

EFFECTS OF SOIL pH, ROOT DENSITY, AND TREE GROWTH REGULATOR TREATMENTS ON PIN OAK CHLOROSIS

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Abstract. A relationship between chlorosis and soil pH or fine root development could not be established for pin oaks (*Quercus palustris*) growing on highly disturbed sites along streets and on a less disturbed golf course site. Regression coefficients were low ($P \leq 0.28$) and not significant ($P \leq 0.58$) in all cases. Soil injection of 0.8 g/cm paclobutrazol (PBZ) resulted in a significant increase in fine root density on yellow golf course trees compared to controls and significant greening on yellow street trees compared to untreated controls over a 4-year period. Root density was improved by PBZ treatment on the golf course site where the soil was generally better for root growth. The effect on color was most pronounced on street sites where chlorosis development and decline were progressing rapidly. Untreated green golf course trees did not develop chlorosis rapidly enough to show conclusively that the growth regulator treatment could help to stabilize the trees. Little color or root density improvement was expected from the treatments on healthy green trees.

Key Words. Chlorosis; iron deficiency; soil pH; root development; pin oak; *Quercus palustris*.

Chlorosis of pin oaks (*Quercus palustris*) is a common problem in developed landscapes (Wysong et al. 1989; University of Illinois Extension 1996). Symptoms may include yellowish green to golden yellow coloration of interveinal leaf tissues, while the network of veins remains green. If severe, leaves may be dwarfed, turn ivory colored, and appear scorched along the margins; or angular brown spots may develop between the veins. Such leaves eventually curl, wither, and drop prematurely (University of Illinois Extension 1996).

The cause of chlorosis in pin oaks is most commonly attributed to an iron deficiency caused by high-pH soils. This assumption stems primarily from leaf color responses following soil or trunk application of various iron compounds (Himelick and Himelick 1980; Messenger 1986). Iron is an essential element for plant growth required for the formation of chlorophyll. Iron is usable to plants only as the Fe^{++} ion, and availability of this form in the soil decreases with increasing pH. Published reports of the critical pH value over which iron deficiency and chlorosis occur in pin oak vary from 6.2 (Messenger 1984) to 6.7 (University of Illinois Extension 1996) to 7.5 (Wysong et al. 1989). Messenger (1984) reported significantly higher pH soils to 45 cm (18 in.) deep associated with yellow trees. Himelick and Himelick (1980) found no correlation between

chlorosis and pH in the upper 15 cm (6 in.) of soil. Other factors have also been reported to contribute to chlorosis, including compacted soils, poor drainage, low temperature, high levels of macronutrients, and high macronutrient–micronutrient ratios (Jones 1972; Messenger 1983, 1984; Wysong et al. 1989; University of Illinois Extension 1996).

Root injury and disease can also cause chlorosis. If a tree's root system is underdeveloped, it is logical that that tree will have difficulty absorbing nutrients, including Fe^{++} , from the soil. Chlorosis can be induced in pin oaks growing on a favorable site by severing their roots. In a study of root injury to pin oaks (Watson 1998), chlorosis developed after significant portions of the root systems of healthy trees were severed. The green color returned over several years as the root system regenerated (unpublished data from the study). Reduction of chlorosis in white oaks (*Quercus alba*) was associated with improved root development after mulching (Himelick and Watson 1990). Chlorosis of spruces (*Picea abies*) was directly linked to root and butt root disease caused by *Heterobasidion annosum* (Tomiczek 1995).

If inadequate root development can be a contributing factor to pin oak chlorosis, then improving root development should reduce chlorosis. The tree growth regulators paclobutrazol (PBZ) and flurprimidol (FPD) have been shown to improve root development of pin oaks and other tree species (Bausher and Yelenosky 1986; Wang and Faust 1986; Ashokan et al. 1995; Watson 1996, 2001). Foliar greening is commonly observed after application of tree growth regulators such as PBZ and FPD (Gilliam et al. 1988). The objective of this study was to test these tree growth regulators as a treatment for pin oak chlorosis based on changes in root development and color previously associated with such treatments.

