A PRACTICAL GUIDE TO THE USE OF STEEL RODS FOR THE ASSESSMENT OF AERATION IN URBAN SOILS

by S. J. Hodge and K. Knott

Abstract. Diagnosing the reason for poor performance of urban trees requires a means of evaluating soil physical conditions. Soil aeration status can be inferred from the corrosion of steel rods inserted into the ground. The technique is inexpensive, non-destructive and can provide information on the vertical distribution of anaerobic conditions. Practical aspects of the use of steel rods and their interpretation are described.

Diagnosing the reason for poor performance of urban trees requires a means of evaluating site physical conditions; sometimes below hard urban surfaces. The UK Forestry Commission's Research Division (with funding from the UK Department of the Environment) has developed the steel rod technique for the assessment of aeration in urban soils. The use of the steel rod technique in forest research was pioneered in the UK by Carnell & Anderson (1), and development of methods of analysis and interpretation are detailed in Hodge et al (2).

Oxygen is one of the basic requirements for the survival and functioning of tree roots, most of which must be absorbed from air in the soil. The rusting characteristics of steel rods can be interpreted to infer the spatial distribution of aeration in an urban soil.

Planning to use steel rods. Rods are inserted in the soil to a depth of 60 cm (2 ft) for three month periods and it is useful if these periods relate to the four seasons. While much information can be gained from rods inserted during a single season, the best interpretation of soil aeration characteristics comes from a comparison of corrosion patterns between the seasons, or at least between spring and summer.

Rods should be inserted into the ground close enough to the tree stem to be within the rooting zone. For well established trees the insertion of rods into planting pit soil should be unnecessary but for recently planted trees, conditions in the planting pit must be assessed. Rods can be used to evaluate the contrast in conditions inside and outside the planting pit.

The number of rods inserted around each tree depends on the number of trees to be investigated, the size of each tree and the expected variability of soil conditions. We have used four rods per tree for mature trees, three rods per tree for semi-mature trees (including one rod in the planting pit), but only one rod per tree in the planting pit for recently planted trees. If the soil is being evaluated around very few trees, rod numbers should be increased to allow reliable conclusions to be drawn. Extracting rods from hard or stony ground can be difficult, particularly if they have bent during insertion. Some of the corrosion information can be lost on extraction, so additional replicates are advisable in these situations.

Before inserting rods, information on underground services must be obtained.

Preparing, inserting and extracting steel rods. Rods are 60 cm long, 6 mm wide and made of bright mild steel (U.K. industrial specification E.N.1.A non-leaded, low sulphur content). One end of each rod should be pointed and the other should have a groove around it to aid extraction. The groove should start 3 mm from the top of the rod, should be machined to 1 mm deep and 5 mm wide. Steel must be free of rust when purchased and have a coating of engineering oil to prevent corrosion prior to its insertion into the ground.

Table 1 details the equipment required to insert and extract steel rods. On arrival at the site the first task is to confirm the location of any underground services present. As an additional precaution, while inserting steel rods, rubber-soled boots, a

Table 1: Equipment required for the insertion and extraction of steel rods

For insertion
Steel rods
Paper towels
Insertion tool (Figure 1)
Insulated rubber gloves (high voltage specification)
Rubber mat
Cable avoidance tool and relevant plans of underground services
For removal
Spade (to find rod tops in soil of turf)
Initial levering tool (Figure 2)
Blocks for increasing fulcrum height of levering tool
Locking pliers
Extraction jack (Figure 3)
Bucket
Cloths for swabbing
Plastic bags to hold cloths
10% v/v ammonia solution
Quiver and latticed frame to transport rods
Labels and indelible pens
Protective goggles, rubber boots, rubber gloves and waterproof coverall
Clean water and eyebath.

rubber mat and gloves safe to 4000 volts were used.

One of the benefits of the steel rod technique is that soil aeration can be assessed beneath hard urban surfaces. Rods can be driven through thin layers of tarmac or the depths of hardcore usually encountered. However, to insert rods through thick tarmac, concrete or paving slabs, holes must be drilled to the depth of the material. Care must be taken to drill no lower. The use of 6.5 mm masonry drill bits results in a close fit when rods are inserted. We have inserted rods through as much as 25 cm (10 in) of concrete, drilling holes with a heavy duty hammer-drill powered by a mobile generator. If rods are not tight fitting when inserted, water and air ingress can be prevented by sealing the gap with a putty or resin.

