals, a study was conducted over a two year period to evaluate the use of Mauget Stemix-Hi Vol injections and their effect on sugar maple decline symptoms.

CHAPTER II

MATERIALS AND METHODS

Site Selection

Sugar maple decline was observed on roadside trees, sugarbushes, and natural forest stands throughout western Massachusetts. Sites were selected from these 3 growing conditions. Sugarbush plots were selected on the basis of active management and landowner cooperation. Sites in Charlemont, Shelburne, Ashfield, Conway, and Worthington Massachusetts were chosen. Forest plots were selected from University of Massachusetts at Amherst property located in Sunderland and Pelham Massachusetts. For ease of application and subsequent observations, roadside plots were selected from the towns of Sunderland and Whately, Massachusetts because each had sugar maples in typical street-side sites.

Trees showing moderate symptoms of decline were used in the study. Approximately 20 representative trees were selected per site; ten were randomly selected to be treated and the remaining ten untreated trees served as controls.

Treatment

All treatment of trunk injection minerals was done in late May of 1989. Treatments included Mauget Stemix Hi-Vol (6ml./capsule) versus non-treated controls. Each capsule contains 6 milliliters of liquid comprised of, 0.2% nitrate nitrogen, 0.27% ammoniacal nitrogen, 0.68% phosphoric acid, 0.61% soluble potash 0.07% copper, 0.27% iron, 0.07% manganese and 0.27% zinc. The recommended procedure for Mauget microinjection application was followed (J.J. Mauget Co., Inc., Los Angeles, CA).

The number of capsules used per tree was determined by dividing the diameter of the tree at 1.3 meters above the ground, in centimeters, by 5. The injection point was at the root collar (within 10 centimeters of ground level) on root flares. A cordless rechargeable drill and a 4.25 mm diameter drill bit was used for all injections. Holes 6.85 mm to 9.38 mm deep were drilled into the xylem, at 15 cm intervals around the tree base. The feeder tube and pressurized (1 atmosphere) capsules were put into place, the seal on the capsule was broken by tapping the capsule allowing the fertilizer to enter the tree. Capsules were removed within 2 days of treatment. At least 2 control trees per site were given drill wounds without chemical injection to compare wound closure between treated and untreated trees.

Site Descriptions

Terrain and slope were observed for each site. Soil types were noted using United States Geological Survey Soil Survey maps. Disturbances such as logging, grazing, tapping, pavement, and construction were also noted.

Measured Parameters

Foliage Density and Branch Dieback

Foliage density, expressed as the percent of foliage missing, and dieback, expressed as a percent of twigs which had died back, were evaluated, to the nearest 5%, in the field as described by Millers and Lachance (1988). These were noted at each sampling period throughout the two year study.

Classification

Trees were classified based on an average of foliage density and dieback percentages at the beginning of the study. Classes are as follows: (1) trees with percentages 0 - 5, (2) trees with percentages 6 - 15, (3) trees with percentages 16 - 30, and (4) trees with percentages above 30. This allowed us to see if crown classes responded differently to treatment.

Sampling

A pole pruner ranging in height from 5 to 12 meters was used to obtain twig samples from the periphery of approximately half the trees on each site in this study. Sampling height varied due to the different heights of individual tree's branches. Trees growing along the street had branches closer to the ground in comparison to forest and sugarbush trees. Twig samples were taken 4 times during the course of the study. Time periods were: 1) early summer 1989 (serving as before treatment sample), 2) late summer 1989, 3) early summer 1990, and 4) late summer 1990. All trees that were sampled were sampled at each of the 4 sampling times.

Samples were brought back to the lab for observations. Individual leaves were removed from twigs, placed into plastic bags and refrigerated to keep them as fresh as possible. Leaf area and leaf color were evaluated the same day of sampling. Approximately 30 leaves per tree per sampling time were measured.

<u>Leaf Area</u>

Leaf area (cm^2) was measured for each individual leaf using a portable area meter (LI-COR Model LI-3000, LAMBDA Instruments Corporation, Lincoln Nebraska 68504). Means were determined for each tree at each sampling time.

<u>Leaf Color</u>

Leaf color was determined for individual leaves by comparing them with the Munsell plant color scale (Anonymous, 1977). For the purpose of analysis, the Munsell color system was converted to a simpler numerical system ranging from 0 to 30, with 0 being the more chlorotic leaves and 30 being very dark green. Means were determined for each tree at each sampling time. Leaves for all sampling times were rated by the same individual to reduce variation.

<u>Twig Increment Growth</u>

Twigs from the late summer sampling period were used to measure twig increment growth (mm) using hand held calipers. This was done by measuring the distance from the tip of the terminal bud to the previous bud scale scar. Twig increment growth for each year from and including 1987 was determined by measuring the distance between the apical ends of the bud scale scars.

Analysis

A repeated measures analysis of variance was performed on the leaf area, leaf color and twig increment data. Analysis was performed on the data as a whole to see if there were significant differences between treatment and control trees. Analyses were rerun using site, site type, and class (general health) as variables, also to see if there were differences between treatment and control trees. T-tests were also performed to see if there were significant differences between treated and control means at any one time. All analyses were conducted using SAS for Personal Computers (SAS Institute Inc., SAS Circle Box 8000, Cary, NC 27512-8000).

CHAPTER III

RESULTS

Uptake and Wound Response to Injection

All treated trees absorbed the liquid Stemix-Hi Vol minerals in all capsules put on trees. Wound closure of injected trees and control trees which were wounded but not injected were compared.