MATERIALS AND METHODS

Both green and chlorotic pin oaks were identified in front of residential properties (typical U.S. Midwest urban soils, highly variable and disturbed, compacted, high clay content) and on a golf course (Morley silt loam and Markham silt loam) in Naperville, Illinois. These will be referred to as "street" and "golf course" sites, respectively. Sixty golf course trees and 95 street trees were used in the study. Because there were unequal numbers of yellow and green trees available, the number of replications varied from 7 to 8 for golf course trees, and 9 to 14 for street trees.

Trunk diameters averaged 27.6 cm (11 in.) for street trees and 43.2 cm (17.3 in.) for golf course trees. Foliage color was rated on a scale of 1 to 10 (Table 1). If a tree was not uniform in color, the most consistent shade of yellow was rated. Yellow trees were those rated less than 6. Trees rated 6 and above were considered to be green. To minimize subjectivity, color was rated independently by two persons, and the ratings were averaged.

Table 1. Rating scale used to evaluate color of pin oaks (after Himelick and Himelick 1980).

Scale	Leaf description
10	extremely dark green, not normal
9	very deep green, darker than normal for most species
8	deep green, normal for some species
7	green, normal for many species (normal for pin oaks)
6	somewhat off-color, not truly chlorotic
5	yellowish green
4	golden yellow
3	pale yellow to ivory, sometimes scorched along the margins, some dieback
2	dwarfed, curled, wither, extensive dieback
1	extreme symptoms, nearly dead

Soil pH of the upper 15 cm (6 in.) of soil within the drip line was determined using a 1:1 volume ratio of soil to water and a glass electrode pH meter. At the same time, one core sample was taken 2 m (6.6 ft) from each tree for analysis of root density. Roots were washed from the 15 cm deep, 6 cm (2.4 in.) diameter soil cores, and root length was measured and converted to root density with a WinRhizo system (Regent Instruments, Québec City, QC).

Linear regression was used to determine the relationship between pH and color and between root density and color ($P \leq 0.05$). T-tests were used to compare soil pH and root density ($P \leq 0.05$) of yellow and green trees before treatment (SigmaStat 2.0, SPSS Science, Chicago, IL).

PBZ (Profile 2SC®, Dow AgroSciences, Indianapolis, IN) treatments were 0.4 g active ingredient (a.i.)/cm dbh and 0.8 g a.i./cm dbh, applied as a basal soil injection in April before budbreak. The concentrate was diluted with water per label instructions at 12.5:1 for the 0.8 g rate. The 0.4 g rate was diluted 25:1 so that the same volume of solution was applied. FPD (Cutless®, Dow AgroSciences, Indianapolis, IN; no longer available) was applied as trunk implants at 0.3 g a.i./cm dbh, also in April before budbreak. Controls were untreated.

Color was rated annually in July for 4 years. Treatment color responses were expected to be most pronounced in the fourth year, based on experience with other large oaks. Interim color ratings were essentially an inventory and record of tree condition. If a tree was discovered missing during the annual ratings, and last recorded in very chlorotic condition, it was

assumed to have declined so badly that removal was necessary and was rated 0. Other missing trees were assumed to have been lost to other causes and eliminated from the study. Trees showing evidence of other treatment for chlorosis, such as recent trunk implants, were also eliminated from the study. After 4 years, root densities were determined as explained above. Two branch samples were pruned from mid-crown on opposite sides, and twig growth for the past 5 years was measured as the distance between terminal bud scale scars. Leaf area of the last three fully expanded leaves was measured on a Delta-T Area Meter (Delta-T Devices, Cambridge, UK).

Root, twig, and leaf area data were compared with one-way ANOVA ($P \leq 0.05$), with separation of means by Dunnett's Method. Color data were compared with one-way ANOVA on ranks ($P \leq 0.05$), with separation of means by Dunn's Method (SigmaStat 2.0, SPSS Science, Chicago, IL).

RESULTS AND DISCUSSION

Pre-Treatment Analysis

Foliage color and soil pH. On both street and golf course sites, the relationship between leaf color and soil pH was weak. Linear regression coefficients were very low, and not significant, indicating very little evidence that leaf color can be predicted from soil pH in pin oak (Table 2). Himelick and Himelick (1980) also found no relationship between leaf color of pin oaks and pH in the upper 15 cm (6 in.) of soil. Color ratings ranged from yellow to green over nearly the whole range of pH measurements on both sites. On the streets, where the soil pH was generally higher, both yellow and green trees could be found where the soil pH was higher than 7.0 (Figure 1, top). On the golf course site, where the soil pH was generally lower, both yellow and

Table 2. Pre-treatment analysis of the relationship among pin oak leaf color, soil pH, and root development.

