A STUDY OF THE RELATIONSHIP BETWEEN SITE CONDITIONS AND URBAN TREE GROWTH

by S.J. Hodge and R. Boswell

Abstract. A study of 105 urban London plane (*Platanus acerifolia*) was undertaken between May 1990 and May 1992. One third of the 25 year old trees were in compacted gravel, one third in a paved area and one third in turf. Significant differences in tree condition were found between the three sites, as well as significant differences in soil dry bulk density, aeration (measured using steel rods), soil moisture tension and foliar essential element concentrations. Regression analysis was used to explore these relationships; spring soil aeration, summer soil moisture stress, and foliar nitrogen and potassium concentrations were found to have most influence on tree performance. Leaf colour and shoot extension were found to be the most sensitive measures of tree condition. Practical advice is given on the implications of the study on the assessment and monitoring of urban trees.

Understanding the relationship between urban site conditions and tree growth is essential if remedial treatments are to be targeted and effective. A two year study of London plane (*Platanus acerifolia*), funded by the UK Department of the Environment, was undertaken between May 1990 and May 1992 to investigate this relationship. The study had three principal objectives:

- to develop methods of assessing and quantifying urban soils;
- to investigate relationships between urban site conditions and tree growth;
- to work towards more targeted and successful treatment of slow growing urban trees.

The Study Site

The study was undertaken in the city of Milton Keynes, Buckinghamshire, England; a 'garden city' planned and developed in the last 40 years. A population of 105, 25 year old London planes (mean height 12.3 m, mean diameter at breast height 6.9 cm) was selected for the study. These trees were raised by Milton Keynes Development Corporation and planted as heavy standards (1) in their present locations about 15 years ago. The underlying substrate at Milton Keynes is Oxford clay and the soils of the area are in the Hanslope series (17) of slightly stony, calcareous clays. These soils were disturbed considerably during the construction of the town.

The population of trees in the study was divided into three groups:

- A double row of 35 trees in the central reservation of a dual carriageway grid road. The clay subsoil was overlain with 25 cm (10 in) of compacted "2 cm to dust" limestone gravel which was capped at the surface, laid up to the tree stems and largely weed free.
- A line of 35 trees planted down the center of a carpark between two rows of parking spaces. This centre strip was paved with 0.5 x 0.5 m paving slabs bedded on sand over 25 cm of coarse concrete which was laid onto the clay subsoil. The center strip was 2.5 m wide and the carpark on either side was brick-set bedded on hardcore and sand. The soil surface was exposed at the 0.5 m diameter gap in the paving around each tree and kept largely weed free.
- A line of 35 trees in a turf strip; part of a green corridor between a large carpark and the grid road network. These trees were the outer row of an avenue and were 4 m from the edge of the brick set carpark. A 1.0 to 1.5 m diameter area was maintained weed free.

Assessments

Annual assessments of tree performance were undertaken in August of 1990 and 1991. A standardized suite of tree assessments has been used for assessing a number of experiments involving established urban trees (13).

Annual Shoot Extension. 10 lateral and 10 apical shoots per tree, taken from the outermost branches around the outside of the crown, were measured.

Leaf Colour. Eight leaves were objectively selected from each tree for assessment of colour on a green to yellow axis. All leaves came from the most southerly branch in mid crown. Each leaf was the fifth leaf back from the terminal on eight twigs on the outside of the crown. A range of leaves were collected to establish the extremes of darkest green and yellow. From these sample leaves were selected five to act as the one (greenest) to five (yellowest) scale for assessment.

Leaf Area. In addition to the eight leaves collected for leaf colour assessment, another eight leaves were collected from the branch pointing most due north from halfway up the crown. The area of these 16 leaves per tree was measured electronically in the laboratory.

Crown Density. Each tree was photographed using black and white film (where possible using the sky as a contrasting background). The density of the crown was subsequently determined using computerised image analysis equipment, the result being expressed as percentage of total crown area obscuring the background light.

Foliar Chemical Analysis. Foliar samples were taken from each tree, using the leaves from the leaf size assessments. In both years samples were analyzed for nitrogen (N), phosphorus (P), potassium (K), magnesium (Mg) and calcium (Ca). In 1991 a chloride (Cl) assessment was also undertaken to investigate the effect of road salt application over the winter of 1990/91.

