JOURNAL OF
ARBORICULTURE

May 1988
Vol. 14, No. 5

WHITE PINE DECLINE: A CASE STUDY FROM VIRGINIA LANDSCAPES

by Michael J. Weaver and R. Jay Stipes

Abstract. Various problems of Eastern white pine *(Pinus strobus)*, primarily in the forest situation, have been observed and examined over the last 80 or so years. These have included causal agents from both biotic (fungi, insects, etc.) and abiotic (gaseous, liquid and solid toxicants) classes; abundant controversy in many cases exists on accurate documentation of the cause and effect relationships. In this study, we report the results of findings made on abiotic factors strongly associated with declining and dying white pine primarily on human-altered sites; these include high soil pH, high soil clay content, shallow and restrictive root growth zones, compacted sôils and disturbed soil horizons that impede lateral and vertical water movement. Additional biotic and abiotic factors were, in some cases, associated with declining trees.

Résumé. Pendant plus de 80 ans, plusieurs chercheurs ont attribué la cause de l'infection et de la mort du *Pinus strobus* L. à une multitude de facteurs causals. Dans la plupart des rapports, un effort fut fait pour Associer un agent causal unique à un syndrome de maladie. Une étude systématique de pins blancs poussant sur des sites modifiés par les humains en Virginie a indiqué un ploblème de dépérissement. C'était particulièrement évident lorsque ces observations furent comparées aux arbres situés sur des sites naturels. Les résultats ont indiqué que le problème pouvait ne pas être causé par un seul agent, mais par un ensemble de facteurs amenant des stress qui agissent en concert pour détériorer la santé d'arbres autrement en santé. La plupart des agents causals associés au dépérissement des pins blancs étaient de nature abiotique incluant un pH élevé, un contenu en argile élévé, un espace racinaire limité, des sols compactés, et des horizons de sol perturbés qui ont probablement occasionné une modification du mouvement de l'eau à travers le sol, tant en profondeur que latéralement. En plus, d'autres facteurs biotiques et abiotiques furent indentifiés, allant des dommages causés par des insectes (à l'arbre ou aux racines) et des dommages causés par la pollution de l'air.

Key words: white pine, decline, stress, *Pinus strobus*, tree diseases.

For over 80 years, numerous investigators have attributed the unknown causes of diseased and dying *Pinus strobus* to a multitude of causal factors. In most reports, an attempt was made to identify a single factor as the disease-causing agent (3, 4, 5, 6, 7, 8, 13, 18, 22, 24, 25, 26, 27).

In the past, most plant disease diagnosis has involved the recognition of individual causal factors as the sole contributors to disease. Although those workers who reported white pine disease problems often speculated that other factors may have been associated with disease, there has been a tendency to categorize one cause to one disease. According to Wallace (23), this "one-cause-one-disease" philosophy has at times been a hindrance to good plant disease diagnosis. The recognition of declines and diebacks in recent years has helped to remove this philosophic boundary from disease diagnosis because more than one stressor is often associated with these syndromes. We also approached the diagnosis of "white pine decline" (WPD) in this study on a suspected multi-stressor basis.

Declines and Diebacks

Houston (9, 10, 11) defined a dieback/decline as a "progressive disease condition that begins when trees are altered initially by stress and continues as they (trees) become invaded by organisms of secondary action." He stated that a stress/host-change/organism attack relationship exists in forest tree declines. In many urban tree declines, repeated and prolonged severe stress can by itself result in loss of tree vigor and can even cause tree death. Both situations are associated with WPD.

Houston (9, 10, 11) linked the onset of diebacks and declines with environmental stress. He defined "stress" as "an environmental pressure, sufficient to bring about changes in the physiology, form, or structure of a tree, that predisposes it to attack by organisms that it would resist under normal conditions." Stress includes biotic and abiotic factors (15, 20). Biotic stress is caused by attacks on plant parts by insects, fungi, nematodes and other living organisms. Abiotic stress can be caused by extremes in weather, gaseous, liquid and solid chemicals, changes in soil physics and chemistry, various damages and modifications made by man and his activities, extremes in nutrient levels, and most importantly, in most cases, extremes in soil moisture levels (14).

Tattar, (21) in 1978, considered declines and diebacks to be synonymous, and described them as complex diseases with causes that can not be attributed to any one agent. He also indicated that a decline was initiated by one or more stresses that deteriorated the health of a tree to a point where any number of secondary pathogens or insects can kill the host.

P.M. Wargo (personal communication, 1980) described the contributors to decline as "initiators" and "finishers." The "insitiators" start the deterioration of a host's health and the "finishers" are the final contributing stressors.

White Pine Decline in Virginia

In Virginia, what we now call "white pine decline" was observed by the junior author for years on this species in landscape plantings (on human-altered sites). The term "human-altered" (HA) is used to describe trees growing on sites tended by humans, and include rural, suburban and urban areas, along streets, around homes, along highways or any place where soil has been disturbed or the natural environment has been altered. Although this problem has probably occurred for as long as man has manipulated the white pine's natural environment, it has not been recognized as a decline until recently (24, 25, 26).

In 1977, a problem was identified in western and northern Virginia where some white pines were declining when grown on HA sites. A pattern of decline was identified after attempting to diagnose the cause of disease of a number of white pines from various parts of the state (24, 25, 26, 27). In some cases, trees died within a few months after initial symptoms were observed, while in other situations trees died gradually over a longer period of time, in some cases over a period of years. In most instances, once tree owners recognized that there was a problem, their trees were already dead or in the latter stages of decline.