	Golf course	Streets
<i>Soil pH*</i>		
Green trees	6.3	6.9
Yellow trees	6.6	7.0
<i>Root density (cm root length/cc soil)*</i>		
Green trees	6.94	19.85
Yellow trees	4.65	13.66
<i>Color-pH relationship</i>		
Regression coefficient (R)	0.28	0.30
P-value	0.22	0.11
<i>Color-root length relationship</i>		
Regression coefficient (R)	0.13	0.28
P-value	0.58	0.14

*The difference between values for green and yellow trees was not significant on either site.

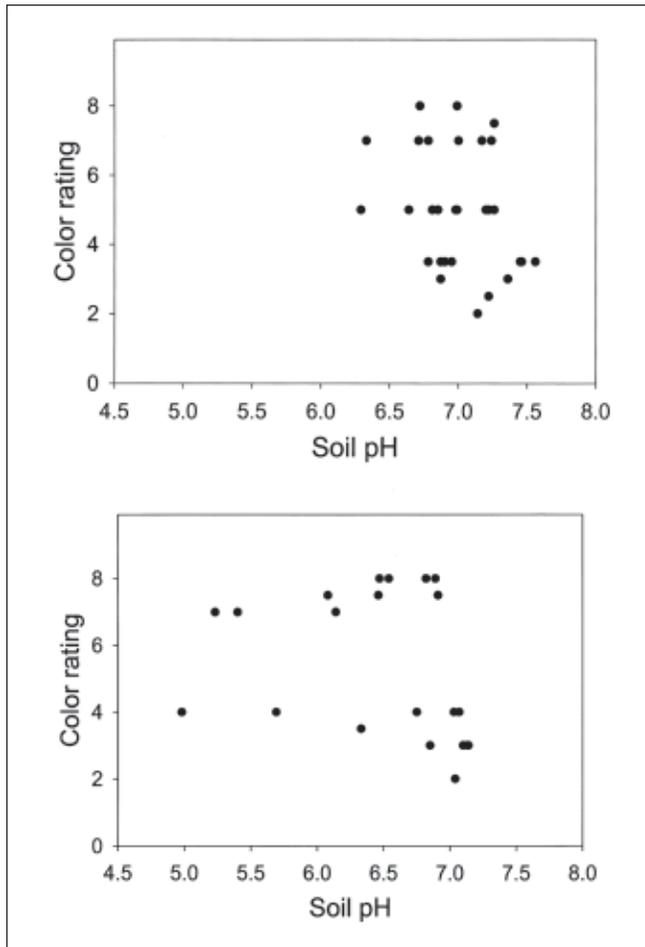


Figure 1. The relationship between leaf color and soil pH on street trees (top) and golf course trees (bottom). Color rating of 1 (chlorotic) to 10 (green) is fully described in Table 1.

green trees could be found where the soil pH was less than 6.0 (Figure 1, bottom). Soil pH values on all the street sites and 70% of the golf course sites were above the 6.2 value that has been reported to cause iron to be unavailable (Messenger 1984). The average soil pH was not significantly different for yellow and green groups of trees prior to treatment on either site. This contrasts with the earlier findings of Messenger (1984) in the same region, who reported a significant difference in soil pH between green and yellow trees throughout the upper 45 cm (18 in.) of soil. Based on data from this study, it would appear that soil pH is not the primary cause of pin oak chlorosis, as has been commonly accepted in the past.