Soil Aeration Status was assessed by interpreting the corrosion patterns on steel rods inserted into the ground (14,15). One rod was inserted into the planting pit, 25 cm from the stem of each tree. Another two rods were inserted 1.0 m from the stem on opposite sides of the tree. The first rods were inserted on 22 March 1990, and rods were extracted and inserted every three months until 28 February 1992. Extracted rods were assessed for corrosion types that indicated the presence of anaerobic soil conditions. The presence of these corrosion types was recorded in 20 3 cm sections down the rod (15). From this assessment it was necessary to obtain data that could be statistically compared with the tree performance parameters.

Principal component analysis was used to determine if aspects of this rod data could be grouped to simplify subsequent analysis (14). These analyses indicated that data from the two rods outside the planting pit could be combined and that data for each rod could be collected in 15 cm rather than 3 cm sections. Principal component analysis also revealed that the variation in corrosion patterns could be adequately expressed by two values; the sum of anaerobism scores over the whole length of the rod, and a contrast of corrosion in the top and bottom halves of the rod. The soil aeration values used for regression analysis were, therefore: 2 measurements (sum, contrast) x 2 rod positions (1 m from tree, planting pit) x 4 seasons x 2 years.

Soil Dry Bulk Density was assessed 1.0 m from each tree at 30 cm depth using a gamma probe (26). Assessments using a penetrometer, the tin method and the balloon method were tried in previous studies (5), but these proved inadequate for the compacted, stony soils and hard surfaces common in the urban environment. The gamma probe is based on the principle that gamma radiation passes more slowly through a dense soil than through a soil with a low bulk density. The equipment has two prongs which are inserted into the soil, one of which emits gamma radiation and the other containing detection sensors. The machine measures the time taken to receive a preset amount of radiation, and this is converted into dry bulk density using a calibration equation established by comparing these time counts with bulk densities taken by the tin method in a range of soils. In order to assess bulk density under hard surfaces, boring equipment was used to create access holes.

Soil Moisture Tension was assessed every two weeks during the growing season using gypsum blocks (27). Blocks were inserted 70 cm from the stem of each tree to 30 cm depth. The ends of wires running from the blocks protruded 1 cm from a small pad of concrete, allowing the meter to be connected up for assessment whilst avoiding damage from mowers and passers-by. The meter measures the resistance between two electrodes in the block of gypsum. When the gypsum is wet, resistance to the passage of current is low and when dry, resistance is high. The meter displays readings in a scale of 0 to 100. 0 equates to wilting point (pF 0.05); 80 equates to the point where growth starts to be limited by lack of moisture (pF 2.7); and 100 equates to field capacity (pF 4.2). The soil moisture tension data were expressed as the cumulative tension scores (total shortfall of values below 80 units) between 1 May and 31 July, when most tree growth takes place.

Results

Analysis of variance was used to compare the results for individual variates between the three site types.

Mean Annual Shoot Extension was low in 1990 (Table 1), probably due to the particularly dry summer, and in both years shoot extension was greatest for the trees in turf. *Leaf Colour* and *Leaf Area* scores were highly consistent between the two years of assessment, with trees in turf having larger, darker green leaves than trees in the paved and gravel areas. *Crown Density* scores were inconsistent between years, the trees in turf having relatively sparse crowns in 1990 and relatively dense crowns in 1991.

Foliar Chemical Analysis revealed adequate levels of Mg and Ca (4). However, whilst deficiency symptoms were not apparent, levels of foliar N and P in the gravel and paved areas were lower than published deficiency thresholds for London plane (2). Foliar K concentration for trees in the gravel and paved areas was much higher than the 0.9% suggested as adequate by Binns et al (2), resulting in an imbalance of macronutrients (Table 2) as well as the possible deficiencies. Foliar Cl concentration in 1991was particularly high in groups of trees near pedestrian ways and roads cutting across the avenues in the gravel and paved sections, relating to the application of de-icing salt.

