A CRITICAL ANALYSIS OF THE ROLE OF TREES IN DAMAGE TO LOW RISE BUILDINGS

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Abstract. Trees have been blamed for damage to building foundations in the United Kingdom This has resulted in large numbers of high value insurance claims Trees exert their influence through removal of moisture from clay soils The existing data do not adequately explain the problem A review of the situation as related to trees, biology, soil, water relations, and the effects of climate is presented. The published data are shown to be inadequate. A working model of how trees affect clay soils is proposed which explains the observed patterns. The need for greater interaction between the consulting arborist and the structural and building professionals is emphasized.

In Britain, there has been an increasing concern for the level of damage caused to built structures, mostly private dwelling houses, as a result of alleged tree-induced subsidence Damage has resulted in a large volume of insurance claims Within the London metropolitan area, claims against the Borough Councils alone have exceeded £23 million during the period 1988-1992 [20]. Nationally during the same period claims exceeded £1 6 billion [12].

Insurance policies for buildings have for many years carried a 'ground movement' element of coverage. In the early 1970's this was offered as a policy "sweetener," i e , free cover as insurance carriers competed for business. Following the dry period of 1975/76 there was a large increase in the volume of claims, subsequently free subsidence coverage was removed. Attention has focused upon trees as the causal agents for many claims.

History of the problem. Following the drought of 1975/76 and the increase in insurance claims, the interaction between man-made structures and the clay soils upon which they are built, and the trees growing in that same soil received much attention. The common conclusion was that where a tree is growing close to a building, moisture is extracted from soil by the tree, which causes clay soils to shrink, leading to subsidence and failure of foundations. When the soils rewet, they swell, causing heave and associated damage. That this happens everywhere clay soils occur has assumed the status of *scientific fact* which is often cited by surveyors and engineers and from which it is proving difficult to shift opinion.

The need for research to investigate the relationship between trees, soil and buildings became clear. This research was undertaken by various organizations and has resulted in a number of well known and often cited publications, two of which are the National House Building Council's (NHBC) Practice Note 3 *Precautions when Building Near Trees* [26] and the Kew Root Survey [8]

The Building Research Establishment (BRE) has produced a number of publications on the subject [5,6]. Likewise the NHBC has revised the Practice Note 3 [26] and included it in their Building Standards, Chapter 4 2, *Building Near Trees* [27]. (The NHBC offers a 10-year guarantee for new properties but these must be built and certified in accordance with the NHBC Standards)

Claims. Claims continued to rise and by 1990/1991 were in excess of £500 million per year [12] (Fig 1). Despite all the information which went to produce the BRE Digests, the NHBC Chapter 4.2 and other publications, the claims problem is still occurring. Since the first escalation following the 1975/76 drought and subsequent court actions, notably *Greenwood-v-Portwood CLY 1985*, which held that trees had been responsible for subsidence leading to building damage, the building professionals, i e , surveyors and engineers, seem to have assumed that if a tree is growing close to a building that is exhibiting signs of subsidence damage, the tree is responsible for that damage. These assumptions are usually based on limited data