Seventy percent of the tree's drill wounds (treated and control combined) had not closed after the first season. At the beginning of the second season control tree wounds were closing while many treated wounds remained open. At the end of the second season 50% of control tree's wounds had closed. Twenty percent of the treated tree's wounds had closed while 80% remained open. Wound closure was compared to general health rating (class) to see if healthier trees had closed sooner than the less healthy trees. No correlation was noticed, all classes (1-4) had trees with closed and open wounds.

Site Descriptions

Site descriptions are presented in Table 2. They are organized according to site type - street, forest and sugarbush. Soil composition, % slope, pH, site index for hardwoods, understory composition and disturbances are noted.

TABLE 2. Site descriptions.

SITE	SOIL COMPOSITION**	% SLOPE**	PH**	SITE INDEX FOR HARDWOODS**	UNDERSTORY COMPOSITION	DISTURBANCES
STREET SITES						
SL	fine sandy loam	3-8	4.5-6.5	52-57	turf	mowing pruning
WL	fine sandy loam	3-8	4.5-6.5	52-57	turf	mowing pruning
FOREST SITES						
CD	NA	3-8	NA	NA	ferns and seedlings	none
MT	fine sandy loam	3-8	4.5-6.5	52-57	saplings	hiking
SUGARBUSH						
AF	extremely rocky loam	3-25	4.5-6	46-51	seedlings ferns	annual tapping
CW	extremely rocky loam	3-25	4.5-6	46-51	seedlings ferns	annual tapping cattle grazing
CM	extremely rocky loam	3-25	4-5.5	46-51	seedlings ferns	annual tapping
SB	extremely stony fine sandy loam	3-25	5-6.5	58+	seedlings ferns	annual tapping cattle grazing
WT	NA	3-8	NA	NA	saplings	annual tapping

** From Soil Survey Maps (Mott and Fuller, 1967; Mott and Swenson, 1978; Swenson, 1981)

The 2 street sites SL and WL are essentially the same in site descriptions. Both towns have a wide tree belt along both sides of the street with many trees lying on the edge of homeowners property. Overall the sites are the same in site qualities, maintenance and tree size.

It was difficult to compare the forest sites because no USGS soil survey is available for CD. Apparent differences are the lack of understory and the pure sugar maple stand at CD. MT, on the other hand, has other hardwoods and pines mixed in the overstory and has a well stocked understory.

Sugarbush sites are similar in most aspects except for understory composition and disturbances. Also, SB has a higher site index than the other sites. No USGS soil survey map is available for WT, therefore, site qualities were not noted except for those the investigator could identify.

The overall health of sugarbush sites however, appears different. CM and AF support very healthy looking trees which exhibit low amounts of decline. CW and SB appear less healthy with many trees having branch dieback and foliage which has an overall yellow appearance. WT does not appear as healthy as CM and AF but does not look as unhealthy as CW and SB.

Foliage Density and Branch Dieback

General quality ratings for each site at the beginning of the study were determined by averaging foliage density and branch dieback ratings. The resulting figures are in Table 3.

TABLE 3. General quality rating for each site.

SITE TYPE	SITE	* Average of Foliage Density and Branch Dieback
STREET	SL	12.5
	WL	15.4
FOREST	CD	11.6
	MT	21.9
SUGARBUSH	AF	9.5
	CM	11.8
	WT	13.7
	CW	18.5
	SB	19.6

* Average of Foliage Density and Branch Dieback was calculated by averaging both ratings for all trees on a particular site.

Higher numbers represent lower average foliage density and higher branch dieback ratings. This is interpreted as lower quality. Table 3 shows that the two street sites are comparable in quality SL=12.5 and WL=15.4. The forest sites seem quite different in quality, CD=11.6 while MT is 21.9. The sugarbush sites are varied. AF, CM and WT are on the upper end of the scale with AF and CM being among the top 3 sites overall. CW and SB are among the lowest three sites in terms of quality.

The overall change in foliage density and branch dieback was calculated. The average change was calculated for each class for both treated and control trees (Figures 1 and 2) Zero represents a "no change" rating. Averages