Before inserting each rod it must be thoroughly wiped with an absorbent paper towel to remove the protective film of oil. The rod is then driven vertically into the ground using a purpose designed tool (Figure 1) which holds the rod upright and stops it from vibrating during the insertion process, thus ensuring good contact between rod and soil to prevent contact with atmospheric air. Rods should be driven in until the top of the rod is flush with the soil level or 8 mm (.3 in) above the level

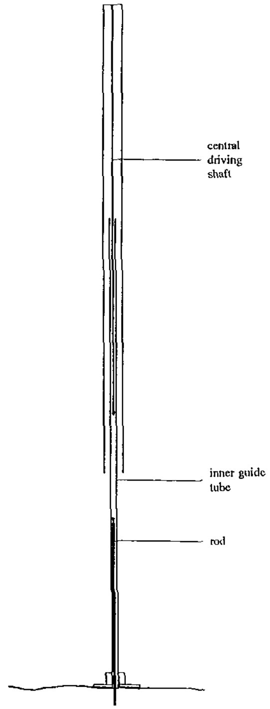

Figure 1: Tool for inserting steel rods.

of the hard surface (to facilitate extraction). In hard surface areas rods must be located to avoid this protrusion presenting a hazard to pedestrians, or a recess must be provided to allow subsequent extraction of flush rods.

The exact location of each rod must be noted for retrieval. Particular care is needed in recording location of rods inserted into bare soil or grass sward which can become totally obscured after three months.

After three months, corrosion patterns will be well developed and rods should be removed. Two tools have been developed to extract rods. The first (Figure 2) levers the rod out of the ground far enough to attach the extraction jack (Figures 3 and 4) which, with its fine pitch thread, steadily extracts the rod vertically from the ground. If inserted into bare soil or turf small numbers of rods may be extracted using locking pliers, first giving a sharp twist to break the bond between the rod and the soil. Rod extraction can be a strenuous job but it must be undertaken with care to ensure that the patterns of corrosion are not damaged.

After extraction the rod should be immediately

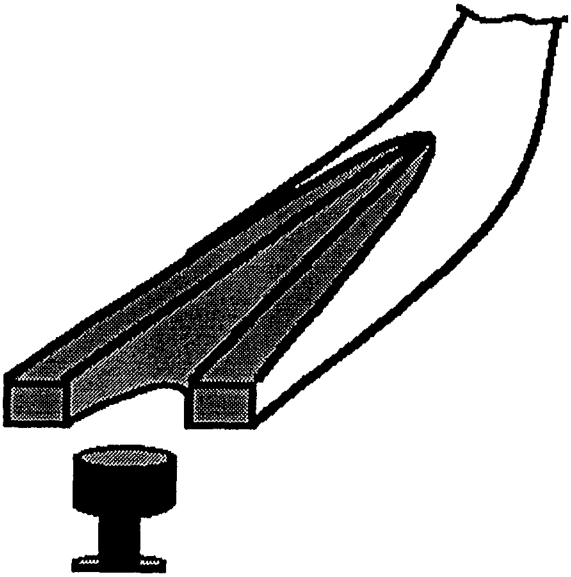

Figure 2: Levering tool for extracting rods.

swabbed with a fabric cloth soaked in a 10% V/V solution of ammonia to remove any soil and to stop further rusting from any moisture remaining on the rod. The cleaning action must be one of squeezing rather than rubbing and some rods require considerable swabbing with a saturated cloth to remove excess soil. A little practice is needed to develop the most effective swabbing action that removes soil but not rust. During this operation goggles, rubber gloves, rubber boots and a waterproof coverall are worn.

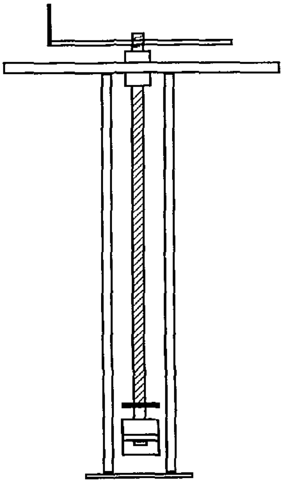

Figure 3: Jack for extracting steel rods.