Soil Aeration Status. Analysis of steel rod corrosion data for the gravel site revealed evidence of a compacted layer outside the planting pit between 15 and 30 cm depth (Figure 1). The layer was apparent throughout the year making it unlikely to be due to waterlogging. Figure 1 shows that during the winter this compaction impeded the infiltration of rainwater, resulting in poor aeration between the surface and 15 cm. Seasonal waterlogging outside the planting pits on all sites was

Table 1: Mean values of tree performance and soil assessments over the three site types.

	gravel	paved	turf	signif
1990 shoot exten (cm)	5.4a	4.2b	6.8a	.001
1991 shoot exten (cm)	12.9b	1.1b	19.9a	.001
1990 leaf colour (1-5)	2.97b	3.15b	1.94a	.001
1991 leaf colour (1-5)	2.88b	3.09b	1.78a	.001
1990 leaf area(cm^2)	59.0b	57.4b	79.1a	.001
1991 leaf area(cm^2)	99.5b	94.1b	140.9a	.001
1990 crown density (%)	77a	77a	70b	.05
1991 crown density (%)	69b	66b	78a	.001
1990 N (%)	1.24c	1.40b	1.90a	.001
1991 N (%)	1.43b	1.52b	1.99a	.001
1990 P (%)	0.11b	0.12b	0.14a	.001
1991 P (%)	0.13c	0.15a	0.15b	.001
1990 K (%)	1.42b	1.78a	0.88c	.001
1991 K (%)	1.42a	1.49a	1.02b	.001
1990 Mg (%)	0.27ab	0.28a	0.24b	.05
1991 Mg (%)	0.30a	0.31a	0.23b	.001
1990 Ca (%)	1.80a	1.51b	1.75a	.01
1991 Ca (%)	1.59ab	1.47b	1.71a	.01
1991 Cl (%)	0.44a	0.35b	0.41ab	.058
dry bulk density (g/cm^3)	1.92a	1.83b	1.76c	.001
cum s.m.t.* 1 May 90 - 31 Jul 90	2820b	1020c	3841a	.001
cum s.m.t. 1 May 91 - 31 Jul 9	12907a	26c	1214b	.001

Within each row, figures accompanied by the same letter are not significantly different.

* cumulative soil moisture tension expressed as the total shortfall of values below 80 as recorded on the gypsum block meter.

apparent from a reduction in the presence of anaerobic conditions during the summer and autumn compared to the winter and spring, particularly below 30 cm depth. The effect of the spring waterlogging shown in Figure 1 would be most severe in the paved area where the 25 cm thick layer of concrete restricts rooting to below this level.

Compaction outside the planting pit on the gravel site appears to have affected aeration inside the planting pit during the winter and spring (Figure 2). Poor aeration above 30 cm during these seasons appears to result from waterlogging as it is not apparent in the summer and autumn assessments. The impermeability of soil outside the pits may have been preventing the lateral movement of water. In the paved area, waterlogging in the planting pits was severe below 30 cm

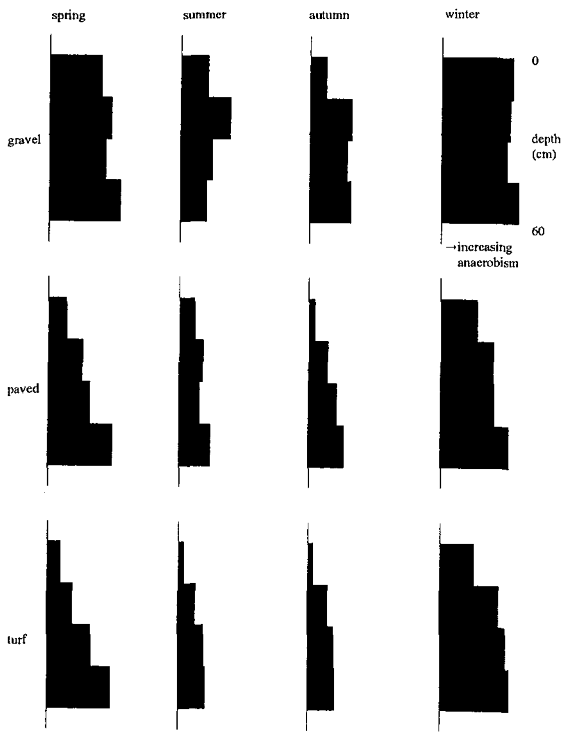


Figure 1: Presence of anaerobic conditions outside the planting pit (average of values from corresponding seasons in 1990 and 1991).