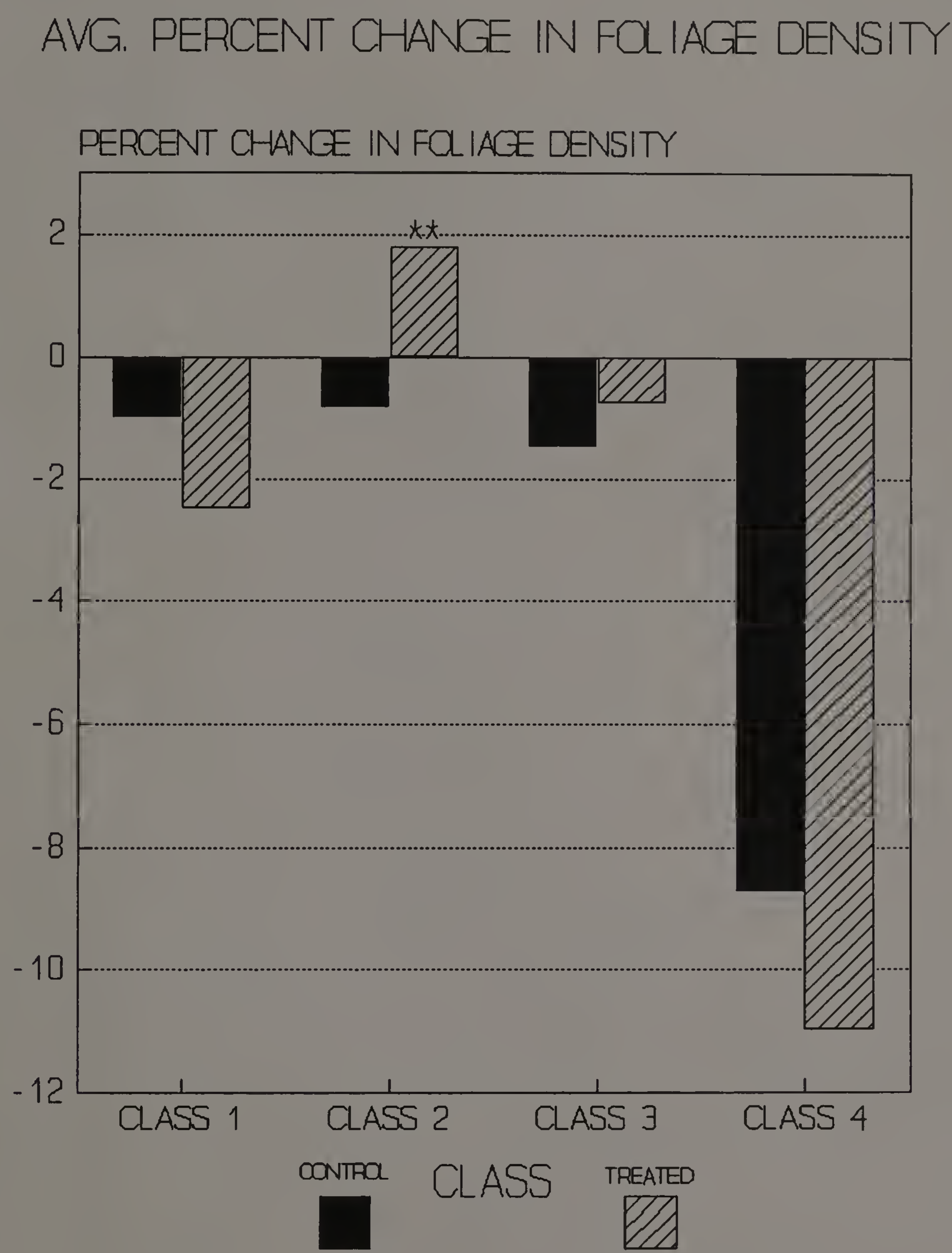

FIGURE 1. Mean change in foliage density rating for treated and control trees, shown by general health classes.
** = significance at the .10 level.

