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THE RELATIONSHIP BETWEEN AUTUMN ROOT STARCH CONTENT AND DECLINE SYMPTOMS IN URBAN MAPLE TREES

A Thesis Presented

By

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INTRODUCTION

Each year many trees, especially maple, birch, ash, and oak, decline: their buds and twigs dieback, foliage changes color earlier than normal, and leaves become dwarfed and sparse. The implicated causes of decline of sugar maple include drought (3), poor nutrition (32), salt damage (30), soil compaction, and site disturbance (16); each of which can interact with the others producing what is termed a complex disease (20). Trees in moderate to mild stages of decline sometimes recover through continuous, therapeutic pruning, fertilizing and watering practices. Yet, it remains difficult to arrest this state of decline and save the affected trees from eventual death. The development of a diagnostic tool capable of evaluating tree health prior to the onset of decline symptoms is needed. Such a test should allow us to detect and treat trees with presymptomatic injury rather than treat only those showing obvious decline symptoms.

Wargo (53) developed a root starch test that effectively determined the degree of gypsy moth defoliation of individual deciduous forest trees. In theory, this root starch test could apply to any case in which a deciduous tree's photosynthetic capacity decreases: the tree will draw on central starch reserves not normally utilized or will be unable to augment its stored starch in autumn (57). All implicated causes of declines reduce the photosynthetic capacity of plants in general. The ability of a root starch analysis to reveal the health of deciduous trees needs to be tested decisively. If effective, this simple test could aid the ability of tree disease specialists and arborists to determine the condition of a tree as medical doctors determine human condition with blood tests.

The first objective of the research is to seek a correlation between root starch content and crown condition ratings of declining urban sugar maples. The second is to determine the effect of spring fertilization with a complete fertilizer on the amount of stored root starch in the next autumn in urban maples. And also to determine whether the fertilization resulted in a change in crown condition.

CHAPTER I

LITERATURE REVIEW

Sugar Maple Decline

Sugar maple decline occurs in the forest, sugar-bush and urban environments; the most prevalent occurs in the urban environment and has been known and observed by arborists and forest pathologists since the turn of this century (23, 50, 61). The disease, its many contributing causes and the literature have been extensively reviewed (5, 15, 16, 19, 20, 61). The causes most often attributed to the decline of urban sugar maples include road salt (1, 12, 13, 16, 18, 27, 29, 30, 44, 46), drought (2, 3, 15, 19, 23, 50), site disturbance (2, 11, 17, 21, 29, 30) and nutrition (10, 23, 25, 32). It is interesting to note all the factors associated with decline cited above principally affect the root system of the trees. Other attributed causal agents also affect the root system including nematodes (7, 8, 43, 45), reduced mycorrhizae (12, 49), gas leaks and improper transplanting (16).

Sugar maple decline continues to be prevalent in the eastern United States (4, 10, 44) because treatments to prevent or alleviate it have been unsuccessful. Each tree must be diagnosed and treated individually for the predominant cause. This procedure is very costly and time-consuming and often fails to achieve its end (10, 21, 25, 30, 44). Griffin (11) found moderately declining trees recover in the woodlots of Ontario. However, in the continuously disturbed urban environment recovery of moderately affected trees is less frequent (4, 15, 44).

It is apparent that more parameters are needed with which to measure a tree's health in order to effect its recovery. The rating of symptom severity in the crown of trees is often the only parameter used and is subject to error. Increment cores show strong correlation to symptom severity (34) and drought (36, 61). Though, these are difficult to obtain and analyze from sugar maple (61) and can lead to decay in already decadent trees. Twig increments have been shown to indicate salt stress on sugar maple (47). They have also been often used by arborists, tree physiologists and forest pathologists to indicate how well a tree is growing. However, maples have three distinct types of shoots: long shoots, short shoots and heterophyllous shoots (6, 26, 62). Nevertheless, Critchfield (6) states that for sugar maple the shoot length is fixed in the winter bud. A third measure of tree growth rate used is electrical resistance of the cambium (48, 55, 56, 58). But Newbanks and Tattar (34) found these measurements to vary considerably depending on time of year, air temperature, tree diameter, bark blemishes, callus tissue, decay and measurement techniques.

Root Starch Analysis

The histochemical analysis of autumn root starch is another parameter used as a measure of tree health (54). Deciduous species store food reserves as starch (as well as lipids and proteins (37, 40, 64)) in the bark and wood of the stem and the wood of the root (24). The bulk of starch reserve in these species occurs in the root wood (9, 24, 39, 53, 54, 56, 59). On the other hand coniferous and evergreen trees store a large portion of their food reserves in the older foliage (28, 64) with the root reserves being less important (28). Regardless of where a tree stores its reserves the timing of its accumulation and mobilization is similar, with reserves being accumulated in mid-summer to late fall and being mobilized in early spring prior to bud break (52, 57, 63, 64). The reserves are used primarily for the formation of new shoots, secondly for cambial activity and growth and lastly for fruit and seed production (64). In sugar maple root starch is stored as a reserve material in ray parenchyma and in starch storage fiber cells of the xylem (9, 39).