We observed two decline syndromes. One was associated with a more rapid death (within a period of several months) and symptoms included chlorosis, wilting, fluxing and necrosis of needles producing a reddish-brown appearance. In the other syndrome, declining trees died slowly (over years) and symptoms included chlorosis, shortened inter-nodal growth, premature annual defoliation causing abscission of all except the current year's needles and thinning of the crown, needle drooping (especially in the winter) and an eventual desiccation of the tree producing a shriveled bark. We suspect that timing of stressor incidence and host physiology and genetics play a significant role in syndrome sequence. A comparison of foliage from a "healthy" and declining white pine is illustrated in Figure 1.

Because WPD seemed to be so prevalent in Virginia, a study was conducted to identify some of the stress factors associated with the problem. Although there were many people who speculated as to the cause of the decline problem, no individual or group had previously recognized the disease or attempted to identify the factors associated with this disease.

Two groups of observations are described in this study: 1) one of trees typical of a "natural" habitat (Jefferson National Forest, VA) and 2) another of trees growing on home landscapes, parks, and other HA sites.

Materials and Methods

A systematic indexing method (using an information indexing form) was developed for collecting data from a group of natural and HA site trees. Over 100 trees were selected from western and northern Virginia and were examined for over 100 variables. Tree age and the amount of time after planting were factors considered when selecting trees for the study. Only two trees were selected that were under age 10 and trees which had not acclimated for a period of at least two years after planting were not chosen for the study.

Data were categorized into growth and environmental components. Tree growth measurements included: height, diameter at breast height (dbh), age, growth rate, and bark, bole, crown, and root qualities.

Environmental or site quality measurements included: aspect (% slope, elevation, slope length, site type, and direction/amount of sunlight), competition (type, % of root zone that competed with other plants, and the competitor's health), amount of damage by humans and weather, type of location (urban, suburban, or rural and campus, park, industry, etc.), traffic flow patterns (vehicular, human, etc.), types of chemicals applied to the sites, sources of air, ground and water pollutants, types of biotic agents, weather patterns, amounts of mycorrhizae, soil qualities for all artificial and natural profiles (including pH, calcium, magnesium, phosphorus, potassium, manganese, zinc, soluble salts, organic matter, organic nitrogen, color, structure, consistence, texture, compaction, mottles, foreign matter, and type of parent material), root zone depth, root mat thickness, and the percent of impedance from man-made structures. Methods used to measure the parameters which presented the best indicators of decline are described below.

Because many of the trees in the study were high value trees, it was necessary to develop methods of non-destructive testing. A large number of the trees were located on the Virginia Tech campus and private property. Also, new methods had to be developed to measure some parameters which had never been documented in the past; many of them could easily be adopted by the layman to evaluate tree health.

Tree growth measurements included: (1) height (using a Blume-Leiss altimeter), (2) dbh (using a standard dbh measuring tape), and (3) interwhorl (-nodal) distances. The inter-whorl measurements were used to determine percent growth rate per year over the last ten years of growth. This rate was developed by totaling the inter-whorl measurements for each tree over a 10-year period and averaging the per year growth rate in percentage of the total. Tree age was measured by counting the numbers of whorls or branch scars from a terminus or intact branch to the base of the tree. In addition, for older and larger trees, an increment borer instrument was used to collect duplicate data in order to confirm the accuracy of the inter-whorl method and aging technique. This was particularly useful when branch scars were obscured by growth in older trees. Increments were easily converted to percent growth using the same method used for conversion of inter-whorl measurements. Increment core samples were measured by dendrochronometry.

General observations were made of the trees' overall health or growth quality. Roots, bole, branches and needles were evaluated for disease symptoms and mechanical damage. The tree root zone was measured by carefully digging in several locations within the "theoretical root zone area" (TRZ) around the tree. The TRZ is the area in which the roots are anticipated to be growing according to current knowledge of tree rooting patterns and was measured by calculating the area from the tree center to the drip line and multiplying

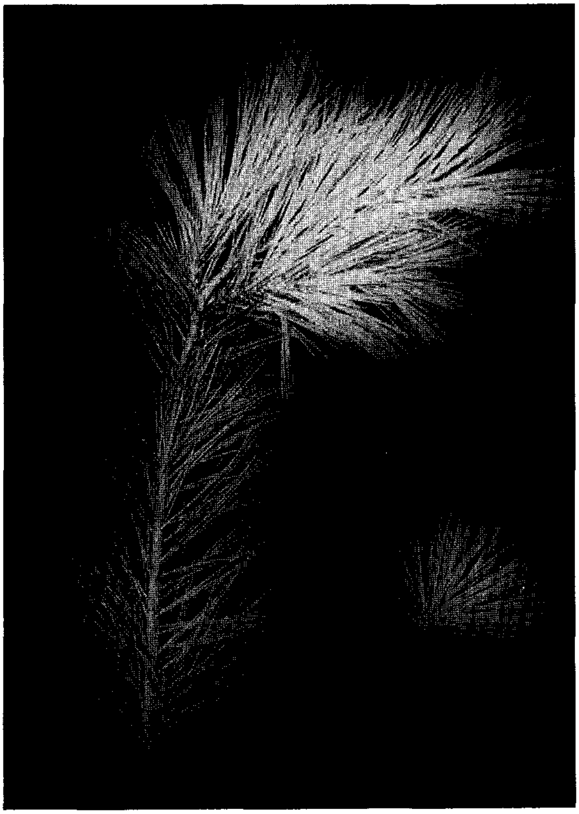

Figure 1. Foliage of declining and "healthy" eastern white pine.

by 1.5, squaring this radius and multiplying times pi (3.14). By knowing the TRZ, one could determine the percent inhibition of the roots that occurred from obstructions such as roads, buildings, sidewalks, other trees, etc. The percent impedance from man-made obstructions was measured separately from competition from other plants.