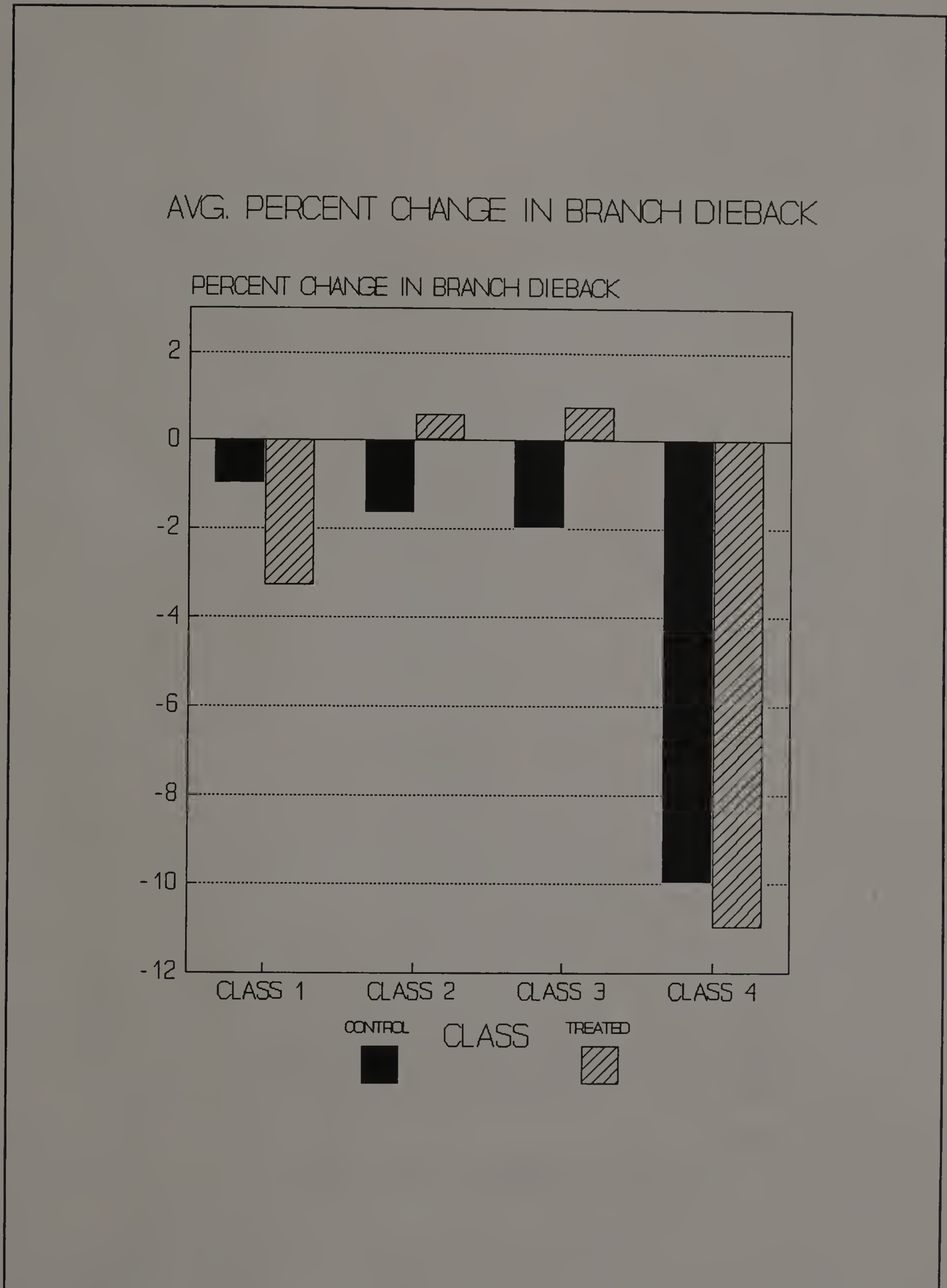

FIGURE 2. Mean change in branch dieback rating for treated and control trees, shown by general health classes.

below zero represent a negative change or lower ratings, while those above zero represent positive changes, higher ratings. The trends for both foliage density and branch dieback are very similar. All averages were below zero - negative change - except for classes 2 and 3 treated trees with respect to branch dieback and class 2 treated trees with respect to foliage density. All classes went down in ratings - interpreted as worsening for each respective parameter except for those mentioned above.

A trend is apparent in both figures with respect to control trees. Percent change becomes more negative as you go from class 1 to class 4. This indicates that trees which are of lower quality continue to get worse with respect to branch dieback and foliage density.

This trend is not as apparent in treated trees. Class 1 does have a negative percent change, as does class 4, and these are more negative than the respective controls. But in both figures classes 2 and 3 do not follow the same trend as controls. In fact class 2 treated trees have a positive change in both foliage density and branch dieback. Class 3 also exhibits a positive change in branch dieback.

Leaf Area and Leaf Color

Leaf area and leaf color means varied between treated and control trees at the beginning of the study. In order to analyze for differences over time we standardized by dividing the mean of a particular parameter for a particular tree at each sampling time by that parameter's mean at the beginning of the study. For example, if a tree's leaf areas for the 4 sampling times were: 42.40, 43.10, 53.78, and 52.95, it's standardized leaf areas would be 42.40/42.40=1.00, 43.10/42.40=1.02, 53.78/42.40=1.27 and 52.95/42.40=1.25. Numbers higher than 1 reflect an increase in the measured parameter from the beginning to the end of the study. Numbers below 1 represent a decrease in the measured parameter.

Standardized parameters were then analyzed for differences between treated and control trees. A repeated measures analysis of variance revealed no significant difference in the data as a whole.

ANOVA for measured parameters was then performed at the site, class and site type levels. No overall significant difference was detected. When trees were analyzed at the class (general health) level, trends became more apparent. A T-test analysis was performed to compare the means for differences between treated and control trees for each class.

Figure 3A presents the average standardized leaf area for treated and control trees by class over the 3 sampling times following treatment. In looking at the 3 sampling times overall, there is a similar trend. Class 1 exhibits the lower standardized leaf area and the leaf area increases as you move from class 1 to class 4. This is apparent in both treated and control trees. Significant difference