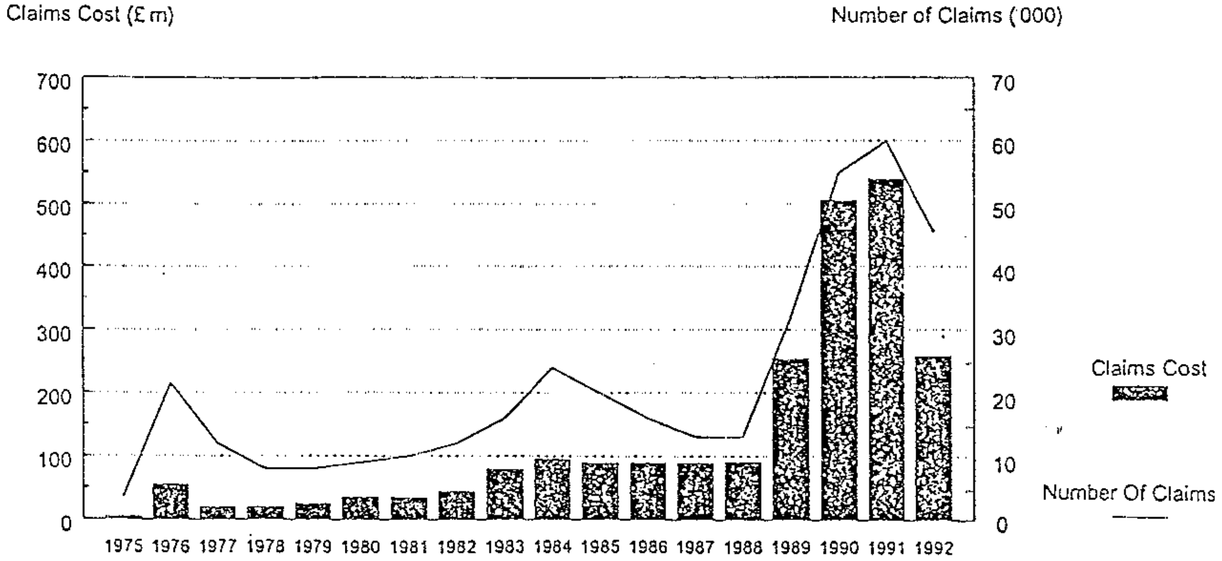

Fig. 1. Annual value of insurance claims for subsidence and heave damage to housing. From *ISE, March 1994 (12).*

The Basis for Current Practices

The soils. Clay soils have been classified as being shrinkable when the volume can be shown to change with the addition or abstraction of water. The usual measure of a soil's potential to shrink (subsidence) and to swell (heave), is the Plasticity Index (PI). This is a measurement of the moisture content of clay soils between the plastic and liquid limit (Atterburg limits) [4]. The NHBC [26,27] have, for the purposes of their *Standards of Building Near Trees,* classified clay soils as high, medium or low shrinkage potential based on the PI of the soil (Table 1).

Trees do extract moisture from the soil in which they grow and the main way in which moisture gets into the soil is by precipitation. Analysis of the British climate suggests that evaporation almost always exceeds precipitation in the period of greatest tree activity, May through October, in the English lowlands [19,24,25]. This results in the production of a seasonal soil moisture deficit (SMD). In an urban environment, trees need to obtain water as not all the precipitation reaches the soil. Some is intercepted by canopy foliage, some runs off, some is taken by other vegetation, thus compounding the deficit. Therefore, during dry weather, trees must extract more and more moisture from greater and greater soil volumes to keep their physiological processes functioning. This can contribute to the drying and cracking of clay soil and thus to subsidence with resultant foundation damage. It should be noted that much of the UK housing stock is built on shallow concrete strip foundations and that basements are relatively rare; timber framed houses are also rare.

Water demand of trees. For insurers the main reason for implicating trees in claims is a result of their requirements for water and this has been called their *water demand.* However, the water demand of individual trees is not known and is

Table1. Soil classification in relation to plasticity index. From *NHBC Chapter 4.2 (27)*

Plasticity index**	Shrinkage* potential
>40%	High
20 - 40%	Medium
10 - 20%	Low

* Shrinkable soils are those containing more than 35% fine particles (silt and clay) and have a plasticity index of more than 10%

**Plasticity index is related to shrinkage potential as shown. If the shrinkage potential is unknown high shrinkage potential should be assumed.

difficult to measure. Attempts to do this using a combination of leaf area index and pan evaporation rates has yielded some success [18], although the methods need to be refined. However, the term *water demand* has not been defined by any of the publications which refer to it continually. For the present purposes the following definition is proposed:

The amount of water required by a tree in order to keep its metabolism functioning at optimum levels to meet its physiological requirements.