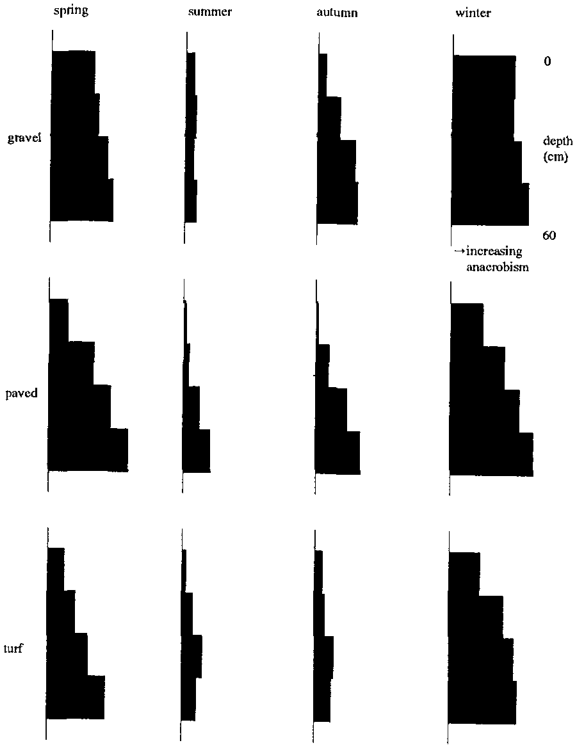


Figure 2: Presence of anaerobic conditions inside the planting pit (average of values from corresponding seasons in 1990 and 1991).

during the winter and spring, more so than outside the planting pits. This may be due to the unsurfaced pits receiving runoff from the surrounding paving. On the turf site there was very little difference between aeration inside and outside the planting pit but the data did indicate the presence of some compaction within the pits between 30 and 45 cm. There appeared to be less waterlogging during the autumn within pits in the turf area than in the gravel or paved area, possibly because of interception and transpiration of rainfall by the grass sward and the unimpeded infiltration of rain water over the entire rooting zone.

Table 2: N:P:K balance in the study trees in relation to the optimum (2)

	gravel	paved	turf	optimum
				10:1:5
1990	11:1:13	12:1:15	13:1:6	
1991	11:1:11	10:1:10	13:1:7	

Soil Dry Bulk Density. The bulk density of a cultivated loam top soil is about 1.3 g/cm^3. At bulk densities above 1.5g/cm^3 root growth can be reduced (22) and values above 1.7 g/cm^3 can physically impede root growth (23). The high soil bulk densities recorded on all three sites (Table 1) are likely to stem from the time of development. However, continued heavy pedestrian pressure on the gravel area is reflected in its particularly high bulk density.

Soil Moisture Tension. During the 1990 growing season, moisture was in short supply in the turf site (Figure 3) due to competition from the grass sward (6). Moisture availability in the paved area was relatively good, particularly in the early summer, the surface acting as a "concrete mulch" (3). In 1991 moisture was in shortest supply in the gravel area. This is likely to be related to the highly compacted nature of the gravel and the fact that much of the rainfall in the summer of 1991 was heavy (Figure 4). The layout of the gravelled central reservation was such that rainwater had to move only a short distance across the capped surface to be lost down storm drains. The paved area, where run off of rainwater might also have been expected, had no storm drains and much of the runoff would have been into the planting pits. In the turf area, rainwater infiltrated the entire rooting zone. Characteristic of both years was two periods of high soil moisture tension during the summer, separated by a short period of low tension due to rainfall. The rapid increase in soil moisture tension in the second period reflects the high rate of transpirational water loss from the trees at this time of year.

Relationships between Variates

Regression analysis was used to explore the relationship between site factors and tree performance. Individual regression analyses were undertaken in which the measures of tree performance and foliar essential element concentrations were related to the assessments of soil physical conditions. A second set of analyses compared tree performance with foliar essential element concentrations. In addition to within year comparisons, 1991 tree performance indicators were compared to 1990 site factors. Variations in the data were best explained by separate regression equations for each site (Figure 5). In most cases these separate regression lines were parallel, indicating a consistency of tree response to assessed site factors on each site, but at the different levels indicated by the site means (Table 1).

