A SURVEY TO DETERMINE THE LEAF NITROGEN CONCENTRATIONS OF 25 LANDSCAPE TREE SPECIES

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Abstract. A survey was conducted to determine the concentrations of leaf nitrogen in 25 landscape tree species. Leaf samples were taken from mature, healthy trees in the landscape and analyzed for percent (total) nitrogen. Concentrations ranged from 1.0% (dry weight basis) for deodar cedar *(Cedrus deodara)* and Southern magnolia *(Magnolia grandiflora)* to 3.6% for white mulberry *(Morus alba)*. The leaf nitrogen levels determined by the current study were compared to two other published surveys. From a practical standpoint, the list of tree species and their corresponding minimum leaf nitrogen values from visually healthy trees will allow arborists and landscape maintenance professionals to more effectively use leaf analysis for diagnosing nitrogen deficiency. The information can also be used for designing fertilizer programs, much as critical leaf nutrient level guides are currently used in the fruit and nut tree industries.

Key Words. Nitrogen; leaf nitrogen; leaf analysis.

The use of visual symptoms alone to diagnose nitrogen deficiency in ornamental trees is a longstanding practice. Visual nitrogen deficiency symptoms based on leaf color and shoot growth are well known. The leaves of nitrogen-deficient broadleaf trees are uniformly yellowish green, especially the older leaves; the leaves are small and thin, with premature and high fall color, and the shoots are short, small in diameter, and may be reddish or reddish brown (Harris et al. 1977). Trees with high foliar nitrogen concentrations appear greener than those with a lower foliar nitrogen content (Khatamian et al. 1984).

Unfortunately, visual nitrogen deficiency symptoms may be confused with symptoms caused by numerous other problems. Anything that restricts root growth, such as soil diseases, insects, root pruning, soil compaction, adverse soil temperatures, low oxygen, and poor drainage, may reduce nutrient uptake. Such root problems may produce symptoms, including chlorotic leaves, smaller and fewer leaves, and reduced shoot growth, all of which resemble nitrogen deficiencies (Smith 1978). Symptoms of other deficiencies may also be confused with those of nitrogen deficiency. Sulfur deficiency, although rare, results in uniformly yellow leaves and stunted growth, much like nitrogen deficiency. Iron deficiency is relatively common in landscape trees, but iron chlorosis always occurs on new leaves rather than on older basal leaves. Because a tree may exhibit multiple symptoms, including those related to diseases and improper amounts of water, considerable experience is needed to visually determine the nutritional status of a plant (Harris et al. 1999). Recent studies (Perry and Hickman 1998) show that the use of visual symptoms alone to diagnose nitrogen deficiency in landscape trees is unreliable.

The misdiagnosis of nitrogen deficiency usually leads to unnecessary fertilizer application. The application may be justified by factors other than actual need, for instance, as "insurance" in case the tree is truly deficient, and because many nitrogen-containing fertilizers are relatively inexpensive to purchase and apply. However, applying nutrients without knowing they are deficient wastes time and money and can lead to excessive soil salts and water pollution (Harris et al. 1999). "On the basis of the review of the scientific literature, nitrogen, and in particular nitrate, is the nutrient posing

the most serious threat from an environmental and water quality perspective" (Balogh and Walker 1992). The excessive use of nitrogen fertilizer is already a concern in the turfgrass maintenance industry, where there is evidence that the total amount of nitrate leaching increases with increasing rates of application (Petrovic 1990). Excessive nitrogen fertilization favors the development of several insect pests, including the redgum lerp psyllid *(Glycaspis brimblecombei)* and the wooly adelgid *(Adelges tsugae)* (Dreistadt et al. 1999; McClure 1991). Fire blight *(Erwinia amylovora)*, a destructive bacterial disease of plants in the rose family, is also favored by excessive nitrogen fertilization (Ohlendorf 1999). Excess nitrogen can promote shoot growth late into summer and fall, making plants more susceptible to winter injury (Hanson 1996; Maleike and Pinyuh 1996). Also, higher than necessary amounts of nitrogen applied to flowering trees, such as crabapple *(Malus* spp.), may stimulate excessive shoot growth at the expense of flowering (Maleike and Pinyuh 1996).