Such a definition of water demand has not been attempted before in the arboricultural literature and certainly not in NHBC Chapter 4.2 [27] and the Table of Relative Water Demands and Mature Height of Trees in that Chapter, i.e., Table 4.2B, which is reproduced here as Figure 2. Note that trees are ranked as high, moderate or low in their demand for water in this table. Yet there are no published scientific data on water demand of mature trees to support such a classification. Data published by Biddle [1,2] on the patterns of soil drying and moisture deficits as measured by a neutron probe in the vicinity of trees, has been taken as meaning *Water Demand*. Indeed, Biddle confirms that the term *water demand* in this context is not accurate in biological terms, but the concept in this instance refers to the *lateral extent, depth and intensity of soil drying which is achieved by different tree species* (Biddle, 1993, Pers Comm.)

Experimental data published by Biddle [2] and supported to some extent by the work of Messenger & Ware [23] was produced by neutron probe analysis of soil moisture levels and deficits. While the probe does measure soil moisture levels, there is no allowance in either set of data for the influence of other vegetation in the area where the measurements were made, nor was any attempt made to locate the roots of the trees whose "demand" was being measured. In addition no controls were reported in either experiment. There is also some doubt as to the reliability of the neutron probe to accurately measure soil moisture contents in aerated and fissured upper soil horizons [13].

The term *water demand* continues to be interpreted biologically by arborists. The target audience for the Building Standards is builders [26,27]. The term was not designed for use by arborists but it has been used by them throughout its publication history. Advice provided to builders by arborists often relies heavily upon this publication, Table 4.2B and the data contained therein

It must be remembered however, that the amount of water taken up by the tree can and will vary through the seasons and with changes in physiological activity. It is important that the amount of moisture extracted from soil by trees is examined and quantified separately from the other mechanisms by which moisture is lost to the soils, i.e., interception of precipitation by tree canopy and man-made structures, evaporation, albedo, surface run off, etc. Only canopy interception is the result of the biological activity of trees and other vegetation. If the contribution of trees to the soil moisture loss equation, and thus, their contribution to deficits, subsidence and possibly structural damage, is to be a factor in claims, then it must be separated and quantified accurately.

Trees & damage. A correlation between trees and damage to buildings was attempted by the Royal Botanic Gardens at Kew [8]. The survey database comprised root samples and record cards compiled by professionals working in the field (loss adjusters, surveyors, structural engineers, arboriculturists, etc.) and sent to Kew for identification and compilation. The record cards were completed when a tree was suspected of causing damage. Various common species were then classified with regard to the following: 1) maximum tree-to-damage distance recorded, 2) normal maximum tree height on shrinkable clay in urban areas, and 3) proportion of cases of damage occurring within a certain distance from the tree on shrinkable clay soils. It should be remembered that the majority of these records were taken from trees within a 60 km radius of central London. However, these data have, and continue to be, erroneously cited by building and arboricultural consultants as representative of the whole country, regardless of varying climate and clay type

The concept that trees extract water from the soil and thus cause foundation damage, wherever clay soils exist, persists among most building

Broad leaved trees			Conifers			Orchard trees (take as broad leaved)		
Water Demand	Species	Mature height (m)	Water Demand	Species	Mature height (m)	Water Demand	Species	Mature height (m)
High	Elm		High	Cypress				
	English	24		Lawson s	18			
	Wheatley	22		Leyland	20			
	Wych	18		Monterey	20			
	Eucalyptus	18						
	Oak							
	English	20						
	Holm	16						
	Red	24						
	Turkey	24						
	Poplar							
	Hybrid black	28						
	Lombardy	25						
	Willow							
	Crack	24						
	Weeping	16						
	White	24						
Moderate	Acacia False	18	Moderate	Cedar	20	Moderate	Apple	9
	Alder	18		Douglas fir	20		Cherry	15
	Ash	23		Pine	20		Pear	12
	Bay Laurel	10		Spruce	18		Plum	10
	Blackthorn	8		Wellingtonia	30			
	Cherry			Yew	12			
	Japanese	9						
	Laurel	8						
	Wild	17						
	Hawthorn	10						
	Honey locust	14						
	Hornbeam	17						
	Horse chestnut	20						
	Laburnum	12						
	Lime	22						
	Maple							
	Japanese	8						
	Norway	18						
	Mountain ash	11						
	Plane	26						
	Sycamore	22						
	Tree of heaven	20						
	Walnut	18						
	Whitebeam	12						
Low	Beech	20						
	Birch	14						
	Holly	12						
	Magnolia	9						
	Mulberry	9						