Regression comparisons were disregarded

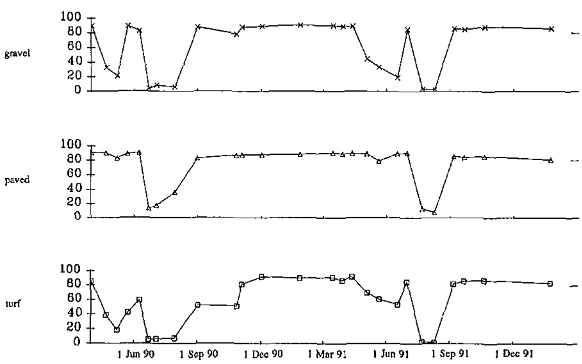


Figure 3: Soil moisture tension over the study period (100=field capacity; 0=wilting point).

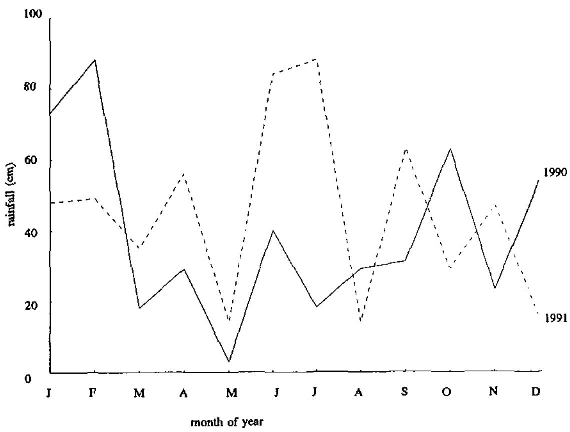
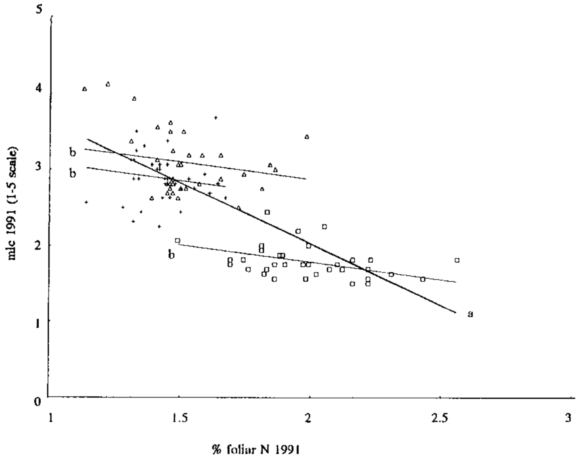


Figure 4: Rainfall over the study period (source: the UK Meterological Office).

unless significant at $P<0.05$ (ie. less than a 5% probability of the relationship being by chance) and explaining at least 20% of the variation in the data. In the two years of assessment both site physical and chemical factors were found to be related to tree performance (Table 3). Most closely related to tree performance were, in 1990 the degree of moisture stress during the growing season and foliar N and K concentrations, and in 1991 spring soil aeration, and foliar N, K and Mg concentrations. There were also relationships between foliar concentrations of N and K, and soil moisture related factors.

In 1990, high soil moisture tension during the summer resulted in yellower foliage despite a positive correlation between moisture tension and foliar N and K concentrations. No other relationships between site factors and growth parameters were detected in 1990, probably because sustained high soil moisture tensions did not occur until mid June, by which time the trees had already put on much of that year's growth. Foliar N and K concentration increased with increasing moisture tension because of a concentration effect as tree growth was limited by moisture stress (7). In 1991 the spring and summer were wetter than those of 1990 and hence soil moisture tension was not closely correlated with tree performance. However, high spring rainfall in 1991 resulted in poor soil aeration during the spring which was associated with yellower foliage, reduced N uptake and smaller leaves in 1991. The smaller and yellower leaves



a: n = 105, mlc1991 = 5.266 - 1.627 %N1991, 55% variance accounted for.
b top (paved): n = 35, mlc1991 = 3.787 - 0.459 %N1991, 76% variance accounted for.
b middle (gravel): n = 35, mlc1991 = 3.543 - 0.459 %N1991, 76% variance accounted for.
b bottom (turf): n = 35, mlc1991 = 2.699 - 0.459 %N1991, 76% variance accounted for.

Figure 5: An example of the nature of regression relationships on the three sites: 1991 mean leaf colour (mlc) (1: dark green, 5: yellow) against 1991 foliar N concentration, "a" when data for the three site types are analysed together and "b" when data for the three site types are analysed separately. Triangle=paved; plus=gravel; square= turf.

are likely to have resulted from the limit imposed by anaerobic conditions on spring root growth and N uptake.