Root starch reserves in sugar maple have been shown by chemical extraction and histochemical methods to decrease following defoliation (37, 38, 40, 59) and to decrease significantly following repeated defoliation (37, 41, 59). Starch reserves in roots of sugar maple and black oak seedlings are lowered by drought and lowered further by drought plus defoliation (37, 42). Thus the quantity of root starch reserves can be used to indicate the current state of trees affected by biotic and abiotic stresses (37, 56, 59). The determination of root starch reserves in deciduous trees has been incorporated into a simple technique which can be used in the field or laboratory (38, 53, 54, 56).

The roots of sugar maple within eight cm of the soil surface grow maximally in March, April and June while later in summer they turn black or brown and become suberized due to soil temperatures over 18-23°C (33). Morrow (33) found that sugar maple roots can grow in winter provided frost does not penetrate below one half inch, though tissue maturation and suberization keep a close pace with this growth. Lyford and Wilson (31) found woody roots of red maple to grow in the upper 25 cm of soil with non-woody root "fans" growing off these and up into the forest floor where they become beadlike via association with vesicular-arbuscular mycorrhizae. Fine root development by shade trees is confounded in the urban environment by the turf with which these roots must compete. Yet, at the same time, these fine roots and their associated mycorrhizae are essential to the survival of trees (22). Root regeneration is optimal in sugar maple following 2,500-3,500 hours of chilling at around 5°C minimum (51, 60). This regeneration could very well be decreased by the mild winter temperatures experienced in the northeastern United States over the past decades (14). Another factor which could decrease the ability of sugar maple to survive in the urban environment is its high root transpiration occurring in dry soil and leading to dehydration of the root tissues (35). This could help explain why drought plays an important role in urban sugar maple decline.

CHAPTER II

METHODS AND MATERIALS

Hosts and Location

Ninety-three urban sugar maples (Acer saccharum Marsh.) were chosen for study in October, 1979, seventy-seven growing in West Springfield, Massachusetts and sixteen growing in the University of Massachusetts, Amherst campus. The trees ranged in diameter 1.4 m above ground from 24.75 cm to 82.5 cm. The maples growing in West Springfield were located in the tree belts along residential streets: forty-eight on Roger's Avenue, eleven on Sherwood Avenue, thirteen on Churchill Road and eight on Harwich Road; all had turf over their roots. The trees growing in the Amherst campus were located near streets, service access roads and sidewalks; all had turf over their roots or bare soil worn from pedestrian traffic.

Root Starch Analysis

During November and December in 1979 and in 1980 three root samples per tree were collected and stored in labelled plastic bags in the freezer. The root samples were collected from buttress roots at least thirty cm down the root from the soil surface using a 1.9 cm (3/4 in.) diameter arch punch and hammer. Some samples were cut from one half to three cm diameter roots growing at least eight cm below the soil surface making sure they originated from the test tree. The type of root sampled depended upon availability and ease of collecting them; some buttress roots were not large enough to sample or small roots might not be readily found. The soil cover made certain the sample consisted of root tissue only and not stem tissue. No attempt was made in 1979 to include in the three samples a certain number of buttress and/or small roots. However, in 1980 at least one buttress root sample was taken from each tree.

In the summer of 1980 the 1979 samples were daily thawed, debarked and trimmed to fit the platform of a sliding microtome. The samples were kept moist in distilled water to soften, and uniform microsections were taken transversely at sixty microns with a sharp knife. The 1980 samples were sectioned in April and June of 1981. All the microsections were stained to detect starch content with an iodine solution consisting of 1.5 g of potassium iodide and 0.3 g of iodine dissolved in 100 ml distilled water. In order to dissolve the iodine, the staining solution was kept on a stirrer overnight. Once prepared the stain had to be kept in an opaque container in the refrigerator. New stain was prepared every thirty days as needed to ensure its reaction with the starch.

The staining procedure (56) was as follows: the microsections from each sample once cut were placed onto a labelled microslide and immediately flooded with the iodine stain. These microsections were blotted dry and then reflooded with stain. The second stain remained on the microsections for at least five minutes to thoroughly stain the starch. The microsections were blotted dry and examined for similarity of staining; usually four were cut from each sample. Two similar microsections were kept and the rest discarded. A drop of glycerin was added to the microsections on the microslide and a coverslip placed on top. The microsections were then held up over a white background and visually rated as either high, medium, low or depleted in starch content (53). Each tree was given one overall root starch rating based on the three sectioned root samples.

Two color transparencies were taken of one stained microsection from each root sample to preserve a record because the stain faded within forty-eight hours. The color transparencies were taken through a dissecting microscope at ten times and twenty times magnification for each microsection. In 1981 a blue daylight filter was used to improve the color of the transparencies taken with Ektachrome 200 film.