Root zone depth was measured by digging within the TRZ in several locations and measuring the depth of soil covering the roots, the average depth, maximum depth and the thickness of the root mat. Data were averaged for each observation when taking multiple samples.

The depth of soil covering the roots was a critical observation, since exposed or very shallow roots were often a clue to the capability of roots to penetrate the underlying soil strata. In some cases, a "traffic" pan or other unfavorable soil conditions may have encouraged roots to push to the surface for nutrition, water and growing space.

Root mat thickness was measured by digging through the root mat in several locations and measuring the average depth from the first occurrence of roots until one reached the depth at which they were no longer present. This measurement was done in the feeder root area between the drip line and edge of the TRZ. A root mat was defined as any occurrence of feeder roots in the TRZ.

Needle color was an important indicator of health which was measured by comparison under a standard tungsten light source with the Munsell plant (botanical) color scale (2). A typical Munsell rating would include the color's hue, value and chroma. An example of a rating would be 7.0GY5/6, where 7.0 would be a specific hue sub-division, GY (Green Yellow) would be the hue names, 5/ would be the value or degree of lightness, and /6 would be the degree of saturation or chroma. A small set of trees, six from the natural site and seven from the HA site, were observed monthly for seasonal foliar color changes. Needle samples from each observation (tree) were taken monthly and colors were measured using the Munsell scale and the same method as above.

Old and new growth needles were measured if present on the trees. Old needles were needles older than one year. New needles were the present year's growth.

Soil samples were analyzed for pH, calcium, phosphorous, potassium, magnesium, manganese, zinc, soluble salts, organic matter, and organic nitrogen. Physical characteristics were measured for color (1), structure, consistence, texture, amounts of compaction, presence of mottles, presence of foreign matter, and the type of parent material.

Compaction was determined by observation, finger touch (feel) and by using a Proctor penetrometer. Penetrometer measurements were in pounds per square inch (psi) required to penetrate soil, averaged from 12 successful probings in one square foot. A successful probing was one which did not hit an obstruction such as a rock, soil clod, root, etc. The method is illustrated in Figure 2.

In addition to the above parameters, a complete

Figure 2. Proctor penetrometer method used to measure compaction.

clinical history was compiled on each tree. Tree owners were interviewed to determine the use of pesticides, fertilizers, and watering regimes. Data were also compiled on agents of disease, mycorrhizae, and other abiotic and biotic agents that may have caused decline.

Results and Discussion

After extensive testing, a variation of parameters appeared between natural and HA site trees. The following is a summary of the factors which produced an obvious variation between the two test groups. In most cases, statistical analysis was used only to measure the interaction of certain stress parameters. An exception was the use of multiple regression analysis to determine a correlation between age and dbh, vs. tree height. Details of this analysis will be discussed below under tree growth. "Discrim" analysis was used to weigh each parameter to determine if a particular observation between the two groups fit either a "decline" or "non-decline" set of criteria, based on those qualities of tree growth and site quality. "Discrim" analysis did not prove or disprove the hypothesis that trees on HA sites were associated with decline and eventual death or vice versa. Therefore the results and examples of the statistical method will not be shown in this article.

Differences in tree growth. Tree growth indicators were weighed against a group of site quality and disease indicators to determine a correlation. A height vs. age index seemed to be the most reliable indicator for tree growth quality. However, some consideration was given to the effect of shading on open-grown trees (such as some of those on HA sites) vs. high-density stand trees (such as those grown on natural sites). There was some evidence that this hypothesis may have been unfounded since trees on some HA sites were close-grown at about the same stand density as natural site trees and were still shorter than their forest (natural site) counterparts of similar age. However, when a comparison was made of the regression analyses for height vs. age and dbh vs. age it became evident that natural site trees were taller and more slender.

Tree age for natural site trees ranged from 33 to 75 (average = 55) years and tree age for HA site trees ranged from 7 to 75 (average = 29.8) years. Tree height for natural site trees ranged from 16 to 34 (average = 27.9) meters and for HA site trees ranged from 1.8 to 26.8 (average = 12.4) meters. Tree dbh for natural site trees ranged from 245 to 790 (average = 487) millimeters and for HA site trees ranged from 10 to 1350 (average = 349.1) millimeters. Height and dbh varied according to age and because of this, these data did not produce a good correlation with tree health or between sites.

The inter-whorl(-nodal) measurements plotted as percent growth per year over a 10-year-period seemed to be a more reliable record of growth history. Inter-whorl measurements can easily be conducted by arborists and tree owners to determine a tree's growth history. These measurements reveal a pattern similar to tree growth ring analysis, except they can be obtained without damaging the tree or the need for special tools. These data are averaged into a chart illustrated in Figure 3.

Parker (19) has indicated some fluctuation of needle color during the growth cycle of white pine. In this study, however, we found marked color changes in HA site trees which developed the "winter yellows." Trees on good quality and natural sites tended to exhibit blue-green foliage which did not change drastically over the growth cycle. Figure 4 indicates the color changes in the growth cycle of trees on HA and natural sites.