Foliage color and root density. The relationship between leaf color and root density was also weak (Figure 2). Regression coefficients were very low, and not significant, indicating that there is also very little evidence that leaf color can be predicted from root development in pin

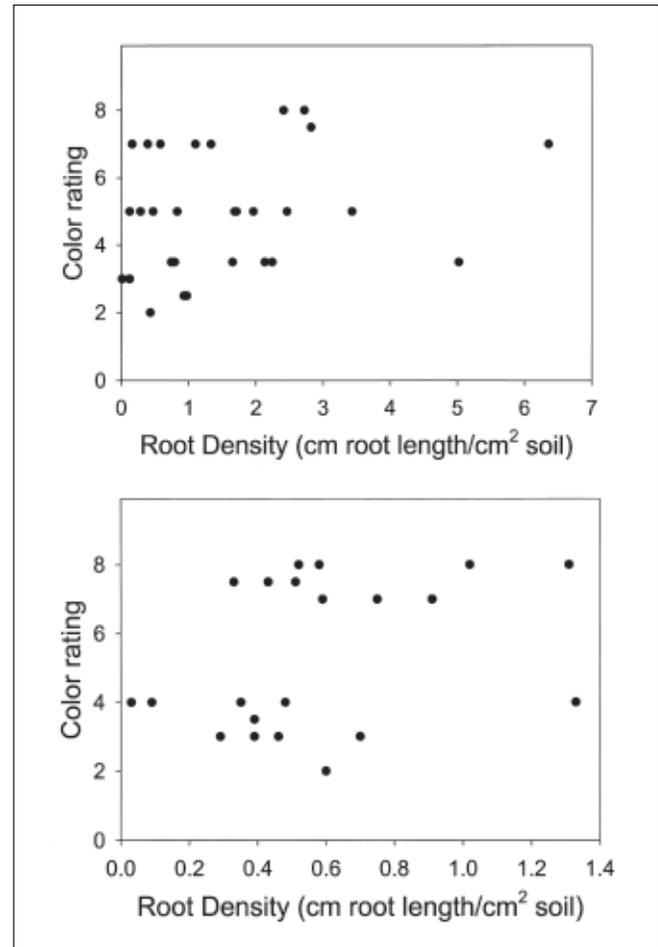


Figure 2. The relationship between leaf color and root density on street trees (top) and golf course trees (bottom). Color rating of 1 (chlorotic) to 10 (green) is fully described in Table 1.

oak (Table 2). The average root density was not significantly different for yellow and green trees prior to treatment, though green trees had nearly 50% higher root density than yellow trees on both sites.

Total size of the root system is not reflected in root density cores. Total spread of the root system is also a factor but is not possible to measure effectively and nondestructively. Rooting depth can be dependent on soil type and compaction, which often varies widely in urban areas. Root spread can be limited by pavements, structures, and competition with other trees. Two trees with the same root density may differ in total root development because of different limitations on depth and spread of the root system. The relationship between chlorosis and root development could be stronger than shown by root density measurements alone.

Root densities were nearly three times as high on street sites. Root development is highly influenced by soils and

cultural practices, and these factors are likely responsible for the difference. Soil texture, fertility, and water availability can all alter root development. The golf course trees had nearly unlimited space for roots to spread, and the turfgrass around them was more intensively managed. Greater competition with the turfgrass may have resulted in the tree roots spreading wider and less densely to obtain needed water and nutrients.

Chlorosis is a complex problem. Neither soil pH nor root development seems to be the dominant cause in pin oak chlorosis, but both may be contributing factors.

Response to Treatment After 4 Years

The trees in this study were exposed to pressures and disturbances that occur in real landscapes. On the golf course site, where all trees on the site were under the supervision of the grounds superintendent, there were no trees cut down for reasons not related to chlorosis or excluded from the study because of circumstances that interfered with the growth regulator treatments. In contrast, 33 of the original 95 trees on streets, subject to actions of individual residents, had to be excluded from the study. The primary reason was the unexpected discovery of trunk implant treatments for chlorosis. Though all residents had agreed not to treat their trees at the beginning of the study, over time some home ownership changed, and some owners chose to treat their trees anyway. Approximately 50% of the original yellow trees were excluded, while only 25% of the original green trees were excluded.

Color change. On the streets, color ratings of treated yellow trees were all somewhat greener after 4 years, while the untreated control trees were more yellow (Figure 3, top). The difference between treated and control was significant only for the 0.8 g/cm PBZ treatment. The color difference was 3.5 units, a highly noticeable difference. This would represent the difference between a tree with normal color and one with bright yellow foliage beginning to decline. Treated green trees were unchanged to 0.5 unit more yellow on the rating scale. Untreated green trees (controls) were a full unit more yellow. The difference was not significant at $P \leq 0.05$ but was significant at the less rigorous $P \leq 0.10$. Apparently, the primary difference was that the trees were not declining as fast as those that were already yellow at the start of the study, so differences were not as pronounced.