Many arborists use soil analysis in conjunction with visual symptoms to help diagnose nitrogen deficiency in landscape trees. While soil analyses are useful for pH and salinity determinations, they are not reliable for determining the nitrogen needs of trees. The availability of nitrogen depends on soil condition and root extent, which makes soil analysis difficult to interpret (Kopinga and van den Burg 1995). For example, the rate of nitrogen mineralization is affected by lack of aeration, a common problem, especially in frequently irrigated landscapes. The available nitrogen in soil is so transitory that soil tests for determining the nitrogen status of landscape trees are of little value (Harris et al. 1999). Coder (1997) states that soil testing for nitrogen is so fraught with problems that, except for detecting toxicity and extreme deficiency, such testing may have little meaning.

Leaf tissue analysis is a good quantitative method for detecting nutrient deficiencies and evaluating fertilizer programs. It has been used for years in tree fruit production as a guide for determining

nutrient deficiencies and timing of fertilizer applications. Critical nutrient levels have been established for most major fruit tree crops (Childers 1966; Reisenauer 1983) and for a number of woody ornamental species grown as container nursery stock (Smith 1972). In landscape plant culture, plant tissue analysis is a valuable tool in identifying mineral deficiencies and in designing an efficient fertilization program (Smith 1978). It is especially useful in determining the nutritional status of established, deep-rooted ornamentals such as trees, shrubs and vines, where soil samples of the entire root zone are difficult to obtain and interpret (Ludwick 1990). In the Netherlands, chemical leaf analysis has become more important than soil analysis in studies of the supply of nutrient elements to trees (Kopinga and van den Burg 1995). Leaf analysis reveals the total amount of a nutrient accumulated over the course of the leaf's growth and shows the integrated effects of nutrient supply, uptake, and transport within the plant prior to sampling (Mills and Jones 1996). In their plant analysis handbook, Mills and Jones (1996) report leaf concentrations of various elements for 252 landscape and forest trees. All of the values reported in the handbook are from trees growing in container or field nurseries, field research plots, or a botanical garden or arboretum, which may be different from trees growing in the landscape.

Leaf analysis may become a more commonly used management practice for determining landscape tree nitrogen needs, especially as concerns about nitrate pollution increase. However, much more information is needed before leaf analysis will be generally accepted by arborists as a useful tool. Appleton (1992) writes that analysis of foliage can be helpful in determining fertilizer needs, but comparison standards are needed for interpretation. The American National Standards Institute section on tree fertilization, ANSI A300, states that soil and/or foliar nutrient analysis should be used to determine the need for fertilizer (American National Standards Institute 1998). However, it does not give any guidelines with which to compare the analy-

ses. Before meaningful standards can be developed for determining the nutrient status and needs of woody landscape plants, more work on correlating tissue analysis with plant symptoms and fertilizer responses must be documented (Harris et al. 1999).

The main objective of this survey was to determine a range of leaf nitrogen concentrations for 25 commonly used landscape tree species in California, U.S., and to compare those ranges with currently published values.

MATERIALS AND METHODS

Twenty-five landscape tree species common in northern California were selected for this survey. Trees sampled were well-established, over 10 years old, of good vitality, and typical for the species. No visual disease symptoms or insect infestations were present in the trees sampled. Leaf samples were taken from 20 trees per species, the minimum number suggested as an adequate sample size (Reisenauer 1983). Trees were sampled in Modesto, Stockton, and Lodi, California. Trees sampled were located primarily in irrigated landscapes in lawns or ground covers. Most of the trees were street trees in the front yards of residences. A sample for analysis consisted of approximately 30 leaves collected from each tree, taken at random from throughout the low to mid-crown. Samples consisted of the most recently matured leaves near the shoot tips on the current season's growth (Harris et al. 1977). All samples were taken between June 10, 1999, and August 4, 1999. The samples were dried in a forced-air drying oven at 112°F (44.4°C), milled, then sent to the University of California Division of Agriculture and Natural Resources Analytical Lab in Davis, California, for analysis of total nitrogen. Analysis was by a Nitrogen Gas Analyzer (LECO FP528), utilizing an induction furnace and thermal conductivity.