Even though several methods were tried and the results seemed to produce reliable information, a single, suitable, non-destructive measure of growth quality for this type of study has not yet been found and only several indicators weighed together may prove reliable. However, many of the tree growth indicators (particularly general observations) provided evidence that most trees on the selected HA sites in this study were in "poor health."

Competitive growth factors. Competition and shading were present on most HA sites, with turf grass being a major competitor with feeder roots for nutrients and water. Although shading and competition from other tree species were present in the forest, turf grass was not and was considered a factor of great importance to initiation of decline, particularly since the natural habitats had an acidic layer of needle mulch and humus over the soils containing the feeder roots. This natural mulch did much to reduce soil compaction, promote the movement of water to the roots, maintain low soil pH, and promote proper soil aeration and cooling during the summer months. The turf management methods used on most HA sites preclude any natural qualities which might enhance white pine growth. Liming, dethatching, mowing and fertilization are all geared to grow better turf grass while compacting the soil. In addition, most building developers move only enough good quality soils into an HA site to allow for proper turf grass growth. Trees are usually ignored as just another plant that can survive anywhere turf can be grown properly.

The quality of growth of trees located on HA sites was poor for the majority of trees observed in this study. There were a few exceptions to this observation since not all trees on poor quality sites were declining. "Healthy" trees had thicker root mats than declining trees. When trees on many poor quality HA sites grew older and larger they outgrew their rooting area, moisture became a limiting factor, and decline was imminent.

Many trees on poor quality sites still appearing in good condition at the time of this study have been observed since to be in a state of decline; some have either died or were removed from the time of this study in 1979 until the present is illustrated in Figure 5; it was in relatively good condition when the photograph in Figure 5A was taken in 1979. A second photograph (Figure 5B), taken in May, 1987, provides evidence of the decline syndrome. An 8-year period has allowed the tree to decline gradually; having a chlorotic and thinned crown. Many of the other symptoms from this tree included shriveled bark and shortened internodal growth (also evident in 1979). The 1979 study did indicate that this tree was declining and the site quality was not conducive to recovery. A shallow and limited rooting habitat, and heat and moisture stress were all contributing factors to this tree's demise.

Soil factors. Soils on HA sites had generally disturbed profiles both physically and chemically when compared to the natural habitat. A graphic comparison of two soil profiles, one from a typical natural site and the other form a typical HA site is illustrated in Figure 6. Soil strata on many HA sites were composed of displaced subsoils which had high clay content (averaging 37.05% above and in the root zones and 43.99% for soils beneath the roots) and high pH (averaging 6.95). By comparison, soil strata from the natural site consisted of undisturbed soils with low clay content (17.76% and 17.95% respectively) and low soil pH (averaging 5.5). These data are compared in Figure 7 and 8.

Although they were high, averages for HA site data did not reveal the complete story. Poorer quality HA sites had soil pH readings as high as 8.5 and clay content as high as 80%. These readings, although extreme, were consistent with poor growth observations on many of the trees

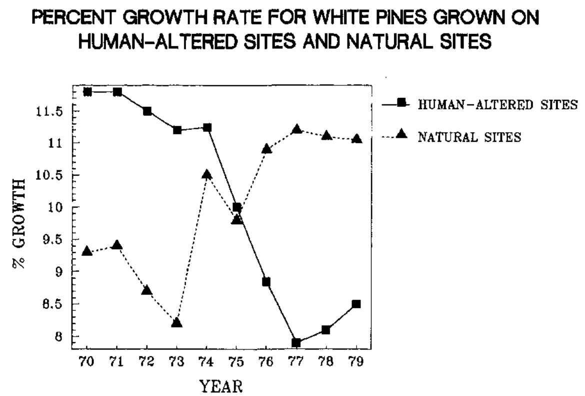

Figure 3. The average percent growth rate per year over a 10-year period based on inter-whorl growth measurements made on the total observations at human-altered and natural sites.

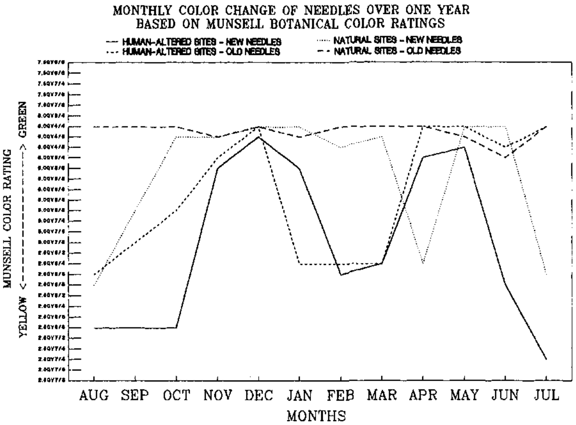

Figure 4. A comparison of the seasonal foliar color change data taken monthly over a period of one year from two observations; one from a human-altered site and the other from a natural site.

located on these sites. Highly compacted soils were observed above and beneath many HA site tree root zones. Penetrometer readings for a small subset of HA and natural site trees indicated a wide variation in compaction between the two groups. Readings were taken at three HA sites with very clayey soil textures; these averaged 1161.7 psi for penetration in the upper layers (readings taken at 3-4 cm) and 1806.1 psi for penetration of deeper layers (readings taken below 10 cm). There were no definite soil horizons in these soils, but there was usually a delineation between a less clayey topsoil layer and a more clayey subsoil. Readings taken on three HA sites with loamy soil texture indicated that these soils were also highly compacted with readings of 766.0 psi for upper layers and 620.0 psi for deeper layers. For comparison, penetrometer readings for soils under four trees at the natural site averaged 138.3 psi for the A horizon (readings at 3-4 cm) and 273.2 psi for the B horizon (readings below 8-10 cm). Soil texture on this site was a sandy clay loam and no sources of compaction were evident except for the weight of the soil itself. Soil compaction on HA sites was compounded by foot and vehicular traffic. It was obvious that soil texture affected the penetrometer readings. Soils with higher clay content seemed to have higher penetrometer readings. An example of compacted loamy soils from an HA site is illustrated in Figure 9.