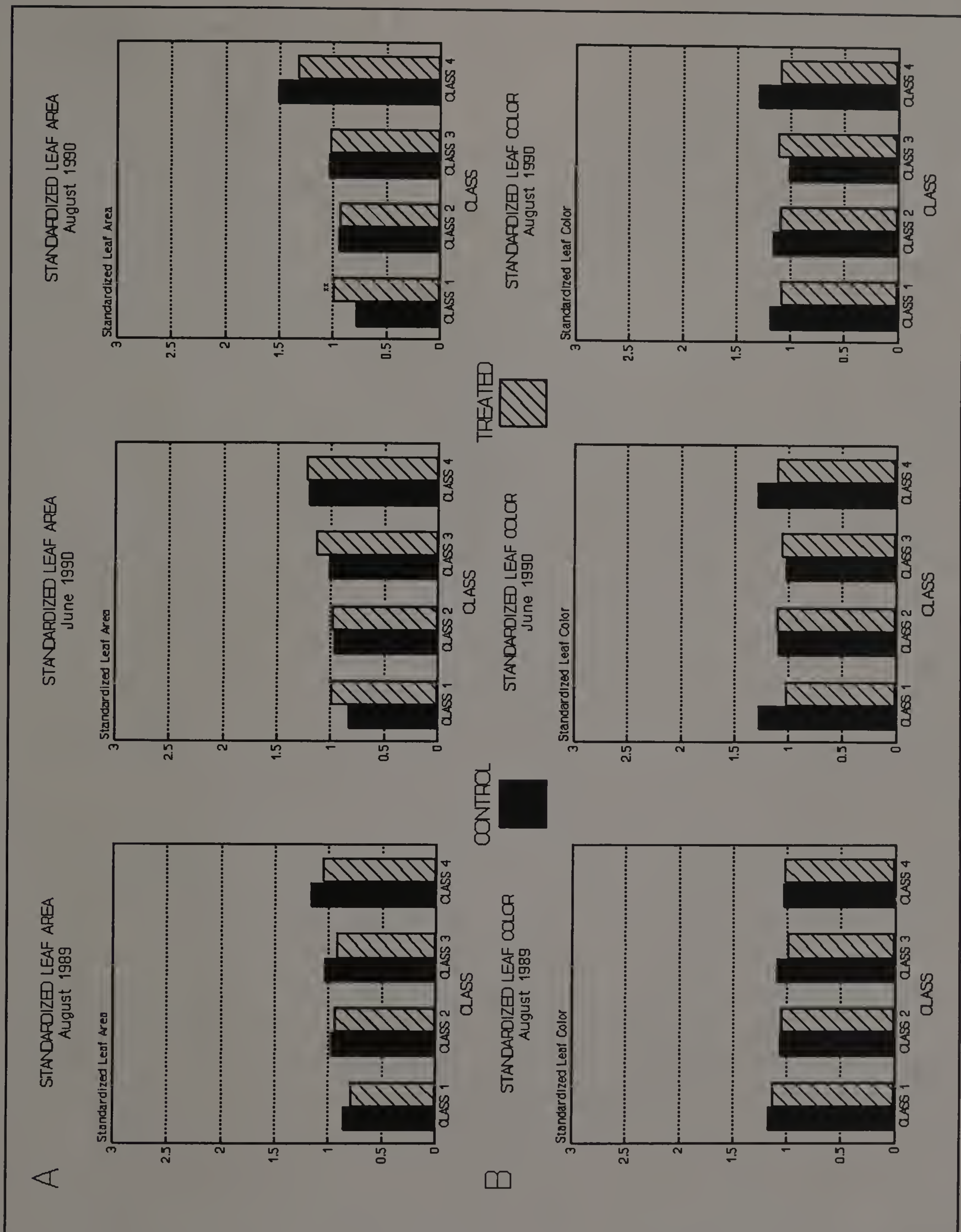

FIGURE 3. A. Standardized leaf area for the 3 sampling periods following treatment, shown by general health classes. **B.** Standardized leaf color for the 3 sampling periods following treatment, shown by general health classes.
* = significance at the .05 level.

between treated and control trees was detected in August 1990 for class 1 trees. Treated trees being significantly higher than controls although the standardized leaf area is similar to the leaf area before treatment (close to the standard 1).

Figure 3B represents the average standardized leaf color for treated and control trees by class, over the 3 sampling periods following treatment. For the sampling period of August 1989 standardized leaf color for control and treated trees are very similar for each class. In the following year, 1990, treated trees, regardless of class, exhibit almost identical standardized leaf color, flucuating very little above and below the standard 1. Control trees however, show a different trend. Class 1 and 4 increase in standardized leaf color in June and remain slightly higher than the other classes in August also. Class 2 and 3 are similar to treated trees.

Twig Increment Growth

Twig growth was standardized by averaging 1987 and 1988 growth, representing the before treatment average growth. 1989 and 1990 growth was also averaged, representing after treatment growth. The first figure (1987-1988) was used as the standard and the 1989-1990 growth was divided by that. Again numbers above 1 represent increased growth, numbers below 1 represent decreased growth. These figures were then averaged for control and treated trees by class (Figure 4).

Twig increment growth increased for both control and treated trees for all classes. Class 1 treated trees increased more than control trees. Mean twig increment growth is significantly different at the .10 level for Class 1 trees. For class 2 both control and treated trees increased about the same amount. In class 3 control trees mean twig increment growth is significantly higher (at the .10 level) than treated trees. This trend is also found in class 4 trees although the difference is not significant.