The accuracy of the starch content ratings was rechecked through the microscope. High starch ratings were given to root microsections in which all the ray parenchyma, the vessel parenchyma and most of all the xylem parenchyma stained darkly. Medium starch ratings had some xylem parenchyma, all vessel parenchyma and most or all ray parenchyma staining. Low starch ratings were those with some ray parenchyma, most vessel parenchyma and no xylem parenchyma staining. Depleted starch ratings had few to no parenchyma cells staining in the entire section (Fig. 1).

Crown Condition

The sugar maples were given ratings from I through V for decline symptom severity (34) in June of both 1980 and 1981 following full leaf expansion and coloration. Trees were given ratings based on foliage size, color and density; amount of small, medium, large and main dead branches; crown shape and overall appearance. The presence of recent or past large pruning wounds and substantial crown removal were also considered.

Twig Increments

Branches approximately one meter long were collected four per tree, two from the street side and two from the yard side of the upper periphery of the crowns in August 1980. Yearly twig growth was measured in cm from the base of a bud scar to the tip of a terminal bud or base of the next bud scar. Five years of growth were measured encompassing 1980, 1979, 1978, 1977 and 1976.

Fertilization Study

Sugar maples growing in West Springfield were used in

Fig. 1. Root microsections stained with iodine to show starch content. Clockwise from upper left: High, Medium, Low and Depleted.

a fertilization project. In April 1980 complete fertilizer, 10-6-4, 25% ureaform, was applied in drilled holes (approximately 30 cm deep, 158.75 g/hole) in the soil under the outer two thirds of the tree crowns at an approximate rate of 0.35 kg fertilizer per cm of tree diameter 1.4 m above ground (2 lb/in dbh). Actual amounts per tree appear in Appendix 1. Fertilized trees were buffered on each side by unfertilized trees which in turn buffered each side of control trees.

In April 1980, prior to fertilizing, composite soil samples were collected from the street and yard sides of these trees consisting each of four soil auger drillings to approximately twenty cm below the turf cover. The samples were analyzed at the West Experiment Station of the University of Massachusetts, Amherst for pH, calcium, potassium, phosphorus, magnesium, nitrate nitrogen, ammonium nitrogen and soluble salts.

Foliage was removed from the four branches per tree collected from the upper crown in August 1980 and dried in a forced-air oven at 60-70°C for approximately twenty-four hours. Once dried they were ground in a Wiley mill to pass through a twenty-mesh sieve. The composite foliage samples, one per tree, were stored in air-tight jars until February 1981 when they were analyzed for percent dry weight of nitrogen, phosphorus and potassium at the West Experiment Station.

Additional twigs were collected from the trees in the fertilization study in July 1981. Twig growth was measured as previously described for the years 1981, 1980 and 1979 to determine any effect of the fertilizer.

Verticillium Infected Sugar Maples

Ten sugar maples (two on Craig Drive in West Springfield, two on Governor's Drive in the University of Massachusetts, Amherst campus and six in the University nursery) with Verticillium wilt caused by *Verticillium dahliae* Klebahn. were sampled and analyzed for root starch as previously described (Appendix 2).

Root Starch Content of Red, Norway and Silver Maples

Fifteen other maple trees, eight red (*Acer rubrum* L.), four Norway (*A. platanoides* L.) and three silver (*A. saccharinum* L.) were sampled and analyzed for root starch content. Of these five red maples, two Norway maples and three silver maples were growing in the University nursery; one red maple and one Norway maple were growing in the Amherst campus; and two red maples and one Norway maple were growing on Harwich Road in West Springfield. Crown condition and twig increment data were also taken for these trees as previously described (Appendix 3).