Mechanical damage was especially hazardous to tree roots when soils were disturbed on sites with established tree plantings (12). In some cases, soils were also chemically distrubed by concentrations of salts from deicing chemicals, fertilizers, lime, and pollutants of various types. None of these factors was consistent throughout the observations or treatments.

Lateral and vertical root impedance was present

Figure 5. Photographs taken of a white pine in the early stages of decline (left) in 1979 and in the latter stages of decline (right) in 1987.

and probably caused by poor choice of planting locations and methods. Disturbances were caused by construction activities which reduced existing root zones and trees growing into areas restricted by physical barriers (17). Root mat thicknesses varied greatly between the site groups with mats averaging 17.1 cm for HA sites and 45.5 cm for trees grown on natural sites. The maximum rooting depth had much to do with these data. Maximum root depth for HA site trees averaged 25.8 cm while for natural site trees it averaged 47.0 cm. These figures make it obvious why root mat thicknesses varied so much between the two site groups. The soils under HA site trees were often so high in clay content at the maximum depth that air, water and nutrients were probably limited to feeder roots. In addition, it was suspected that these soils were heavily compacted, since roots were often observed in a concentrated mat at the line where the thin topsoil layer separated from the clayey subsoil layer. Roots in this area had a flattened appearance (similar to *Armillaria mellea rhizomorphs)* as if they were constricted by some force. A comparison of the average and maximum root mat depths and root mat thicknesses are presented in Figure 10.

The major factor associated with poor quality growing sites was the changing of natural soil profiles by construction activities. The usual situation observed in this study was altering of the soils before planting. Trees were usually planted in an area after construction of buildings and roads. Original tree inhabitants were either removed in this process or damaged to a point where they died at a later date. The original site was usually

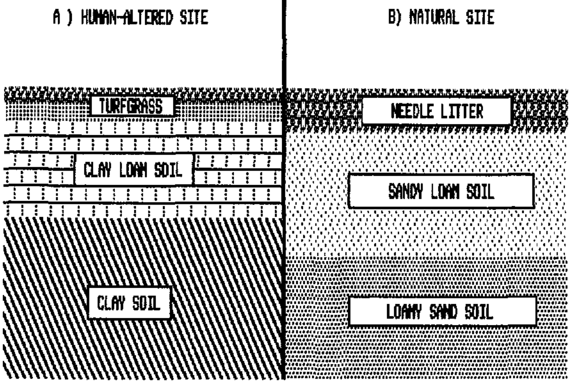

Figure 6. A comparison of soil profiles from a typical human-altered site (A) and from a typical natural site (B).

drastically altered by this activity.

Soil disturbances followed several patterns. One was where deep subsoils were dug up and spread out over the original profiles to reshape a site. In these cases, soils were usually extremely high in clay, were mixed with broken-up parent material (which may have raised the pH if it were a limestone), and were compacted by earth-moving equipment which may have formed a claypan. When sites were landscaped, a thin layer of topsoil (usually 6-10 cm) was graded over these soils where turf grass flourished (which in some cases may have been due to heavy fertilization and liming) but white pines could not survive for a long period of time. One example of such a site was

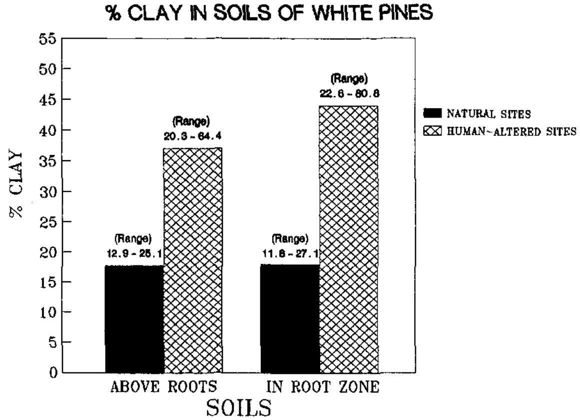

Figure 7. A comparison of averages for soil clay content data above and within the root zones from the total observations made at human-altered and natural sites.

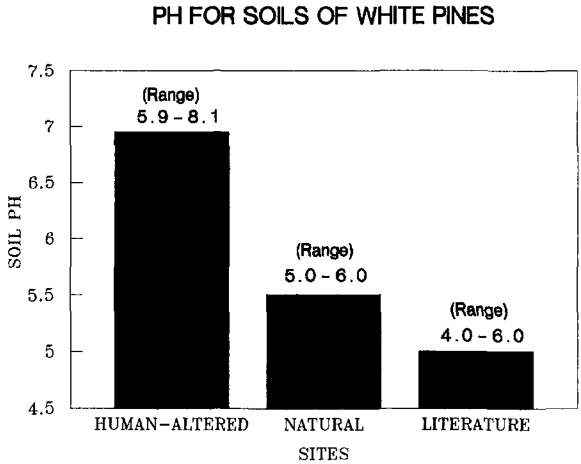

Figure 8. A comparison of averages of soil pH data from the total observations made at human-altered and natural sites and from the literature data.

where a structure was being built and the soils from the foundation were graded out over the surrounding landscape.