RESULTS AND DISCUSSION

The leaf nitrogen concentrations of healthy trees ranged from 1.0% (dry weight basis) for deodar

cedar *(Cedrus deodara)* and Southern magnolia *(Magnolia grandiflora)* to 3.6% for white mulberry *(Morus alba)* (Table 1). Figure 1 shows the ranges and median values of total leaf nitrogen for the 25 species, arranged in descending order of median values. Species such as crapemyrtle *(Lagerstroemia indica)* and Southern magnolia have relatively wide ranges of nitrogen in healthy leaves, while others, such as eucalyptus *(Eucalyptus* spp.) and deodar cedar have relatively narrow ranges. Even though ranges vary, several species tend to group around median values. For example, crapemyrtle and Southern magnolia, which have the widest ranges, had median leaf nitrogen values very similar to Modesto ash *(Fraxinus velutina* 'Modesto'), zelkova *(Zelkova serrata)*, Chinese pistache *(Pistachia chinensis)*, white alder *(Alnus rhombifolia)*, and Chinese tallow tree *(Sapium sebiferum)*, all of which have relatively narrow ranges.

Table 1. Range of total nitrogen (percent total N on dry weight basis) in leaves of 25 landscape tree species.

Tree species	Range(%)*
White mulberry *(Morus alba)*	2.0–3.6
White birch *(Betula pendula)*	2.2–3.4
Goldenrain tree *(Koelreuteria paniculata)*	1.9–3.5
Silver maple *(Acer saccharinum)*	2.0–3.4
Honeylocust *(Gleditsia triacanthos)*	2.3–3.1
Raywood ash *(Fraxinus oxycarpa)*	2.1–2.9
Valley oak *(Quercus lobata)*	2.1–2.9
Crapemyrtle *(Lagerstroemia indica)*	1.1–3.5
Modesto ash *(Fraxinus velutina* 'Modesto')	1.8–2.7
Zelkova *(Zelkova serrata)*	1.8–2.8
Chinese pistache *(Pistachia chinensis)*	1.6–3.0
White alder *(Alnus rhombifolia)*	1.9–2.6
Southern magnolia *(Magnolia grandiflora)*	1.0–3.5
Chinese tallow tree *(Sapium sebiferum)*	1.7–2.7
Chinese hackberry *(Celtis sinensis)*	1.4–2.8
Eucalyptus *(Eucalyptus* spp.)	1.8–2.1
London planetree *(Platanus acerifolia)*	1.4–2.6
Holly oak *(Quercus ilex)*	1.3–2.8
Tuliptree *(Liriodendron tulipifera)*	1.2–2.8
Cork oak *(Quercus suber)*	1.5–2.2
Maidenhair tree *(Ginkgo biloba)*	1.4–2.4
Olive *(Olea europa)*	1.3–1.9
Camphor tree *(Cinnamomum camphora)*	1.2–2.0
Bradford pear *(Pyrus calleryana* 'Bradford')	1.1–1.9
Deodar cedar *(Cedrus deodara)*	1.0–1.4

*Range of 20 trees sampled.