CHAPTER III

RESULTS

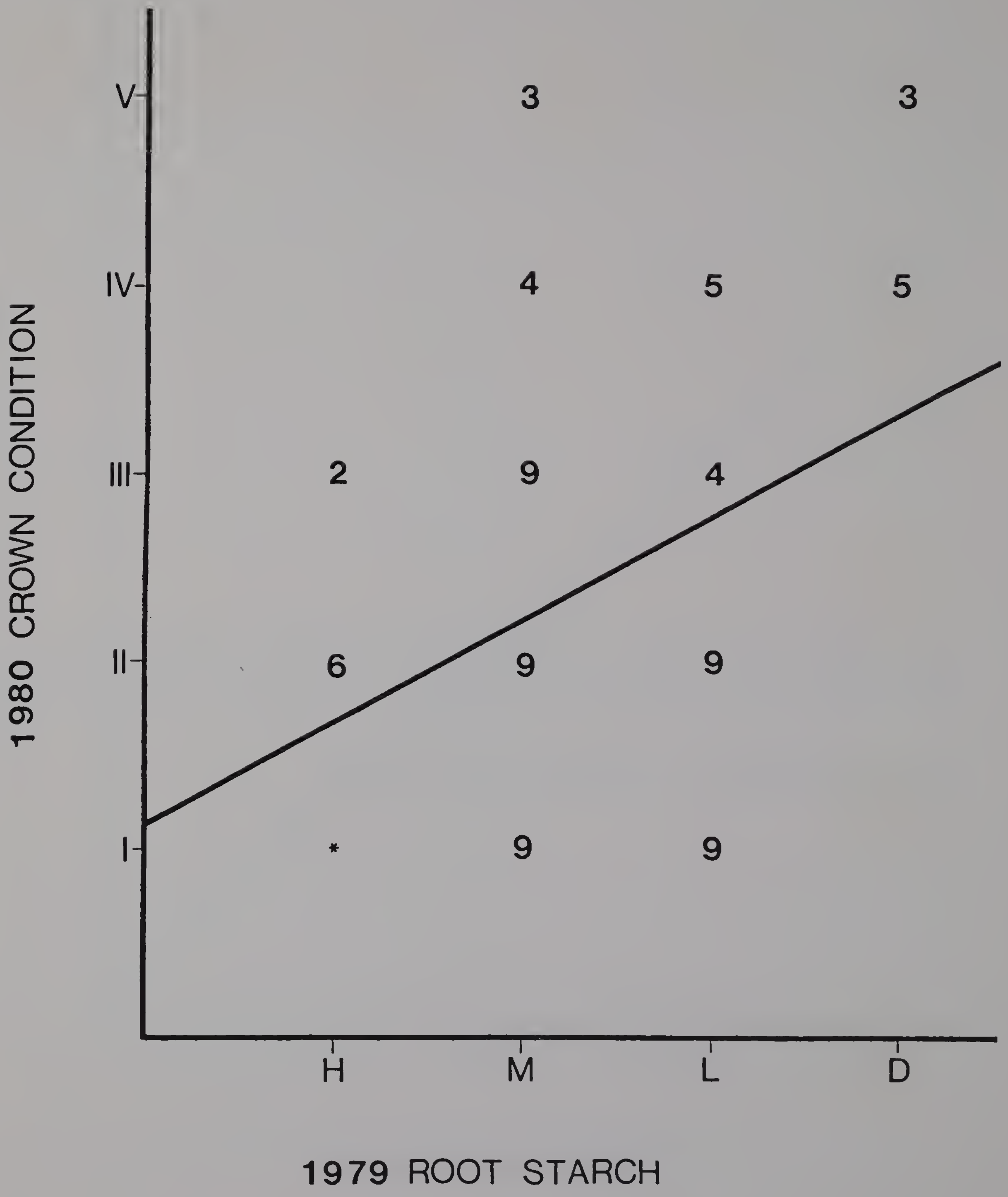
Root Starch Analysis and Crown Condition

The data collected for root starch analysis and crown condition on the sugar maples were statistically analyzed using Pearson's simple correlation and simple linear regression. The relationship between 1980 crown condition and 1979 root starch and between 1981 crown condition and 1980 root starch was sought primarily. The results of the simple linear regression are presented graphically in Fig. 2 and Fig. 3. The correlation coefficients (r) are low for both which indicates that neither root starch content nor crown condition can be fully explained one by the other. However, the two are directly linearly related; as crown condition worsens root starch content decreases. This relationship is shown also in Table 1 where the mean root starch contents were calculated for each crown condition. The second year of data in Fig. 3 shows a higher correlation coefficient than that of the first year of data in Fig. 2. The p value of 0.001 shown in Fig. 2 and Fig. 3 is due to the high number of cases (93) included in the analysis but it also indicates the relationship found is not due to chance.

The relationship between 1980 and 1981 crown conditions and between 1979 and 1980 root starch contents was also

Fig. 2. The relationship between 1980 crown condition and 1979 root starch as shown by simple linear regression.

Numbers on graph indicate numbers of trees falling in each category (* equals one tree).