A second type of disturbance was where existing profiles were graded down, mixed-up, reshaped and landscaped. This also pulled up a deeper clayey (subsoil) layer which was often mixed-up with the lighter upper layers. An example of such a disturbance was the reshaping of a site to locate a road, sidewalk, or structure.

Where soils were disturbed, natural soil water movement patterns could have been altered in several ways. Moving heavy textured soils into an area could create artificial stratification which could restrict downward water movement to roots. In addition, the use of heavy construction equipment could compact these soils which could further restrict percolation and also leave ruts which could divert water away from roots after it percolated down from above. It is possible that these channels (ruts) which were once open ditches could continue to function as such and alter water flow even after being covered with lighter topsoils. The hypothesis could explain (in some cases) why two trees side by side may have completely different growth quality.

Both disturbance patterns created situations where root growth was inhibited in certain areas of the TRZ. Except in extreme cases, it was more likely that root growth was inhibited in these soils due to the unavailability of oxygen, nutrients and water rather than an inability of roots to penetrate the soils (16). In other cases, water may not have percolated down as fast as it should have and during periods of high moisture may have created an aeration problem to the roots (28). If these factors were present they were probably most important during times of moisture extremes.

Other stress factors. Other environmental disturbances and factors probably work in concert with the above factors to reduce the quality of growth in the traditional tree and turf landscape situation. Additional abiotic stresses, other than those listed above, included mechanical damage to the aerial tree parts by man and nature and chemical injury to the aerial parts by oxidants and off-target pesticides.

It appeared that after the abiotic stress factors initiated decline, a number of secondary biotic agents came into play and continued to weaken declining trees until they followed the course of either a short or prolonged decline syndrome. Examples of pests found in large numbers include the white pine aphid *(Cinara strobus)*, pine bark aphid (adelgid) (*Pineus strobi)* and a root aphid (*Prociphilus* sp.). There were a number of other insects and other pests found on HA site trees, but not consistently throughout this study.

The first discovery of the pinewood nematode *(Bursaphelenchus xylophilus)* in Virginia was from an HA site tree in Lexington, VA. The role the nematode plays in WPD, if any, is unknown, although sample counts from study trees and other records do not indicate that it alone is a significant problem in Eastern white pine. This and

Figure 9. Compacted (loamy) soils from a human-altered site.

COMPARISON OF ROOT MAT DATA IN WHITE PINE

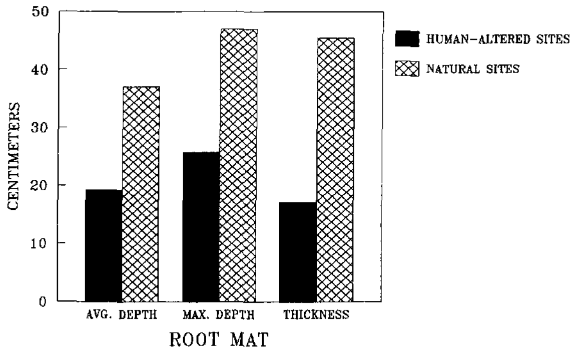

Figure 10. A comparison of the averages of root mat depth and thickness data from the total observations made at human-altered and natural sites.

the insects described above are illustrated in Figure 11.

Conclusion

A number of factors, after combining field observations with laboratory analyses, were found associated with trees on most HA sites and could be suspected as decline-causing factors. Several of these factors were also present at times in the natural sites but never occurred in concert with others.

The factors associated with WPD were those discovered in this study. However, there was the overlying concern that other unknown factors could have played a role in the WPD syndromes. For example, the numbers of potential insect and nematode vectors aroused suspicions that perhaps a virus was involved in the complex. Unfortunately, time and resources limited any further studies to address all possibilities.

This study was an attempt to enumerate the many stress factors associated with a typical decline problem. It was not the purpose of this study to establish that all HA sites are potential decline sites. If HA sites are maintained in a manner similar to a natural site then white pines and other sensitive plants should do well. However, if landscaping practices alter the natural habitat factors, white pines planted in these sites have a poor chance for long-term survival. Thousands of dollars are spent annually replacing trees because many potential stress-causing factors are ignored by tree owners, nurserymen, landscape planners and arborists. These factors must be taken into account if proper management is to occur. In the case of WPD, there are two approaches to management of the disease; prevention and therapy.

Disease Management

Prevention. With WPD, as with all diseases, the best management method is prevention. Prevention methods can be applied either at pre-plant or post-plant.

The pre-plant methods encompass site selection and preparation. The assessment of the site quality and species to be located in a particular site should be a routine part of landscape planning. This process is especially important when choosing a sensitive species such as the Eastern white pine as a planting material for a site. One should always select this species for use in its natural range in undisturbed soils or in soils conducive to good growth. When site alteration is necessary, proper education of construction personnel and architects can help to minimize the deterioration of site quality.

Site capacity to sustain tree growth is often ignored when planting and attempting to predict potential growth quality. If the site capacity restricts root growth, a tree will grow well until it reaches a certain growth threshold where the biomass of shoots exceeds the capability of the root mass to sustain increased growth. At this point, a tree can be weakened and decline in health. To strengthen this statement, one need only compare it with the "pot-bound plant" analogy in which the gardener knows that a plant will not grow properly if it outgrows its pot. The gardener must recognize this need and re-pot the plant in a proper-size pot to maintain the plant's health. Unfortunately, with a field site, the plant (in this case, a "pot-bound" white pine tree) can not be readily re-potted every time it outgrows its pot's (site) capacity. Only proper site planning can overcome this deficiency.