On the golf course, the overall greening response of the treated yellow trees was similar to that recorded on the streets, but the 0.8 g/cm PBZ treatment was not as effective (Figure 3, bottom). Untreated yellow controls were also slightly greener. There was no difference between controls and any of the treatments. All green trees were virtually unchanged. It appears that on this more favorable site, the color was fairly stable. More than anything, the lack of

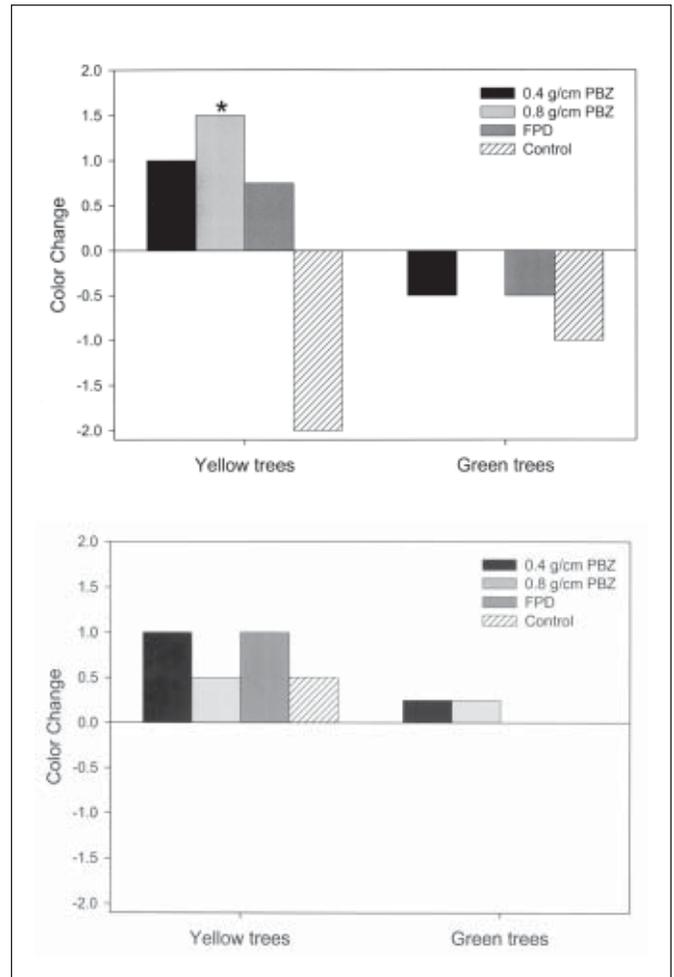


Figure 3. The effect of PBZ and FPD on color of chlorotic and green pin oaks on street trees (top) and golf course trees (bottom). Color change represents the difference in color ratings over a 4-year period on a scale of 1 (chlorotic) to 10 (green) as fully described in Table 1. (An asterisk indicates treatment is different from control at $P \leq 0.05$.)

deterioration of the controls prevented a significant response from the treatments.

Tree death was highest for the untreated yellow controls along streets. Six of the 14 trees declined and died, providing evidence that decline of these chlorotic street trees was rapid without intervention. Only five other yellow trees died on both sites, and not more than one or two trees in each treatment group.

Based on these data, tree growth regulator treatments may be most effective for yellow trees on difficult sites, where chlorosis is developing more rapidly and there is ample opportunity to halt decline and development of chlorosis. When trees were only slightly chlorotic and the opportunity for color improvement was limited, or when