Tree Species	Percent Total Leaf Nitrogen					
	1.0	1.5	2.0	2.5	3.0	3.5
White mulberry (*Morus alba*)			|––––––––↑–––––––|		
White birch (*Betula pendula*)			|––––↑––––|		
Goldenrain tree (*Koelreuteria paniculata*)			|–––––––↑–––––|		
Silver maple (*Acer saccharinum*)			|–––––↑––––|		
Honeylocust (*Gleditsia triacanthos*)			|–––↑––|		
Raywood ash (*Fraxinus oxycarpa*)			|––↑–|		
Valley oak (*Quercus lobata*)			|––↑–|		
Crapemyrtle (*Lagerstroemia indica*)		––––––––––↑––––––––––				
Modesto ash (*Fraxinus velutina* 'Modesto')		|––↑–|			
Zelkova (*Zelkova serrata*)		|––↑––|			
Chinese pistache (*Pistachia chinensis*)		–––––––↑––––––				
White alder (*Alnus rhombifolia*)		|–↑–|			
Southern magnolia (*Magnolia grandiflora*)		––––––––––↑––––––––––				
Chinese tallow tree (*Sapium sebiferum*)		|––↑––|			
Chinese hackberry (*Celtis sinensis*)		––––––↑––––––				
Eucalyptus (*Eucalyptus* spp.)		|–↑–|			
London planetree (*Platanus acerifolia*)		|–––↑–––|			
Holly oak (*Quercus ilex*)		–––––↑––––––				
Tuliptree (*Liriodendron tulipifera*)		–––––––↑–––––				
Cork oak (*Quercus suber*)		|––↑––|			
Maidenhair tree (*Ginkgo biloba*)		|–––↑–––|			
Olive (*Olea europa*)	|––↑––|				
Camphor tree (*Cinnamomum camphora*)	|–––↑–––|				
Bradford pear (*Pyrus calleryana* 'Bradford')	|–––↑–––|				
Deodar cedar (*Cedrus deodara*)	|–↑–|				

[a]20 trees sampled per species.
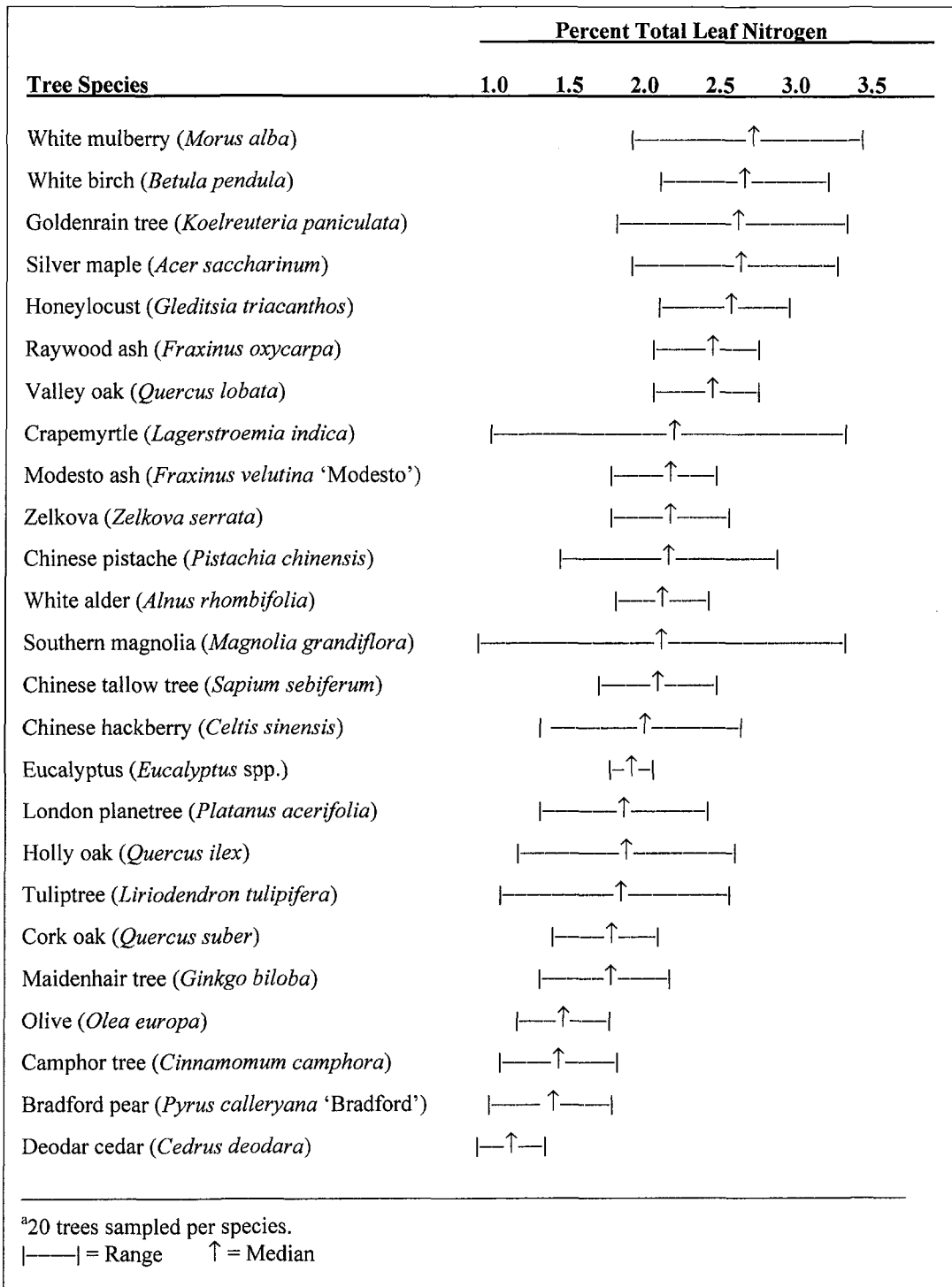
|–––––| = Range   ↑ = Median