In both years of the study, higher foliar N concentration resulted in greener leaves. In 1990, the lack of correlation between foliar N concentration and other growth parameters indicates that other factors, such as moisture stress, were confounding the relationship. In 1991, leaf area was positively correlated to foliar N levels, as was shoot extension in the gravel and paved areas. This is consistent with the results of other studies of urban trees (5,18). In the grass area there was a negative correlation between foliar N levels and shoot extension for which there is no obvious explanation. The high levels of foliar N in the trees in turf resulted from fertilizer application. Details of applications were not available due to the disbanding of the Milton Keynes Development Corporation during the period of the study.

Table 3: Summary of comparison of site factors and tree performance indicators by linear regression (VAF - variation accounted for).

Relationship between tree performance, and site factors and foliar nutrient concentrations	
+ 1991 shoot extension	
	- 1990 moisture stress (VAF 57%)
	+ 1991 N in gravel and paved area (VAF 59%)
	- 1991 N in turf area (VAF 59%)
	- 1991 K (VAF 55%)
	- 1991 Mg (VAF 55%)
greener 1990 leaf colour	
	- 1990 moisture stress (VAF 84%)
	+ 1990 N (VAF 89%)
	+ 1990 K (VAF 84%)
greener 1991 leaf colour	
	- 1990 moisture stress (VAF 75%)
	+ spring 1991 aeration in planting pit (VAF 77%)
	+ spring 1991 aeration in top 30cm outside pit (VAF 75%)
	+ 1991 N (VAF 76%)
	+ 1991 K in gravel and turf area (VAF 78%)
	- 1991 K in paved area (VAF 78%)
+ 1991 leaf area	
	- 1990 moisture stress (VAF 49%)
	+ spring 1991 aeration in planting pit (VAF 49%)
	+ 1991 N (VAF 49%)
	- 1991 K (VAF 49%)
	- 1991 Mg (VAF 52%)
+ 1991 crown density	
	+ 1990 moisture stress (VAF 26%)
	- 1991 K (VAF 23%)
Relationships between foliar nutrient concentrations and site factors	
+ 1990 N:	+ 1990 moisture stress (VAF 76%)
+ 1991 N:	+ 1990 moisture stress (VAF 67%)
	+ spring 1991 aeration in planting pit (VAF 66%)
+ 1990 K:	+ 1990 moisture stress (VAF 69%)
+ 1991 K:	+ 1990 moisture stress (VAF 69%)
	- spring 1991 aeration in top 30cm outside pit (VAF 68%)

Foliar K concentration was found to be positively correlated to leaf colour, but negatively correlated to stem diameter, shoot extension, leaf area and crown density. Similar negative correlations with growth parameters have also been encountered in studies of fertilizer application around mature amenity trees (10). This appears contrary to positive relationships found in some other studies (18,24) and has three possible explanations:

- a negative reaction to high foliar K concentrations, although this is unlikely (9);
- a negative reaction related to the imbalance of N:P:K (Table 2);
- a K dilution effect resulting from enhanced growth due to increasing N uptake. K is a highly mobile cation and, unlike N, is not incorporated into the structure of plant tissues (21). Rapid tree growth can, therefore, reduce the concentration of a finite pool of K in the leaf tissues (20).

As well as within year relationships, site conditions in 1990 affected tree performance in 1991. Soil moisture tension in 1990 was negatively correlated with 1991 shoot extension, leaf colour and leaf area, but positively correlated with 1991 crown density and foliar N and K concentrations. It is well established that conditions in one growing season can affect tree performance in the next (16). The mechanisms most likely to be influencing the Milton Keynes study trees were reduced carbohydrate storage due to drought stress (8) and root suberization and damage due to drought stress (25). The positive correlation between 1990 moisture tension and 1991 crown density may be a result of reduced 1991 shoot extension, and hence shorter distance between leaf nodes, creating the appearance of a denser crown. The positive correlation with foliar N and K concentrations probably resulted from the concentrating effect of reduced 1991 growth.