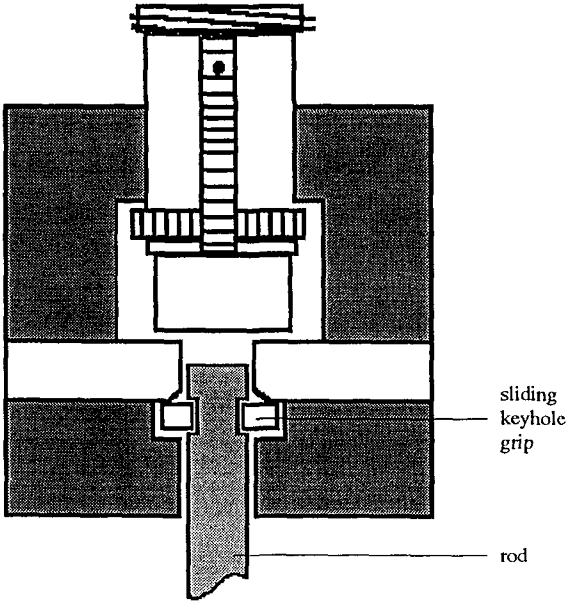

Figure 4: Detail of rod coupling on extraction jack.

Secondary rusting of rods starts very quickly after extraction. Only a few rods should be extracted at a time before swabbing. If possible the extraction of rods during wet weather should be avoided because of secondary rusting problems. Once swabbed, each rod is labelled and carried in a quiver that can be slung across the back. The quiver is made from plastic drainage pipe and has a grid at the top and bottom which serves to keep the rods apart. When back at the vehicle the rods are transferred to a larger box frame which is designed also to keep the rods apart to avoid damage to rusting patterns in transit. Rods must be kept in a dry atmosphere until they are assessed, to prevent subsequent superficial rusting.

If rods are being inserted for a subsequent season, their location must be 10 cm (4 in) away from the hole of the previous rod to avoid any influence on the new rod. Where drilled through concrete or paving practical considerations may mean that the holes must be reused. If this is the case holes should be reused only once and the seal at the surface must be good.

Interpretation of rusting patterns. Five types of surface may be encountered on steel rods that have been in the soil for three months.

Red/brown rust: Indicates a well aerated soil.
Raised black: Occurs where rusting has started but has been interrupted, or where rust has been knocked off during removal of the rod from the ground.
Shiny metal: Can indicate the presence of substances (usually polyphenols or oil products) which have protected the rods from rusting. These can arise from organic residues that are under anaerobic conditions. However, in laboratory tests substantial amounts of shiny metal remained after three months in soils with no organic horizon. Its presence was most common in dry, coarse textured soils and was a result of the action of 'differential aeration cells' (2).
Smooth black: Occurs where anaerobic bacteria utilize soil sulphates producing hydrogen sulphide, which reacts with the surface of the metal.
Matt grey: Indicates totally anaerobic conditions.

For the purpose of assessment, smooth black and matt grey can be treated together as indicating the presence of anaerobic conditions. Red/brown rust and raised black indicate aerated conditions. The presence of substantial amounts of shining metal cannot be used as an indicator of suitability for root growth. A controlled rod rusting experiment was set up to determine typical rusting patterns for different soil moisture regimes. This experiment is detailed in Hodge et al. (2).

Assessment of corroded steel rods. Three forms of assessment have been used by different researchers (2). The first assessment is simply to record the depth of red/brown rust, and to relate this to the depth of the onset of waterlogging. The second form of assessment is to measure the depth to the first patch of matt grey corrosion greater than 3 mm across (indicating the onset of anaerobic conditions) and the depth at which almost continuous matt grey corrosion starts (indicating the depth of conditions totally inhibiting for rooting). The zone between these two measurements is interpreted as less favourable for rooting but not totally inhibiting to root growth.