If after following the pre-plant considerations, you choose to plant white pine, a number of post-plant preventatives can be employed to reduce the risk of decline.

1. Maintaining proper soil moisture at levels which prevent drought or water-logging is critical.
2. Needles should be allowed to accumulate under trees to establish a natural mulch or duff layer in the feeder root area. It is especially important that needle mulch be allowed to build-up under trees in lieu of established turf grass. This improves the rooting area and eliminates an active competitor (turf) with white pine feeder roots.
3. It is very important to maintain an acid soil pH. Trees with an alkaline pH will develop an iron chlorosis and this variation will also adversely affect nutrient up-take and other physiological functions.
4. Trees should be fertilized using conventional regimens as with other landscape trees.
5. Arthropod pests should be controlled,

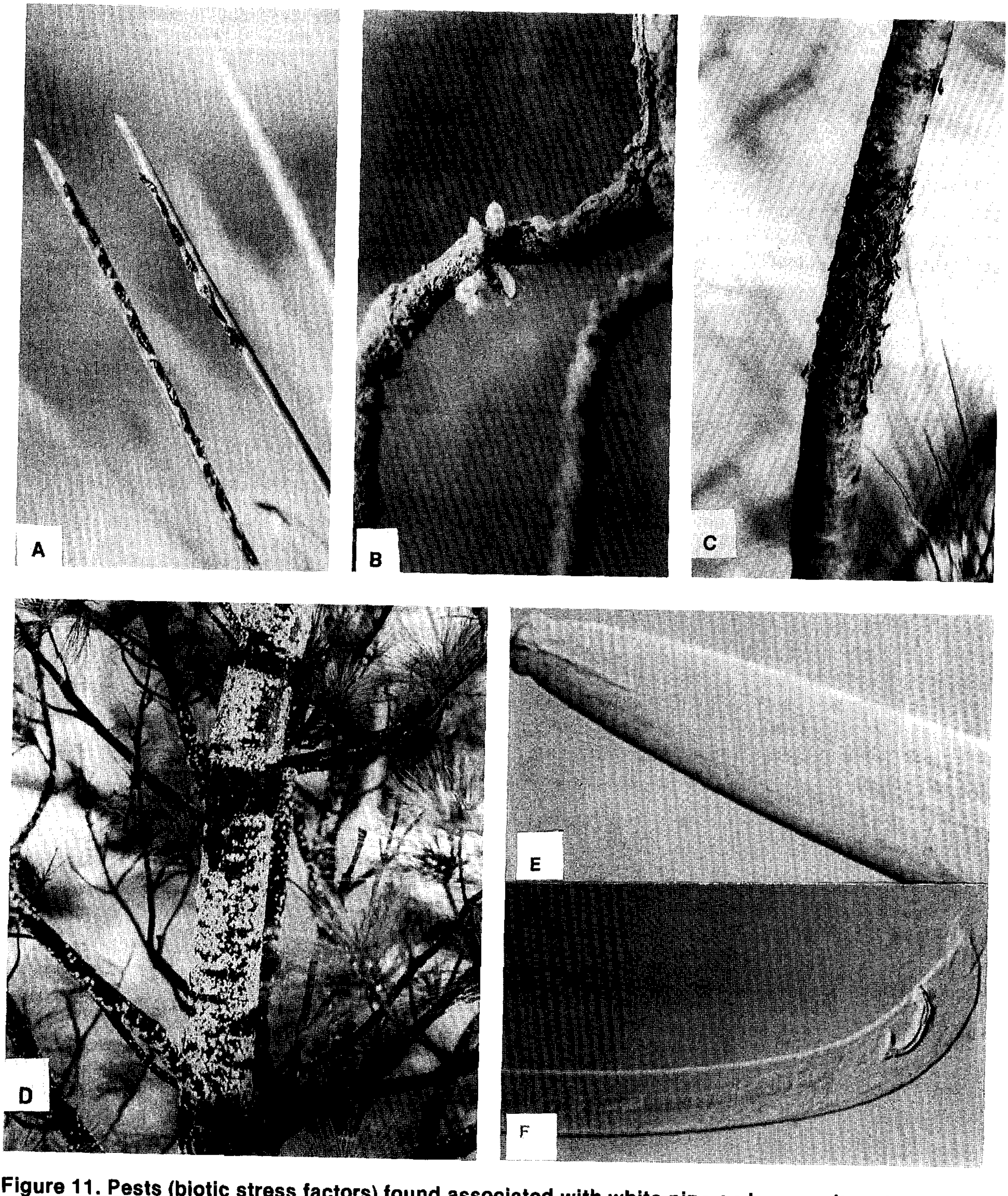

Figure 11. Pests (biotic stress factors) found associated with white pine on *human-altered sites:* (A) white pine aphid—eggs, (B) root aphids (Prociphilus sp.), (C) white pine aphids—adults, (D) pine bark aphids (adelgid), (E) pinewood nematode—*anterior* view, *and* (F) pinewood nematode—posterior view (male).

especially to prevent vectors from introducing pathogenic microorganisms. For example, in the past, lindane was applied in the basal trunk area to preclude attack by certain insects that might vector disease-causing organisms (i.e.—*Leptographium* spp.).