Figure 1. Ranges and medians of total nitrogen (percent total N on dry weight basis) in leaves of 25 landscape tree species.

Table 2 compares leaf nitrogen ranges from the current survey with those determined by two other published studies. Only 12 species from Mills and Jones (1996) and five species from Kopinga and van den Burg (1995) were available for comparison. In some cases, as for silver maple *(Acer saccharinum)*, the ranges from all three studies were similar. In other cases, as for white birch *(Betula pendula)*, the ranges from the current survey and Kopinga and van den Burg were similar but differed greatly from the range found by Mills and Jones.

Table 3 gives mean leaf nitrogen percentages by species. The means were obtained by analyzing the sampling data using an analysis of variance. This analysis shows that significant differences in total leaf nitrogen exist between species. White mulberry *(Morus alba)*, honeylocust *(Gleditsia triacanthos)*, white birch *(Betula pendula)*, goldenrain tree *(Koelreuteria paniculata)*, and silver maple *(Acer saccharinum)* had the highest mean total leaf nitrogen, from 2.6% to 2.9%. Holly oak *(Quercus ilex)*, olive, *(Olea europa)*, cam-

phor tree *(Cinnamomum camphora)*, Bradford pear *(Pyrus calleryana* 'Bradford'), Southern magnolia *(Magnolia grandiflora)*, and deodar cedar *(Cedrus deodara)* had the lowest mean total leaf nitrogen, between 1.1% and 1.6%. It is interesting to note that of this group, all but Bradford pear are evergreen species. Except for Southern magnolia and holly oak, the evergreen species also had relatively narrow ranges of total leaf nitrogen. While Southern magnolia had a wide range of total leaf nitrogen (from 1.0% to 3.5%), the mean total nitrogen was very low (1.3%). This indicates that a small number of individual trees in the sample had unusually high total leaf nitrogen, possibly due to site factors such as heavily fertilized turfgrass. However, in general, the foliage of Southern magnolia can be expected to contain relatively low total nitrogen.