Discussion

Arboriculturists are frequently confronted with slow growth and poor health in amenity trees and must judge whether the tree should be removed or, if not, what treatment or combination of treatments is most likely to improve tree performance. Such judgements are difficult to make even in the relative simplicity of a rural environment where the properties of soils are more predictable and reasons for poor performance are generally related to natural agents. In the urban environment the situation is much more complex. Soils tend to be extremely variable, urban surfaces influence soil conditions, and the intensity of human activity can result in a multitude of intentional and incidental influences on tree performance.

The Milton Keynes study showed that assessed site factors did not always follow expected trends. In the dry summer of 1990 moisture stress was greatest in the turf area due to competition from grass sward. However, in the wet summer of 1991, moisture stress was greatest in the compacted gravel area as intense summer rain fall was lost down storm drains. Contrary to expectation, foliar nitrogen concentration was highest in the trees in turf despite competition for nitrogen with the grass sward (12), because of disparate fertilizer application regimes. Drought stress in one year reduced the performance of the trees in the following growing season.

The study area was divided into three discrete sites which had different surface types, experienced different pressures during and resulting from the development phase, and were subject to different management regimes due to the organization of the city authorities. There were clear differences in the performance of the study trees between the three sites. All of the annual measures of tree performance consistently showed the superior performance of the trees in turf relative to the trees in the paved and gravel areas. This result was unexpected and ran counter to the results of a survey of 3600 street trees (11) which found that trees in turf tended to grow more slowly than those in paved areas due to competition for moisture with the grass sward. This was further shown by the relatively good growth rates of trees in shrub beds and the particularly good growth of trees in bare earth.

Whilst these trends might be true over a large and diverse population of trees, the Milton Keynes study has shown that it cannot be assumed for any particular group. Within each of the three sites shoot extension, leaf colour and leaf area were, as would be expected, negatively correlated with increasing moisture stress. However, when comparing the three sites this was not the case as factors other than moisture stress, particularly nitrogen availability, appeared to be influencing tree performance.

Over the study period, of the parameters assessed, summer soil moisture tension, spring soil aeration, and foliar nitrogen and potassium concentration showed the strongest relationships with tree performance. Furthermore, some of the soil moisture related effects on tree performance appeared to be best explained in terms of their influence on the uptake of nitrogen. The importance of relationships involving foliar potassium may be due to the marked differences in N:P:K ratios between the three sites. This may not a common situation for urban trees, but it does highlight the need to consider the balance of available essential elements as well as absolute levels when considering the essential element needs of amenity trees. The application of a general purpose N:P:K fertilizer may not always be the most effective approach.

Assessment techniques. One of the objectives of the study was to examine and develop methods of assessing urban soils and relevant aspects of the performance of amenity trees. Leaf colour and shoot extension were found to be the most sensitive indicators of tree performance. They are also practical to undertake as long as there is access to the crown, and indicative of the aesthetic contribution of an amenity tree. These measures have been used to monitor the response of trees to remedial treatments, enabling objective assessments of success to be made (13).

As in an earlier urban tree study (5), there was no strong relationship between soil bulk density and tree performance. This may be due to the limits of the sampling frequency but may also raise questions concerning the relevance to tree performance of bulk density assessments per se:

- Because of the vertical and horizontal variability of urban soils the sampling frequency required to gain an accurate picture of soil bulk density is very high. In this study, as in most situations, additional bulk density assessments were not practicable, particularly under hard surfaces.
- Bulk density is an abstract measure which, apart from penetration resistance, is only important in respect of tree growth for the effect it has on other soil characteristics such as moisture and air holding capacity.
- The assessment of soil bulk density may give a misleading impression of the ability of a soil to support root growth. A soil may have peds of high bulk density but a system of fissures and cracks may support extensive root growth.

The assessment of soil aeration using steel rods was found to be a much more revealing indicator of soil conditions than bulk density assessment. The technique is more appropriate to the diagnosis of poor performance in urban trees because:

- it yields information on soil aeration and waterlogging, factors that directly affect tree performance;
- it assesses conditions in a continuum down through the soil profile, which is particularly important in disturbed urban soils.
- it can be used through hard surfaces and in stony soils and allows a high sampling intensity.
- its ability to examine soil aeration over the seasons yields information on the dynamics of soil conditions in relation to the seasonal phases of tree growth.

The use of soil moisture tension blocks is also practical in urban situations and further adds to the ability to examine soil moisture relations over the growing season. The complementary benefits of using both methods was apparent in the study; during the dry year it was the soil moisture tension blocks that yielded the most valuable information, but during the wet year it was the steel rods that were most revealing.