Therapy. If one must cope with decline in established tree communities on HA sites, remedial procedures can be invoked. When soil pH is elevated, acidification with sulfur, aluminum sulfate or another appropriate agents can be carried out. Soil compaction can be mitigated with a variety of soil aerification procedures. Supplemental watering and mulching should be done when needed. At a point where trees have been declining over period of years, some positive response can be encouraged by root watering and feeding.

However, there is a point when trees will decline to an aesthetic eyesore and dependent upon the site will have to be removed. If one replants such a site, one must not make the same mistake twice and replace white pine with white pine. There are many more tolerant evergreen species on the market which will do well in such a site. These include: *Thuja* spp., X *Cupressocyparis leylandii, Juniperus virginiana, Pinus virginiana* and several other *Pinus* species. Although some are not as pleasing to the eye as white pine, they are more functional and resistant to many stress factors.

Literature Cited

1. Anonymous. 1975. Munsell soil color charts. Munsell Color, Baltimore, MD. 25pp.
2. Anonymous. 1977. Munsell color charts for plant tissues. 2nd edition. Munsell Color, Baltimore, MD. 23pp.
3. Campana, R.J. 1952. White pine needle blight and *Corticium galactinum* (Fries) Burt. Ph.D. Dissertation. Yale University. New Haven, Conn. 135pp.
4. Campana, R.J. 1953. *Corticium galactinum and white pine needle blight.* (Abstr.) Phytopathology 43:468.
5. Campana, R.J. 1954. *Corticium galactinum does not cause white pine needle blight.* Plant Dis. Reptr. 38:297-303.
6. Campana, R.J. 1962. *Definitive patterns of white pine needle blight.* (Abstr.) Phytopathology 52:5.
7. Dana, S.T. 1908. Extent and importance of the white pine blight. U.S. For. Serv. Leaflet. 4pp.
8. Davidson, A.G. 1954. Decline in vigor of white pine. Annu. Rep. For. Insect and Disease Survey, Can. For. 1953, 1954:24.
9. Houston, D.R. 1967. *The dieback and decline of northeastern hardwoods.* Trees Mag. 28:12-14.
10. Houston, D.R. 1973. *dieback and declines: Diseases initiated by stress, including defoliation.* Proc. Int. Shade Tree Conf. 49:73-76.
11. Houston, D.R. 1974. *Diagnosing and preventing diebacks and declines of urban trees: Lessons from some forest counterparts.* Morton Arboretum Quarterly 10:55-59.
12. Howe, V.K. 1974. *Site changes and root damage: Some problems with oaks.* Morton Arboretum Quarterly 10:49-54.
13. Kotheimer, J.B. 1967. Physiological factors in the etiology and alleviation of salt-induced decline of roadside maples and pines. (Abstr.) Dissert. Abstr. 28:760-761.
14. Kozlowski, T.T. 1958. *Water relations and growth of trees.* J. For. 56:498-502.
15. Levitt, J.J. 1972. Response of Plants to Environmental Stresses. Academic Press, New York. 697pp.
16. Lindahl, R.B., and Lunt, H.A. 1954. *The effect of soil profile inversion on tree growth and soil properties.* J. For. 52:96-103.
17. Lutz, H.J., Little, S. and Ely, J.B. 1937. The influence of soil profile horizons on root distribution of white pine (*Pinus strobus* L.). Yale Univ., School Forestry Bull. 44:1-74.
18. McKenzie, M.A. 1955. Needle blight, mystery disease of eastern white pine. Res. in Review, Univ. Mass. 4:4-5.
19. Parker, J. 1959. *Seasonal changes in white pine leaves: A comparison of cold resistance to free sugar fluctuations.* Bot. Gaz. 121:146-150.
20. Schoeneweiss, D.F. 1975. *Predisposition, stress and plant disease.* Annu. Rev. Phytopathol. 13:193-211.
21. Tattar, T.A. 1978. Diseases of Shade Trees. Academic Press, New York. 361pp.
22. Toole, E.R. 1949. *White pine blight in the Southeast.* J. For. 47:378-382.
23. Wallace, H.R. 1978. *The diagnosis of plant disease of complex etiology.* Annu. Rev. Phytopathol. 16:379-402.
24. Weaver, M.J. 1982. The etiology of the decline of Eastern white pine (*Pinus strobus* L.) on Virginia landscapes: A survey of stress factors. Ph.D. Dissertation. Va. Polytechnic Institute and State Univ., Blacksburg. 273pp.
25. Weaver, M.J., Stipes, R.J., and Amos, D.F. 1980. *Decline of Pinus strobus L. on landscapes in Virginia.* (Abstr.) Va. J. Sci. 31:108.
26. Weaver, M.J., Stipes, R.J., Amos, D.F., and Heikkenen, H.J. 1981. *Factors associated with declining eastern white pine, Pinus strobus, on Virginia landscapes.* (Abstr.) Phytopathology 71:772.
27. Weaver, M.J., Fox, J.A., Dow, R.L., and Stipes, R.J. 1981. *Pinewood nematode found associated with landscape pines in Virginia.* Phytopathology 71:772.
28. Yelenosky, G. 1964. The tolerance of trees to poor soil aeration. (Abstr.) Dissert. Abstr. 25:734-735.

Assistant Professor and Professor
Department of Plant Pathology, Physiology and Weed Science
Virginia Polytechnic Institute
Blacksburg, Virginia 24061