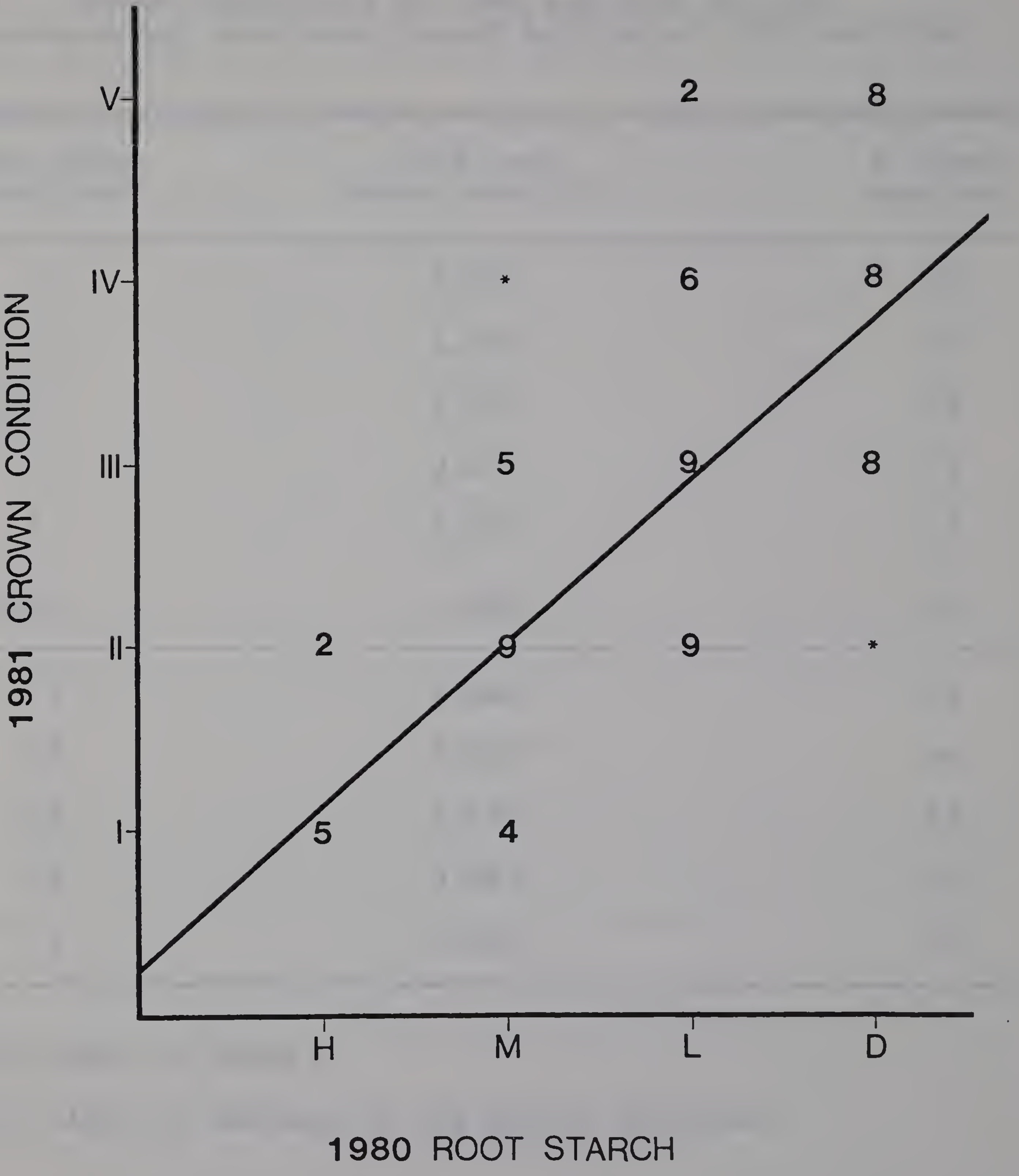


$Y = 1.15657 + 0.53659X$

$r = 0.34212 \quad p = 0.001$

Fig. 3. The relationship between 1981 crown condition and 1980 root starch as shown by simple linear regression.

Numbers on graph indicate numbers of trees falling in each category (* equals one tree).



$$Y = 0.28854 + 0.85097X$$

$$r = 0.58774 \quad p = 0.001$$

TABLE 1

Crown Conditions of 1980 and 1981 and the Corresponding Mean Root Starch Ratings of 1979 and 1980

1980 crown condition*	1979 root starch rating**	# trees sampled
I	2.333	24
II	2.000	33
III	2.125	16
IV	3.071	14
V	3.000	6
1981	1980	#
I	2.444	9
II	2.500	36
III	3.130	23
IV	3.467	15
V	3.800	10

*I, best; V, worst.

**1, high; 2, medium; 3, low and 4, depleted.

sought with Pearson's simple correlation. The correlation coefficient between crown conditions was 0.9075 which is high as would be expected. However, the correlation between root starch contents was only 0.5765. The relationship between the 1979 to 1980 change in root starch content and both the 1980 and 1981 crown conditions and between the change in root starch and the 1980 to 1981 change in crown condition was sought with Pearson's simple correlation. The relationship among these with the strongest correlation ($r = -0.2554$) was that between the change in root starch content and 1981 crown condition. The relationship between the 1980 to 1981 change in crown condition and both the 1979 and 1980 root starch contents was sought with the same test. No strong correlations were found among these.

Overall, crown condition became worse from 1980 to 1981 in thirty-five trees and remained the same in fifty-eight trees. Root starch content ratings decreased from 1979 to 1980 in forty-eight trees, remained the same in forty-three trees and increased in two trees (both from low to medium).