The absolute minimum leaf nitrogen concentrations of healthy landscape trees are not established by any of these studies. However, it can be assumed that tree leaf sample values above the species range minimums given here are not deficient in nitrogen.

Table 2. Ranges of total nitrogen (percent total N on dry weight basis) in leaves of selected landscape tree species from three studies.

Tree species	Ranges(%)		
	Perry and Hickman[z]	Mills and Jones[y]	Kopinga and van den Burg[x]
White mulberry *(Morus alba)*	2.0–3.6	1.2–2.4	—
White birch *(Betula pendula)*	2.2–3.4	4.0–4.6	2.3–3.3
Goldenrain tree *(Koelreuteria paniculata)*	1.9–3.5	2.5–2.8	—
Silver maple *(Acer saccharinum)*	2.0–3.4	2.3–2.6	1.9–2.7
Honeylocust *(Gleditsia triacanthos)*	2.3–3.1	2.4–4.0	2.0–2.5
Crapemyrtle *(Lagerstroemia indica)*	1.1–3.5	1.6–2.1	—
Zelkova *(Zelkova serrata)*	1.8–2.8	2.3–3.1	—
Chinese pistache *(Pistachia chinensis)*	1.6–3.0	2.1–2.8	—
Eucalyptus *(Eucalyptus* spp.)	1.8–2.1	1.2–1.2	—
London planetree *(Platanus acerifolia)*	1.4–2.6	2.0–2.7	2.0–2.6
Tuliptree *(Liriodendron tulipifera)*	1.2–2.8	1.9–4.3	2.6–3.0
Bradford pear *(Pyrus calleryana* 'Bradford')	1.1–1.9	1.6–2.5	—

[z]After Perry and Hickman, Current Study. Samples taken from trees growing in landscapes.
[y]After Mills and Jones, 1996. Samples taken from trees growing in botanical gardens, field research plots, and field and container production nurseries.
[x]After Kopinga and van den Burg, 1995. Sample source not given.

Table 3. Mean total nitrogen (percent total N on dry weight basis) in leaves of 25 landscape tree species.

Tree species	Mean (%)[z,y]
White mulberry *(Morus alba)*	2.9 a
Honeylocust *(Gleditsia triacanthos)*	2.8 ab
White birch *(Betula pendula)*	2.7 ab
Goldenrain tree *(Koelreuteria paniculata)*	2.6 b
Silver maple *(Acer saccharinum)*	2.6 b
Raywood ash *(Fraxinus oxycarpa)*	2.4 c
Valley oak *(Quercus lobata)*	2.3 c
White alder *(Alnus rhombifolia)*	2.3 c
Chinese pistache *(Pistachia chinensis)*	2.3 c
Modesto ash *(Fraxinus velutina* 'Modesto')	2.2 cd
Zelkova *(Zelkova serrata)*	2.2 cde
Crapemyrtle *(Lagerstroemia indica)*	2.2 cde
Chinese hackberry *(Celtis sinensis)*	2.2 cde
Chinese tallow tree *(Sapium sebiferum)*	2.1 cde
London planetree *(Platanus acerifolia)*	2.0 def
Tuliptree *(Liriodendron tulipifera)*	2.0 def
Eucalyptus *(Eucalyptus* spp.)	1.9 ef
Cork oak *(Quercus suber)*	1.9 f
Maidenhair tree *(Ginkgo biloba)*	1.9 f
Holly oak *(Quercus ilex)*	1.6 g
Olive *(Olea europa)*	1.6 g
Camphor tree *(Cinnamomum camphora)*	1.6 g
Bradford pear *(Pyrus calleryana* 'Bradford')	1.6 g
Southern magnolia *(Magnolia grandiflora)*	1.3 h
Deodar cedar *(Cedrus deodara)*	1.1 h

[z]Range of 20 trees sampled.
[y]Means followed by the same letter within a column are not significantly different at 5% (DMRT).