This study shows the critical importance of the thorough investigation of site physical conditions before diagnosing the reasons for, and recommending the solution to, poor performance of urban trees. In some situations, digging of inspection pits and assessment of soil bulk density or penetration resistance may be practical and may give an indication of soil physical conditions at that point in time and space. In the Milton Keynes study, however, it was the assessments that looked at the dynamics of soil moisture and aeration over time that were most informative and most closely related to tree performance.

An assessment of the availability of essential elements is another key factor in the diagnosis of poor performance in urban trees. Foliar analysis is generally more revealing than soil analysis (19) as it reflects more accurately essential element availability to the tree. However, careful interpretation of results is required, keeping several points in mind:

- Levels of a particular elements in the foliage may be influenced by soil aeration and moisture availability as well as by absolute levels of the element in the soil.
- The interpretation of the foliar concentration of any essential element must be related to its balance with other elements as well as to its absolute level in the foliage.

Conclusion and Recommendations

In this two year study of 105 London plane trees, summer soil moisture tension, spring soil aeration and foliar concentration of nitrogen and potassium were found to be most closely related to tree performance. Summer drought stress in the first year of the study was found to influence tree performance in the following year. The most practical and informative means of assessing site parameters were the use of soil moisture tension blocks to measure soil moisture tension, steel rods to assess soil aeration, and foliar analysis to assess the availability of essential elements. The most sensitive indicators of tree performance were leaf colour and annual shoot extension.

The study indicates that the most effective means of establishing the relationship between tree condition and site characteristics requires assessment over time. In addition, if remedial treatments are applied, the effectiveness of treatments should be monitored over time. The results of this study point to the need for tree care regimes that respond to the findings of careful site assessments, involve targeted remedial treatments, and which monitor tree response to treatments. This approach is already well developed in the USA with plant health care programmes and integrated pest management (IPM) and should expand into all tree care programmes.

Practitioners involved with the diagnosis of poor performance in street trees require effective and practical means of assessing soil characteristics and tree condition. Whilst it cannot be concluded that the measures highlighted should be universally adopted at the expense of all others, the evidence of this, and the other studies referred to, supports their inclusion in the diagnostic process.

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Résumé. Une étude sur 105 platanes à feuilles d'érable (*Platanus acerifolia*) fut entreprise entre les mois de mai 1990 et 1992. Un tiers des arbres âgés de 25 ans se trouvaient dans du gravier compacté, un tiers sur une surface pavée et tiers sur une aire gazonnée. Des différences significatives quant à la performance furent découvertes entre les trios sites, tout comme des différences significatives dans la densité de la majeure partie du sol, l'aération (mesurée au moyen de tiges d'acier), la tension en humidité du sol et les concentrations foliaires en éléments nutritifs. Une analyse de régression fut utilisée afin d'approfondir ces relations. L'aération printanière, le stress relié au degré d'humidité estivale du sol et les concentrations foliaires en azote et en potassium furent les critères retrouvés comme ayant le plus d'influence sur la performance générale des arbres. Des conseils pratiques sont donnés quant aux implications de l'évaluation et de la surveillance des arbres en milieu urbain.

Zusammenfassung. Von Mai 1990 bis Mai 1992 wurden 105 Londoner Stadtplatanen (*Platanus acerifolia*) untersucht. Ein Drittel der 25-jährigen Bäume waren in verdichtetem Schotter, ein Drittel in einer gepflasterten Fläche, und ein Drittel in Torf gepflauzt. Signifikante Unterschiede im Erscheinungsbild an den drei Standorten fanden sich, wie auch Unterschiede in Bodenkörperdichte, Belüftung (gemessen mit Stahlstangen), Bodenfeuchtigkeitsspannung und der Nährstoffkonzentration im Laub. Eine Regressionsanalyse wurde benutzt, um diese Beziehungen zu untersuchen. Die Belüftung im Frühjahr, der Bodenfeuchtigkeitsstress im Sommer und die Konzentration von Stickstoff und Kalium im Laub hatten demnach den größten Einfluß auf das Baumerscheinungsbild. Praktische Hinweise werden gegeben für die Schlußfolgerung auf Untersuchung und Überwachung von Stadtbäumen.