Twig Increments

The relationship between twig increment means for the years 1980 through 1976 and both the 1980 and 1981 crown conditions was sought using oneway analysis of variance and linear trend analysis of variance. This is shown in Tables 2 and 3. The oneway relationship between 1980 crown

TABLE 2

Crown Condition of 1980 and the Twig Increment Means for Years 1980 - 1976

Crown condition*	Twig increment means** (year)				
	1980	1979	1978	1977	1976
I	14.83	16.99	13.93	13.80	9.37
II	9.99	10.74	8.49	11.35	10.07
III	7.22	5.59	6.34	7.32	9.57
IV	5.72	3.65	4.67	3.00	4.49
V	4.31	2.05	2.16	2.58	4.58
Oneway F	7.18	8.99	7.38	7.93	2.07
Significance	0.01	0.01	0.01	0.01	ns
Linear F	26.38	33.49	26.89	30.68	5.16
Significance	0.001	0.001	0.001	0.001	0.05

NOTE: Oneway and linear trend analyses of variance performed on yearly means of twig increments.

* I, best; V, worst.

** Each mean based on four twig measurements.

TABLE 3

Crown Condition of 1981 and the Twig Increment Means for Years 1980 - 1976

Crown condition*	Twig increment means** (year) 1980	1979	1978	1977	1976
I	12.87	13.36	10.57	12.22	7.52
II	12.86	14.22	11.34	12.89	10.77
III	8.47	8.93	7.85	9.90	9.78
IV	6.48	3.80	5.94	3.38	5.35
V	3.36	2.05	2.13	2.78	3.97
Oneway F	6.20	6.74	4.59	7.83	2.88
Significance	0.05	0.05	0.05	0.01	ns
Linear F	23.02	24.23	16.41	26.89	6.40
Significance	0.001	0.001	0.001	0.001	0.05

NOTE: Oneway and linear trend analyses of variance performed on yearly means of twig increments.

* I, best; V, worst.

** Each mean based on four twig measurements.

condition and twig increment means for years 1980, 1979, 1978 and 1977 is highly significant (p = 0.01, Table 2). However, by the year 1976 the oneway relationship has lost significance. The linear trend analysis between these data was found to be very highly significant for years 1980, 1979, 1978 and 1977 (p = 0.001) and significant for the year 1976 (p = 0.05). The oneway relationship between 1981 crown condition and twig increment means for years 1980, 1979 and 1978 is significant (p = 0.05, Table 3), and between 1981 crown condition and the year 1977 is highly significant (p = 0.01). Again, there is no significant oneway relationship between 1981 crown condition and twig increments by the year 1976. For these data also the linear trend was found to be very highly significant for years 1980, 1979, 1978 and 1977 (p = 0.001) and significant for the year 1976 (p = 0.05).

The same statistical analyses as above were used to find a relationship between both the 1979 and the 1980 root starch contents and the twig increment means for 1980 through 1976. No significance was found in the oneway analysis between 1979 root starch and the twig increment means for 1980, 1979, 1978, 1977 and 1976. The linear trend analysis showed a significant relationship between 1979 root starch and twig increment means of year 1980 only (p = 0.05). The oneway analysis between 1980 root starch and yearly twig increment means showed a highly significant relationship between the twig increment mean of year 1980 and 1980 root starch ($p = 0.01$), a significant relationship between twig increment means of years 1979 and 1978 and 1980 root starch ($p = 0.05$) and no significant relationship between years 1977 and 1976 and 1980 root starch. The linear trend analysis for this data showed a highly significant relationship between twig increment means of years 1980 and 1979 and 1980 root starch ($p = 0.01$) although these had significant deviations from the linear trend ($p = 0.05$). The relationship between 1978 and 1977 twig increment means and root starch shown by linear trend analysis was significant ($p = 0.05$). No significant linear trend was found between 1976 twig increment means and 1980 root starch.

Fertilization Study

The soil analyses showed the soils under the sugar maple trees in West Springfield to be, on the average, low in potassium, phosphorus, nitrate nitrogen and ammonium nitrogen as well as calcium. Magnesium content averaged medium to medium-high while soluble salts were either absent or very low with the index not exceeding sixteen. pH ranged from 4.5 to 7.1 with most soil samples having pH between 5.4 and 6.3.

Of the trees in the fertilization study twenty-two were fertilized and twenty were controls or unfertilized. These two groups were analyzed by a paired t-test for differences between them of 1979 to 1980 change in root starch, 1980 to 1981 change in crown condition, 1981 versus 1980 twig increment means, 1981 versus 1979 twig increment means, foliar nitrogen, foliar phosphorus and foliar potassium. No significant differences were found between the two groups for any of the variables listed above. For this reason the fertilized versus control groups were split by crown condition. Selecting the two best together (I plus II) yielded fifteen fertilized and thirteen control trees in the groups. The t-test was run again on the 1981 versus 1980 twig increment means, 1981 versus 1979 twig increment means, foliar nitrogen, foliar phosphorus and foliar potassium. Once more the t-test yielded no significant differences among the two groups, fertilized versus control.