These measures may be adequate to determine the depth of onset of waterlogging or potential rooting depth in relatively undisturbed soils. However, for the use of steel rods in urban soils, these simple measures do not adequately express the information offered by the rods. Urban soils are characterized by a high level of disturbance with no clear profile formation. Soil forming materials are often imported to the site; replacing, being mixed with or put on top of the disturbed natural soils. This, and the presence of non-rootable material and underground utilities, means that the aeration of urban soils cannot be easily determined. Consequently, a form of rod assessment was designed to utilize more of the information that could be derived from the rods throughout their 60 cm depth.

The rod is laid along a meter rule with the ground level at 0 cm. The assessment made is of two categories; matt grey and smooth black combined, and shiny metal. By inference, the corrosion not assessed is red/brown rust and raised black, both indicative of the presence of oxygen for at least part of the period. The presence of the two categories along a line down the rod is recorded on a form (figure 5), which is divided into 3 cm sections. The minimum length of a corrosion patch that is recorded is 0.5 cm. When corrosion down the first line has been recorded, the rod is turned through 180o and the process repeated.

The data recorded must now be translated into numerical form. For each 3 cm band down a rod there are a maximum of 12, 0.5 cm sections that can show any corrosion type (6 x 0.5 cm on one side of the rod and 6 x 0.5 cm on the other). The information on each corrosion type from the diametrically opposed assessment lines down the rod is thus presented as a score of 0 to 12 for each 3 cm rod section. These data are collected on an assessment form and used for analysis or histograms. Initially scores for matt grey/smooth black and shiny metal can be combined to form a score for inhospitable soil conditions. However, if results prove inconclusive, and the presence of shiny metal is substantial, the scores for matt grey/smooth black alone can be used for a reconsideration of the profiles.

Data analysis and presentation. Statistical analysis of major rod data sets has been undertaken using principal component analysis (2). This procedure identifies patterns in the corrosion data which explain the variation between rods. Principal component analysis has identified the two major components for the 945 rods used over three seasons of a study of urban plane trees (3).

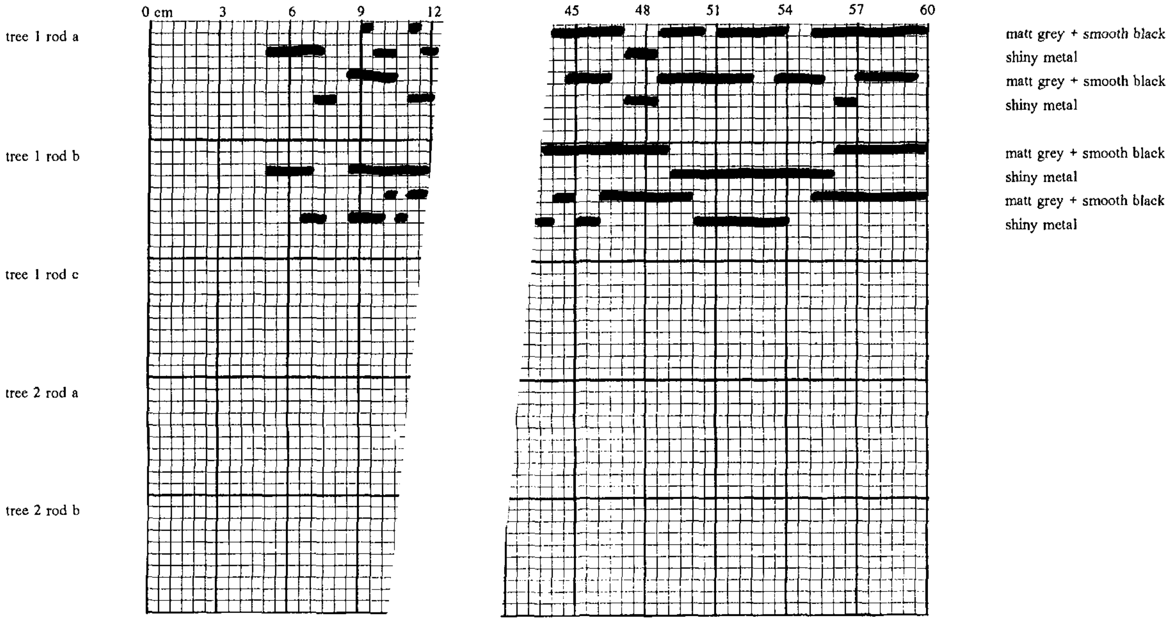

Figure 5: Form for the assessment of steel rod corrosion patterns.