CONCLUSIONS

There are a number of practical uses for the information developed from this survey. The list of tree species and their corresponding minimum leaf nitrogen values from visually healthy trees will allow arborists and landscape maintenance professionals to more effectively use leaf analysis for diagnosing nitrogen deficiency. This information can also be used for designing fertilizer programs, much as critical leaf nutrient level guides are currently used in the fruit and nut tree industries. By comparing a leaf analysis to the range in the table, the arborist can obtain greater accuracy when evaluating a tree's nitrogen status. This would result in fewer unnecessary nitrogen fertilizer applications.

Home owners, public park managers, and commercial property owners would benefit from reduced fertilizer costs, and the environment would benefit from less potential nitrogen-related pollution.

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Résumé. Cette étude a été menée pour déterminer les concentrations d'azote foliaire chez 25 espèces d'arbres ornementaux. Les échantillons de feuilles ont été pris d'arbres matures et en bonne santé dans les parterres paysagers et ont été analysés quant au pourcentage total d'azote. Les concentrations ont varié de 1,0% (sur la base de la masse sèche) pour le cèdre de l'Himalaya (*Cedrus deodora*) et le magnolia à grandes fleurs (*Magnolia grandiflora*) à 3,6% pour le mûrier blanc (*Morus alba*). Les taux d'azote foliaire relevés dans cette étude ont été comparés à ceux publiés dans deux autres recherches. D'un point de vue pratique, la liste des espèces d'arbres et leurs valeurs minimales correspondantes d'azote foliaire pour des arbres visuellement en bonne santé va permettre aux arboriculteurs et aux professionnels de l'entretien des espaces verts d'utiliser plus efficacement l'analyse foliaire pour diagnostiquer les déficiences en azote. Cette information pourra aussi être utilisée pour élaborer des programmes de fertilisation, tout comme le font couramment les industries de production fruitières et de noix avec leurs guides de taux foliaires critiques en éléments minéraux.

Zusammenfassung. Diese Studie wurde durchgeführt, um die Konzentration von Blattnitrat bei 25 Landschaftsgehölzen zu bestimmen. Es wurden Blattproben von gesunden, ausgewachsenen Bäumen entnommen und auf N-Anteile analysiert. Die Konzentrationen reichten von 1,0 % TM für *Cedrus deodara* und *Magnolia grandiflora* bis zu 3,6 % bei *Morus alba*. Der bestimmte Blattnitratgehalt aus dieser Studie wurde mit 2 anderen veröffentlichten Studien verglichen. Vom praktischen Standpunkt gestattet diese Liste der Baumarten und ihres korrespondierenden Nitratgehaltes beim gesunden Baum den Baumpflegern und Landschaftspflegern, die Blattanalyse zu Festlegung von N-Defiziten effektiver einzusetzen. Die Information kann auch zur Entwicklung von Düngeprogrammen dienen, ebenso wie der kritische Blattnährstoffgehalt gegenwärtig in der Frucht- und Nussindustrie genutzt wird.

Resumen. Este estudio se condujo para determinar las concentraciones de nitrógeno foliar en 25 especies de árboles urbanos. Las muestras de las hojas fueron tomadas de árboles saludables y maduros y se analizó el porcentaje de nitrógeno (total). El rango de las concentraciones varió de 1.0 % (con base en peso seco) para cedro deodara (*Cedrus deodara*) y magnolia sureña (*Magnolia grandiflora*) hasta 3.6 % para mulberry blanco (*Morus alba*). Los niveles de nitrógeno determinados por el estudio fueron comparados con dos estudios publicados. Desde un punto de vista práctico, la lista de las especies y sus correspondientes valores mínimos de nitrógeno foliar, en árboles visualmente saludables, permitirá a los arboristas y profesionales del paisaje usar más efectivamente el análisis foliar para diagnosticar las deficiencias de nitrógeno. La información también puede ser usada para el diseño de programas de fertilización.