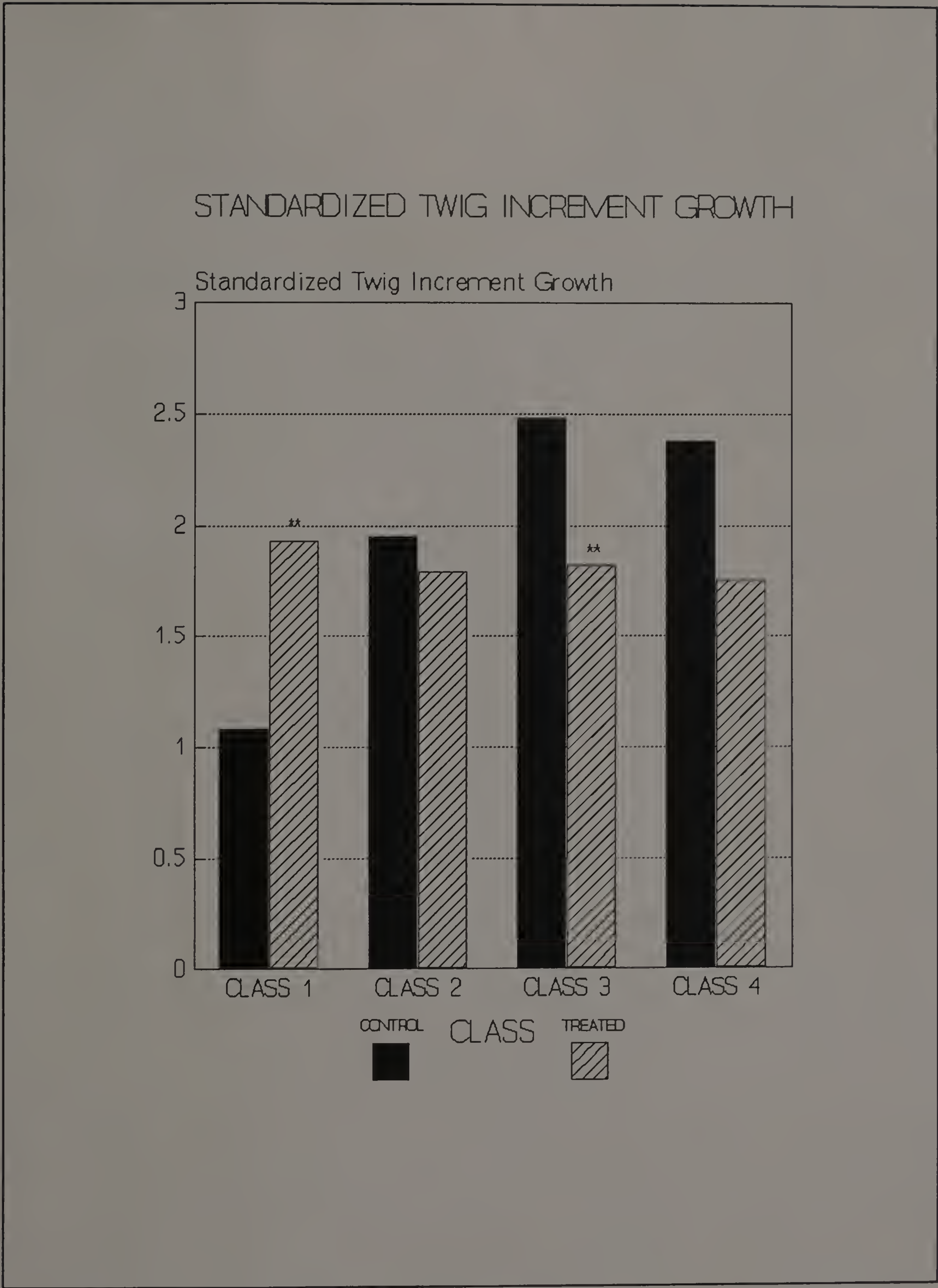

FIGURE 4. Mean standardized twig increment growth for treated and control trees after treatment, shown by general health classes.
** = significance at the .10 level.

CHAPTER IV

DISCUSSION

When looking at the site descriptions (Table 2) the street sites (SL and WL) are very similar to each other in site qualities. These sites also have similar ratings in Table 3. They are found in the middle of the scale - not among the best quality sites and not among the worst quality sites. It is hard to make a comparison between the forest sites (CD and MT) because there is no site description for the Cadwell site. The obvious differences between the sites are, MT has understory competition and hiker pressure and CD does not. In Table 3, these sites have very different ratings with MT at the low quality end and CD at the high quality end.

When comparing the sugarbush sites (AF, CM, CW, WT, SB) AF and CW are found on the same soil type yet they are on almost opposite ends of the scale in Table 3; AF at the high quality end CW at the low quality end. The major difference between these sites is that CW has animal pressure and AF does not. CM is very similar to CW and AF in site description. It is like AF in having no animal pressure and is similarly found on the upper end of the quality scale. SB is similar to the above sites except it has a much higher site index. One might expect this site to be on the higher quality end of the scale. Yet SB has the second lowest rating in Table 3. This site also has animal pressure like CW. The WT site is difficult to compare because it lacks a complete site description. It is moderate in quality rating, found in the middle of the sugarbush sites if Table 3. Perhaps it is not as high quality as AF and CM due to the understory competition at that site. Perhaps it is not as low as CW and SB because the animal pressure is a greater stress than the competition.

Overall, the sites with some sort of stress factor (competition, grazing) are rated a lower quality in Table 3. The street sites are found in the middle of the scale; they have competition with turf and air pollution pressure due to street traffic. The MT site has compaction due to trail traffic and high competition with other trees and the understory. CW and SB sugarbush sites both have compaction, root injury, and bole injury due to cattle pressure. One may argue the animals provide added nutrients but, perhaps, the stresses have a greater affect than these added nutrients. The WT site also has competition and lies toward the middle of the scale.

This evidence supports that decline results from the combined action of stressing factors over periods of years. Whether natural or from management practices, these stresses impact the overall health of each site.

When measured parameters were analyzed at the site level no correlation with site quality ratings was found. Trees on a certain site are not all the same quality. Even the poorer sites (CW and SB for example) had trees in classes 1 and 2. Although the sites can be rated in general quality, each individual tree's status must be considered when analyzing the data. That is why trends became more apparent when data was analyzed at the class (general health) level.

Evaluations of foliage density (figure 1) and branch dieback (figure 2) revealed an interesting trend. As tree quality goes down (moving from class 1 to class 4) the percent change in rating becomes more negative. This is true for control trees. All of the trees continue to decline and the trees which are less healthy at the beginning of the study decline at a faster rate. Change for the higher quality classes (1-3) decreased only 2% while class 4 change was 4 to 5 times that. Perhaps, once 30% or more of the foliage is missing and branches have died back the tree will most likely not recover.

Treated trees in figures 1 and 2 did not follow this trend except for class 1 and 4. Both classes had a negative change comparable to the controls, although both did decrease more than controls (in both foliage density and branch dieback). Class 1 trees expressed less than 5% foliage missing and branches dying back at the beginning of the study. Therefore, a positive change would be almost impossible to achieve. But, it is not fully understood why class 1 treated trees decreased more than controls. The explanation above for class 4 control trees also makes sense for treated trees, because trees expressing this much decline might be unable to recover. But, again, why did the treated trees have a more negative change than the controls? Perhaps the injury caused by the treatment, namely the drill wound, may have caused the class 4 trees to decline more rapidly.

Class 2 and 3 treated trees do not follow the same trend as controls in figures 1 and 2. Class 2 shows a positive change in both foliage density and branch dieback. Class 3 has a positive change in branch dieback; the change in foliage density does not indicate a positive change, but it is, however, less negative than controls. This may represent a positive reaction to treatment. Because the trend is so apparent, with regard to control trees, possibly treatment has disrupted this trend in these moderate health classes (2 and 3).