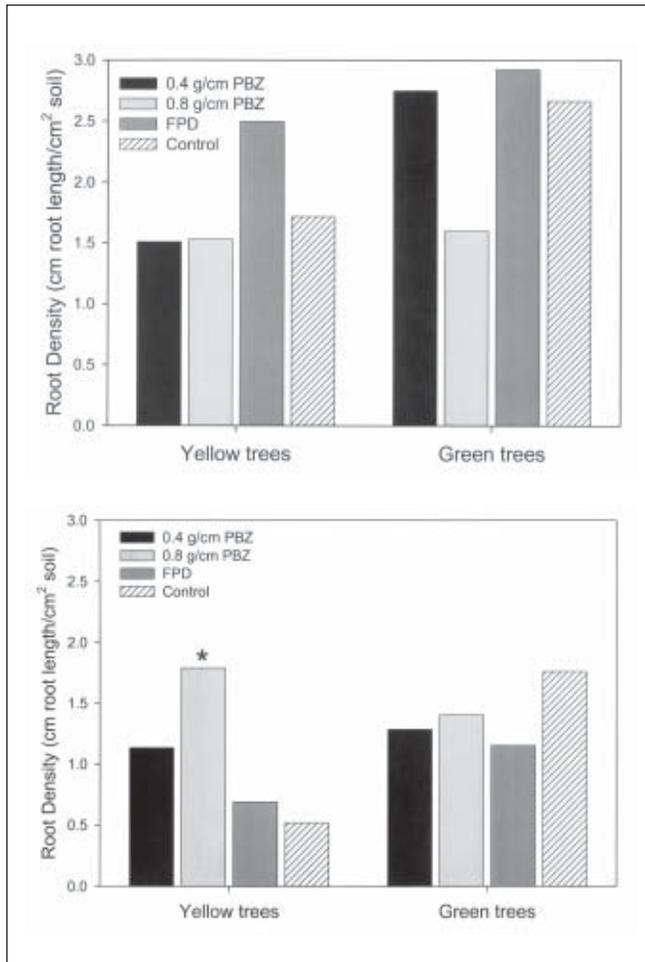


Figure 4. The effect of PBZ and FPD on fine root density of chlorotic and green pin oaks on street trees (top) and golf course trees (bottom). (An asterisk indicates treatment is different from control at $P \leq 0.05$.)

the chlorosis was not rapidly developing, results were harder to measure in this study. Even slight improvement in color may still have value in the landscape to help keep trees green before they become severely chlorotic.

Root response. At the end of the fourth season, there was no difference in root density between treatments and controls in yellow trees on street sites (Figure 4, top). On the golf course site, the 0.8 g/cm PBZ treatment root density was significantly greater than the control for yellow trees (Figure 4, bottom). This is in agreement with an earlier report (Watson 1996) where root development of pin oaks was improved in more favorable higher quality A horizon of an undisturbed soil, but not in the lower soil horizons with greater soil density and higher clay content.

In green trees, root density was unaffected on both sites. If root development was already adequate, root density increases would not be expected. The root density measure-

ments were generally lower on the golf course sites than on street sites, though the difference was not quite as large at the end of the study.

Twig and leaf measurements. There was no reduction in leaf size or twig growth as a result of the treatments (data not shown). The application rates were selected to produce only slight to moderate above ground growth regulation, but apparently too little growth regulator was applied to reduce growth measurably.

CONCLUSIONS

Modest color and root development improvements resulted from the 0.8 g/cm PBZ treatment on yellow trees. When compared to controls, color improved the most on the street sites where chlorosis and decline were developing rapidly. Color improvement was somewhat variable at the low growth regulator rates used, and small improvements in color on slightly chlorotic trees were difficult to measure. Root density was improved on the golf course site. Little color or root density improvement was expected from the treatments on healthy green trees, but untreated green trees did not develop chlorosis rapidly enough to show conclusively that the growth regulator treatment could help to stabilize the trees.

The results may have been different if higher rates of PBZ had been used. Knowing that severe growth regulation of the crown could actually reduce overall root growth, the maximum rate of PBZ used was in the lower portion of the range listed on the label. The label rates were developed primarily for trees growing near utility lines. The crowns of these trees are usually pruned back repeatedly, while the trunk continues to grow each year. This results in a smaller crown relative to the size of the trunk. Application rates are determined by trunk diameter. The crown size–trunk diameter ratio of these trees was probably greater than most utility trees, effectively diluting the rate applied throughout the larger crown and reducing growth regulation effects. The fact that the only significant color or root improvement resulted from the higher PBZ rate indicates that higher rates may produce better results. Product label rates allow up to 1.6 g/cm to be applied to pin oaks. FPD was used at the highest rate allowed by the label and had no effect on color or root density.