Pearson's simple correlation was used to look for a relationship between the foliar nitrogen, phosphorus and potassium of all the trees in the fertilization study with both the 1980 and the 1981 crown conditions and the 1980 root starch. No strong correlation or significant p value was found for foliar potassium with either crown conditions or root starch. The correlation coefficients for foliar nitrogen with 1980 and 1981 crown conditions and 1980 root starch were -0.5292, -0.4650 and -0.4681 respectively. The correlation coefficients for foliar phosphorus with 1980 and 1981 crown conditions and 1980 root starch were -0.3386, -0.3629 and -0.3825 respectively. The p value for all the above relationships was 0.001. All the above coefficients are negative which indicates an inverse relationship between the magnitude of the foliar nutrients and crown conditions or root starch ratings.

Verticillium Infected Sugar Maples

The results of this work appear in Appendix 2. Overall, trees with Verticillium wilt remained unaffected as to root starch content having either low or medium ratings. The one tree which was depleted of starch for both years had only one live branch remaining.

Root Starch Content of Red, Norway and Silver Maples

No difference was found in the manner in which roots of these maple species stained with iodine for the presence of starch versus the sugar maple roots (Appendix 3). Crown condition could be rated similarly as well, keeping in mind the characteristics unique to healthy red, Norway and silver maples. Twig increments of Norway maple were similar to those of sugar maple with the shoot preformed in the winter bud. Twig increments of red and silver maple are similar to one another with long and short shoots distinctly produced.

CHAPTER IV

DISCUSSION

A relationship between autumn root starch content and spring crown condition of the following year was found to exist in the sugar maples included in this study. This relationship can be expressed linearly so that as crown condition worsens root starch content decreases. Since the correlation coefficients for these relationships are not very high, it can be concluded that root starch content is not fully explained by the crown condition, and the crown condition is not fully explained by the root starch content. Nonetheless, probability is very highly significant; so, it can be concluded that root starch content and crown condition are related to one another not by chance alone. The question may then be asked which of the two best predicts the other. This is best answered by the fact that the 1979 to 1980 change in root starch content is most strongly correlated with the 1981 crown condition. This indicates the change in root starch could predict the 1981 crown condition better than the 1980 to 1981 change in crown condition could predict the 1980 root starch content.

In examining the relationships between one year's crown condition and the following year's, and between one year's root starch content and the following year's two things become apparent. The first is that yearly crown conditions are very strongly correlated with one another. This is to be expected since the decline syndrome in trees takes years to proceed to death or recovery with little dramatic change from one year to the next. The second is that yearly root starch contents were not very strongly correlated with one another. This could indicate root starch content from year to year is more plastic and could therefore be used as a more immediate indicator of tree health.

Another factor to be considered when using crown condition as the sole measure of tree health is that it is a very subjective rating system. Utmost care was used to maintain objective guidelines in rating crown conditions. Ratings can be disguised by removal of dead and dying branches and/or right of way maintenance by utilities. The crowns were rated by only one person which is imperative when decisions must be made about the fate or treatment of declining trees. By contrast, root starch analysis is far less subjective because once trained, anyone can follow the same simple observations to produce accurate, comparable ratings. The only problem with root starch analysis which occurred in this work was caused by the difference between buttress roots and small diameter roots. Buttress roots have support fibers which serve no storage function while small roots do not; this can lead to buttress roots mistakenly given lower ratings. For this reason color photographs of buttress roots were included (Fig. 1) which can be contrasted with the photographs of small roots by Wargo (53).

The third parameter of tree growth used in this research was twig increments. Twig increments are easy to measure, the least subjective and yet the hardest to obtain from very large trees. The linear relationship between 1980 through 1977 twig increments and both years of crown conditions were very highly significant. Therefore, we could use twig increments from sugar maple to augment and lend confidence to crown condition ratings. This relationship falls off by 1976 between the twig increments and crown condition. While if we look at the linear relationship between root starch content and twig increments the only significant one with no significant deviation from the linear trend is that of 1979 root starch and 1980 twig increments. Therefore, we could conclude again that root starch content changes more rapidly than does crown condition since the relationship between twig increments and root starch content holds only one year while that between crown condition holds for four years. The fact that 1979 root starch content is significantly related linearly to 1980 twig increments also lends support to the premise that autumn root starch content can predict the following spring's twig growth and so crown condition.

Because soil analyses were low overall in the major nutrients the complete, 10-6-4 25% ureaform fertilizer was used. Measurements of pH were never higher than 7.1; higher pH has been implicated as a cause of manganese deficiency in declining urban sugar maple trees (25). It is unfortunate that no significant differences were obtained between the fertilized and control trees. This could have been due to the level of fertilizer applied, 0.35 kg/cm diameter at 1.4 m above ground, which was the lowest amount recommended for application to trees. Another reason could have been poor uptake by the roots caused by either reduced occurrence of roots in the soil or reduced solubilization of the fertilizer because of the drought experienced in the area the summer of 1980. Regardless, the correlation coefficients were negative between foliar nitrogen, phosphorus and potassium and both 1980 and 1981 crown conditions and between 1980 root starch. An indirect relationship was expected in these trees and lends support to other research on nutrient deficiencies and sugar maple decline even though there was no significance.