The first component reflected the total score of anaerobic conditions for each rod. The second component reflected a contrast between the score of inhospitable conditions in the top 30 cm with that in the bottom 30 cm.

In some situations the mean proportion of anaerobic conditions for a particular tree or site can be revealing. A contrast of conditions in the top 30 cm of soil with 30 to 60 cm adds more information. These two expressions of the data can be used to compare rods by analysis of variance. However, often of most value for practitioners is a graphical representation of the presence of anaerobic conditions. Figure 6 shows the mean rod profiles over three seasons expressed as the percentage of each rod that is anaerobic in each 3 cm band down through the soil. The profiles from the paved area show the effects of a seasonally fluctuating zone of saturation. The profiles from the gravel area show the effect of the seasonal saturation on the bottom 20 cm of the rod, but indicate the presence of a compacted layer between 10 and 30 cm.

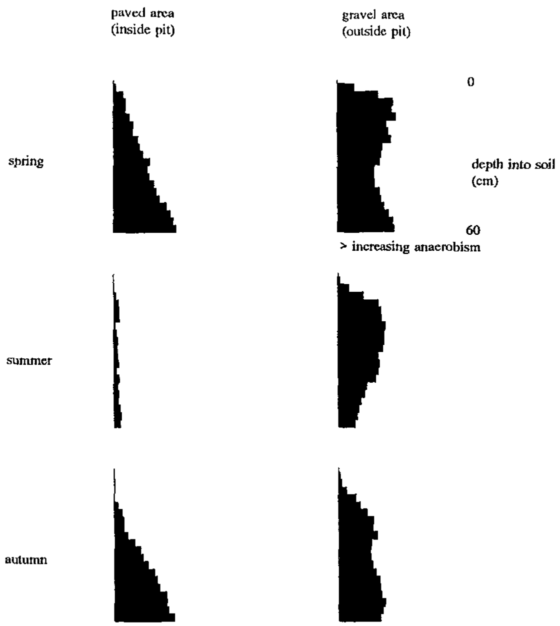

Figure 6: Rod profiles over three seasons from a paved area and a compacted gravel area.

Conclusion

The steel rod technique is a practical and relatively inexpensive means of assessing the aeration status of urban soils. The technique can be used to examine the vertical distribution of anaerobic conditions down through a soil. Comparison of rod information between seasons can show whether anaerobic conditions are due to saturation and/or compaction. Steel rods can can be used to assess aeration under hard surfaces without disturbing the site.

Detection of the cause of decline of mature urban trees, or slow growth of young trees, is notoriously difficult. The steel rod technique can provide information on soil conditions that allows precise targeting of remedial treatments. With an increasing trend towards the PHC (plant health care) approach to tree care, the time requirements for data collection need not be a constraint. The ability to depict visually the condition of soil that cannot otherwise be observed is a compelling advantage of this technique.

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Résumé. Diagnostiquer le pourquoi de la faible perfomance des arbres en milieu urbain exige des moyens pour évaluer les conditions physiques du sol. Le degré d'aération du sol peut être déduit à partir de la corrosion de tiges d'acier insérées dans le sol. La technique est peu onéreuse, non dommageable et peut fournir des indications sur la distribution verticale des conditions anaérobiques. Les aspects pratiques sur l'emploi de tiges d'acier et son interprétation sont donnés.

Zusammenfassung. Eine Diagnose der Gründe für ein armes Erscheinungsbild von Stadtbäumen erfordert Mittel und Wege, die physikalischen Bodenbedingungen zu bewerten. Der Status der Bodenbelüftung kann geschlossen werden aus der Korrosion von Stahlstangen, die in den Boden eingelassen werden. Die Technik ist billig, nicht destruktiv und kann Informationen liefern über die vertikale Verteilung von anaerobischen Verhältnissen im Boden. Praktische Aspekte vom Gerbrach von Stahlstangen und der Interpretation der Ergebnisse werden hier beschrieben.