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Résumé. Une relation entre la chlorose et le pH du sol ou le développement des racelles n'a pu être établie pour le chêne des marais sur des sites fortement perturbés le long des rues ou encore au sein d'un parcours de golf (site moins perturbé...). Les coefficients de régression étaient faibles ($P \leq 0,28$) et non significatifs ($P \leq 0,58$) dans tous les cas. L'injection dans le sol de 0,8 g/cm de paclobutrazol a produit un accroissement significatif dans la densité en racelles sur les arbres jaunés d'un parcours de golf comparativement aux arbres-témoins ainsi qu'un verdissement significatif des arbres de rues jaunés comparativement aux arbres-témoins, et ce sur une période de quatre ans. La densité en racines a été améliorée par le traitement au paclobutrazol sur le site du parcours de golf où le sol était généralement meilleur pour la croissance des racines. L'effet sur la couleur était plus prononcé sur les sites le long des rues où le développement des chloroses et le dépérissement progressaient rapidement. Les arbres non traités sur le parcours de golf n'ont pas développé de chloroses suffisamment rapidement pour démontrer de manière concluante que le traitement avec le régulateur de croissance pourrait aider à stabiliser l'état des arbres. Peu d'amélioration en ce qui regarde la couleur du feuillage ou la densité en racines était attendu à partir de ces traitements sur des arbres biens verts et en bonne santé.

Zusammenfassung. Eine Beziehung zwischen Chlorosis und Boden-pH-Wert oder Feinwurzelentwicklung konnte für Nadeleichen, die an schwierigen Standorten entlang von Strassen stehen und solchen, die auf einem weniger gestörten Standort auf einer Golfanlage wachsen, nicht festgestellt werden. Der Regressionskoeffizient war niedrig ($P \leq 0,28$) und in allen Fällen nicht signifikant ($P \leq 0,58$). Eine Bodeninjektion mit 0,8 g/cm Paclobutrazol führte zu einem bedeutungsvollen Anstieg der Feinwurzel-dichte bei den gelben Golfplatzbäumen im Vergleich zu den Kontrollen und signifikantem Grünen der gelben Straßenbäume im Vergleich zu den unbehandelten Kontrollen. Die Wurzel-dichte wurde durch das PBZ auf dem Golfplatz verbessert, wo die Bodenqualität generell besser für Wurzelwachstum ist. Der Effekt auf die Farbe wurde am meisten bei Straßenbäumen festgestellt, wo die Chlorosentwicklung und Absterben weiter fortgeschritten war. Unbehandelte Bäume auf dem Golfplatz entwickelten keine Chlorosis schnell genug, um nicht abschließend zu zeigen, dass die Behandlung durch Wachstumsregulatoren helfen kann, Bäume zu stabilisieren. Wenig Farbe oder Wurzel-dichteverbesserung wurde von den Experimenten an gesunden, grünen Bäumen erwartet.

Resumen. No se logró establecer una relación entre clorosis, pH del suelo y desarrollo de raíces finas para encinos que crecen en sitios altamente disturbados en la calle y en campos de golf menos perturbados. Los coeficientes de regresión fueron bajos ($P \leq 0.28$) y no significativos ($P \leq 0.58$) en todos los casos. La inyección al suelo de 0.8 g/cm. de Paclobutrazol (PBZ) resultó en un significativo incremento en la densidad de las raíces finas en árboles amarillentos de campos de golf, comparados con los controles, y en un significativo enverdecimiento en árboles de las calles comparados con los controles no tratados, sobre un período de cuatro años. La densidad de las raíces fue mejorada por el tratamiento de PBZ en los árboles de campos de golf donde el suelo fue generalmente mejor para el crecimiento de las raíces. El efecto sobre el color fue más pronunciado en los árboles de las calles donde el desarrollo de la clorosis y la declinación estaban progresando rápidamente. Los árboles verdes no tratados de los campos de golf no desarrollaron clorosis lo suficientemente rápido como para mostrar que los tratamientos con el regulador del crecimiento podrían ayudar a estabilizarlos. En los tratamientos con árboles verdes saludables se dio poco cambio de color o mejoramiento en la densidad de las raíces.