When looking at results for leaf area, leaf color, and twig increment growth, trends are different than those for foliage density and branch dieback. Average standardized leaf area (Fig. 3A) does show a common trend for each sampling time following treatment. The most healthy trees (class 1) have the smallest standardized leaf area while the least healthy trees (class 4) have the largest standardized leaf area. This is apparent in both treated trees and control trees. There is no remarkable improvement of treated trees in these parameters.

Standardized leaf area for treated trees in all classes does increase between August 1989 and June 1990, with all areas higher than controls. This does not remain true by August 1990. The only difference found between treated and control trees in August 1990 are in class 1 and 4. Treated trees in class 1 have significantly higher standardized leaf area than controls. Classes 1-3 all have mean standardized leaf area at or below 1; growing the same as before treatment. Class 4 is above 1 for both treated and control trees. It is unclear why the least healthy trees have the largest leaf area.

When combining the change in foliage density rating (figure 1) with standardized leaf area (fig. 3A) perhaps this can be explained. The less healthy trees (class 4) have much less foliage to begin with and have decreased this density by approximately 9% in one year of study. Perhaps these trees are putting their available energy into making larger leaves. Class 2 and 3 treated trees appear to be essentially the same as controls in figure 3A. But in relation to figure 1, where class 2 showed an increase in foliage density and class 3 decreased less than controls, these trees may be in better condition than controls.

Standardized leaf color (fig. 3B) for treated and control trees in August 1989 exhibit similar trends. The healthier class (class 1) shows an increase in leaf color but this increase is reduced progressively as health decreases (class 4). There is virtually no difference between treatment and control for eah class. This indicates no response to treatment during the first season.

During the following year, treated and control trees' leaf color, do not show identical trends. Treated trees are virtually the same for all classes both during the June 1990 and August 1990 sampling periods; the means are at or slightly above 1. In June 1990 control trees' leaf color increased for class 1 and 4 with class 2 and 3 being comparable to treated trees. This is also apparent in August 1990 although class 2 controls slightly increase. The increase in class 4 may be explained in the same way as is leaf area. These poorer trees have a much reduced amount of foliage, therefore, the energy they have is used to produce greener leaves. The increase in class 1 leaf color may also be due to a similar reason keeping in mind class 1 control leaves have decreased in area. Perhaps, the increase in color is a slight compensation for reducing the leaf area; ie, more sunlight hits each leaf.

Standardized twig increment growth (Fig. 4) averages for both treated and control trees for all classes have increased. Treated trees are similar for all classes but class 1 does show more growth than the other classes. Growth decreases from class 1 to class 4. Control trees are different than each other and show an opposite trend than treated trees. Class 1 controls have increased slightly from the previous year. Growth increases for class 2, and, again for class 3, but appears to even off in class 4. This trend of less healthy control trees having an increase in twig increment growth, is very similar to the trend of control trees for standardized leaf area in August 1990. Again, why would the least healthy trees have the most increase in twig increment growth?

When you Combine twig increment growth (fig. 4) with change in branch dieback (fig 2) a reason comes to mind. There is an opposite trend between the two figures for control trees. The less healthy trees (class 3 and 4) appear to have longer twigs than the more healthy classes. But, these same trees have more twigs dying back (fig. 2). The living twigs that remain, however, are increasing their growth. Treated trees in class 2 and 3 have less twig increment growth than controls, but they have fewer branches dying back.

When taking all the data collected in this entire study into account there is no overwhelming response to treatment. There are some trends toward response in healthier classes (1 and 2). Treated trees in class 1 increase over controls in standardized leaf area (significant at the .05 level) (figure 3A) and standardized twig increment growth (significant at the .05 level) (figure 4). Class 1 also shows a reduction in foliage density and branch dieback, but neither is significantly different than controls.

Treated trees in class 2 are significantly different than controls with regard to change in foliage density. They exhibit less branch dieback than controls. These trees are comparable to controls in leaf area, leaf color and twig increment growth. Treated trees in class 3 increase more than controls in branch dieback and decrease less than controls in foliage density. Other measured parameters for class 3 are comparable to controls except for twig increment growth.

Overall conclusions found in this study are that trees exhibiting characteristics of class 4 trees should not be treated with mineral nutrients by the micro-injection method. Exactly how the tree responds internally was not investigated by this study. One might conclude that these trees showed no positive change in any parameter measured because treatment effects on unhealthy trees do more harm than good.

It appears that there may be some benefits of treating the more healthy classes of sugar maple trees. Trees in class 1 have reacted positively in several parameters as did class 2 during the 2 year study. Trees in class 3 reacted somewhat positively but not as much as class 1 or 2.

One should also keep in mind the impact of management on individual sites. Sites which are similar in natural site conditions can have very different stands growing on them in terms of health. Major impacts on sugar maple trees found in this study are competition, animal and people pressure.

Ideally, in the study it would have been preferable to control all parameters besides treatment but it is virtually impossible in a study of large, mature trees. However, decline symptoms are generally most common in very large mature trees. Finding experimental plots with trees that are similar in all aspects is difficult. Each tree has its own micro-environment and past treatment. Sampling of large trees is also very difficult. Samples for this study often had to be taken from the lower and mid crown of these trees due to their height. These individual samples may not have accurately expressed physiological responses of each tree. Carroll (1981) used a bucket truck to collect samples, this was not available in this study.