The Verticillium wilt-affected sugar maples did not have reduced food reserves provided sufficient crown remained alive to support the demand of root, shoot and diameter growth. The sectoring of depleted portions in the root microsections stained with iodine for starch is an interesting phenomenon but cannot be explained at this time.

The root starch analysis can readily be applied to red, Norway and silver maples in the Acer genus; crown condition as well providing its subjectivity is kept in mind. Only for Norway maple can twig increments be used as they were for sugar maple. When using twig increments in the study of red and silver maples care must be taken to record only long or only short shoot growth and calculate means accordingly.

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APPENDIX 1

TABLE 4

Actual Approximate Amounts of 10-6-4 25% Ureaform Fertilizer Applied to the Soil Around the Sugar Maples

Tree #	Crown condition 1980*	kg/tree	dbh**
1	II	9.35	25.4
5	II	27.75	74.9
8	II	22.14	59.7
12	II	18.71	50.8
16	II	20.58	55.9
20	I	22.77	61.6
24	IV	21.36	57.8
27	III	15.12	40.6
31	II	25.10	67.9
34	III	33.52	90.8
38	II	22.45	61.0
40	III	25.10	67.9
44	I	26.51	71.8
48	III	28.38	76.8
51	I	8.89	24.1
54	II	12.01	33.0
59	II	12.47	38.1
60	I	17.62	47.6
64	I	21.21	57.2
70	V	17.15	43.2
72	II	25.26	68.6
77	IV	17.15	45.7

* I, best; V, worst.

** Actually diameter at 1.4 m above ground in cm.

APPENDIX 2

TABLE 5

Root Starch Content of *Verticillium dahliae* Klebahn. Infected Sugar Maples

#	dbh*	Location	Starch** 1979	Starch** 1980
1	15.2	West Springfield	Depleted	Depleted
2	18.4	West Springfield	High***	High
3	15.9	Campus	Medium	Low
4	13.3	Campus	Medium	Low
5	12.7	Nursery	High***	Medium***
6	3.8	Nursery	Medium***	High***
7	10.8	Nursery	Medium***	Low***
8	7.6	Nursery	High***	Medium
9	14.0	Nursery	High***	High***
10	8.9	Nursery	High***	Medium

* Actually diameter at 1.4 m above ground in cm.

** Starch ratings based on three root samples per tree.

*** V-shaped or ring-shaped sectors depleted of starch occurred in the root microsections from these trees.

APPENDIX 3

TABLE 6

Root Starch Content, Crown Condition and Twig Increments in cm of Red, Norway and Silver Maples

#	Starch* (year)		Crown condition* (year)			Twig increment (year)				
	1979	1980	1980	1981		1980	1979	1978	1977	1976
				Red Maple						
1	M	D	IV	III	S**	7.0	4.5	3.8	2.8	2.9
					Y**	13.9	9.4	13.1	11.2	3.3
2	M	L	II	II	S	28.5	13.8	13.9	24.1	37.5
					Y	14.3	1.9	9.6	12.2	18.6
3	L	D	V	IV	S	2.9	6.1	2.4	3.5	4.0
					Y	2.2	5.6	3.5	3.6	5.8
4	M	M	I	I	N**	1.8	1.7	2.3	3.1	8.1
5	H	L	I	I	N	2.0	2.7	17.4	23.9	44.5
6	M	L	I	I	N	2.2	15.3	17.0	24.7	20.3
7	H	L	I	I	N	4.3	10.2	13.1	13.7	6.0
8	L	L	I	I	N	19.9	49.0	61.0	--	--
				Norway Maple						
1	M	M	II	II	S	10.2	16.6	20.1	21.7	17.6
					Y	14.3	12.5	15.9	17.1	15.6
2	M	H	III	III	S	1.2	1.1	1.1	1.5	1.5
					Y	17.8	17.2	3.5	3.5	2.6
3	H	L	I	I	N	8.0	6.5	23.0	17.0	22.5
4	M	M	I	I	N	18.0	26.0	23.2	26.3	35.1

TABLE 6 (Continued)

#	Starch* (year)		Crown condition* (year)			Twig increment (year)				
	1979	1980	1980	1981		1980	1979	1978	1977	1976
Silver Maple										
1	M	M	I	I	N	2.9	4.3	15.6	56.0	41.5
2	H	M	I	I	N	5.1	10.5	2.5	51.0	62.0
3	H	L	I	I	N	2.4	4.6	24.0	64.0	--

* H, high; M, medium; L, low; D, depleted. I, best; V, worst.

** S, streetside; Y, yardside; both based on mean of two twig measurements. N, nursery; based on one twig measurement.