An ideal situation for a study such as this would be an even aged site with a large number of trees expressing similar symptoms of decline. Additional information on the mineral condition of soil around each tree would also be healpful in future studies. I also believe that it would be useful to compare trunk injection with other tree fertilization methods. A study which compares all the different methods currently available for fertilization treatment of sugar maple decline has not been performed and is needed.

BIBLIOGRAPHY

Anonymous, 1977. Munsell Color Charts for Plant Tissues. 2nd edition. Munsell Color, Baltimore MD. 23pp.

Carroll, J. 1981. The Relationship Between Autumn Root Starch Content and Decline Symptoms in Urban Maple Trees. M.S. Thesis. University of Massachusetts, 1981.

Fowells, H.A. (ed.) 1965. Silvics of Forest Trees of the United States. Agricultural Handbook # 271. United States Department of Agriculture, Forest Service, Washington D.C. 762 p.

Funk, R. and W. Peterson. 1980. Nutrient Treatments for Sugar Maple Decline. Journal of Arboriculture 6(5):124-129.

Harrell, M.O., P.A. Pierce D.P. Mooter and B.L. Webster. 1984. A Comparison of Treatment for Chlorosis of Pin Oak and Silver Maple. Journal of Arboriculture, 10(9):246-249.

Hepting, G. 1971. Diseases of Forest and Shade Trees of the US. USDA Forest Service Agricultural Handbook 386.

Hewitt, E.J. 1963. The Essential Nutrient Elements: Requirements and Interactions in Plants, in Plant Physiology: A Treatise, volume III. F.C. Steward editor. Academic Press, New York, NY.

Houston, D.R. 1981. Stress Triggered Tree Diseases: The Diebacks and Declines. U.S.D.A. Forest Service, NE-INF-41-81.

Kielbaso, J.J. and K. Ottman. 1976. Manganese Deficiency - Contributory to Maple Decline? Journal of Arboriculture, Feb. 1976:27-32.

Lacasse, N.L. and A.E. Rich. 1964. Maple Decline in New Hampshire. Phytopathology, 54(9):1071-1075.

Mader, D.L. and B. W. Thompson. 1969. Foliar and Soil Nutrients in Relation to Sugar Maple Decline. Soil Sci. Soc. Amer. Proc. 33:794-800.

Manion, P.D. 1981. Tree Disease Concepts. Prentice Hall Inc., Englewood Cliffs, N.J.

Millers, I. and D. Lachance. 1988. Cooperative Field Manual for the North American Sugar Maple Decline Project. Canadian Forest Service and U.S.D.A. Forest Service.

Mott, J.R. and D.C. Fuller. 1967. Soil Survey of Franklin County. United States Department of Agriculture, Soil Conservation Service in cooperation with Massachusetts Experiment Station. 204 p.

Mott, J.R. and E.I. Swenson. 1978. Soil Survey of Hampden County. United States Department of Agriculture, Soil Conservation Service in cooperation with Massachusetts Experiment Station. 199 p.

Newbanks, D. and T.A. Tattar. 1977. The Relationship Between Electrical Resistance and Severity of Decline Symptoms in Acer Saccharum. Canadian Journal of Forest Research, 7(3):469-475.

Raven, P.H., R.F. Evert and H. Curtis. 1981. Biology of Plants. 3rd editon. Worth Publishers Inc., New York, NY.

Salisbury, F.B. and C.W. Ross. 1985. Plant Physiology, 3rd edition. Woodsworth Publishing Co., Belmont, California.

Schoeneweiss, D.F. 1981. The Role of Environmental Stress in Diseases of Woody Plants. Plant Disease, 65(4):308-314.

Shigo, A.L., W.E. Money and D.I. Dodds. 1977. Some Internal Effects of Mauget Tree Injection. Journal of Arboriculture 3(11):213-220.

Shortle, W.C., J.B. Kotheimer and A.E. Rich. 1972. Effect of Salt Injury on Shoot Growth of Sugar Maple, Acer Saccharum. Plant Disease Reporter, 56(11):1004-1007.

Sinclair, W.A., H.H. Lyon and W.T. Johnson. 1987. Diseases of Trees and Shrubs. Cornell University Press, Ithaca, NY.

Spitko, R.A., T.A. Tattar and R.A. Rohde. 1978. Incidence and Condition of Vesicular-Arbuscular Mycorrhizae Infections in the Roots of Sugar Maple in Relation to Maple Decline. Canadian Journal of Forest Research, 8(4):375-379.

Swenson, E.I. et al. 1981. Soil Survey of Hampshire County. United States Department of Agriculture, Soil Conservation Service in cooperation with Massachusetts Experiment Station. 172 p.

Teskey, R.O. and T.M. Hinckley. 1986. Moisture: Effects of Water Stress on Trees. In Stress Physiology and Forest Productivity, edited by T.C. Hennessey, P.M. Dougherty, S.U. Kossuth and J.D. Johnson. Martinus Nijhoff Pub., Boston. pp. 9-33.

Wargo, P.M. and D.R. Houston. 1974. Infection of Defoliated Sugar Maple Trees by Armillaria mellea. Phytopathology 64:817-822.

Wargo, P.M. 1977. Wound Closure in Sugar Maple: Adverse Effects of Defoliation. Canadian Journal of Forest Research. 7(2):410-414.

Westing, A.H. 1966. Sugar Maple Decline: An Evaluation. Economic Botany, XX:196-212.

Zoettl H.W. and R.I. Huettl, 1986. Nutrient Supply and Forest Decline in Southwest Germany. Water, Air, and Soil Pollution (31) 449-462.