Notes:

1
Where hedgerows contain trees, their effects should be assessed separately In hedgerows the height of species likely to have the greatest effect should be used

2
Within the classes of water demand species are listed alphabetically; the order does not signify any gradation in water demand

3
When the precise species is unknown the greatest height and highest water demand should be assumed

4
Further information regarding trees may be obtained from the Arboricultural Association of the Arboricultural Advisory and Information Service (see Appendix 4 2-G)

Fig. 2. **The relative "water demand" and mature heights of trees** From *NHBC, Chapter 4 2 (27)*

professionals and some arboriculturists The Kew Root Survey [8] and the NHBC Chapter 4.2 [27] are invariably being cited in support of this concept The relevance of both of these publications to the problem has been questioned [15,16,17,21,22].

In addressing the problems at a practical level, it is becoming obvious that the published data are not always consistent with the field results. Increasing claims costs and a need to solve the problems in the most cost effective way without major tree losses, is forcing a re-assessment of the situation. The problem consists of a number of parts: 1) Geographic Location (Geology, Weather, Climate), 2) Tree Biology and Actual Water Demand, and 3) Interaction of the Structural Professionals.

Shortcomings and the Need for Improvement and Research

To allow a thorough review of the present situation requires an assessment of the conditions prevailing in the urban or built environment. Such data are generally lacking and the only reliable data available on water loss from trees are from closed forest stands or potted specimens where control is possible [29]. In the forest situation it can be seen that oak and beech transpire approximately the same amount of water per day (Table 2) [29], which is at variance with the NHBC Classification of oak as high and beech as low in water demand [26,27].

How relevant these data are to the urban situation is difficult to determine. A single large tree in the urban environment is subject to varying conditions and pressures from that of the forest location. Research has shown that the availability of soil moisture to trees under these conditions is variable in the extreme [18], and attempts to calculate the soil volume necessary to provide enough water and nutrients to support a tree of given canopy size suggest that most urban trees are growing in poor situations without adequate volumes of suitable soil [30]. We must therefore expect many urban trees to be in a stressed condition and not performing to their full biological potential.

Table 2. Daily transpiration (mm) of four species in closed stands in Denmark. Data from Rutter 1968 (29)

	Cloudless summer day (no morning dew)	Mean June - August
Fagus sylvatica	4.1	2.9
Quercus spp	4.3	2.7
Fraxinus excelsior	3.3	1.7
Picea abies	3.6	2.4

Towards a model. The production of fine, non-woody roots, root hairs, etc., are dictated by soil conditions. These are susceptible to decreases in soil moisture and are quickly shed when soil conditions become unfavourable. Energy is required to maintain the non-woody roots and biological energy is generally not wasted.

Roots tend to be most active in spring and autumn when soil moisture is most likely to be available and temperature is favourable. At these times, roots are involved in supply of water and mineral nutrients for the generation of new tissues. In summer, root activity feeds the transpiration needs of the tree. However, as the usual summer soil moisture deficits begin and build up, trees need to conserve water. They will do so effectively by either seeking out water deeper in the soil, by a recycling of metabolic water and or readjusting their mass, or by transporting subsoil water reserves through the deep root system and then "dumping" this water in the upper soil horizons, via the primary root network, a phenomenon known as "hydraulic lift" [7].

However, as the deficits occur and build up in periods of drought, clay soils dry out and cracks / fissures appear in the clay. Clays, particularly those that can swell, show typical cracking patterns of large vertical cracks and a fall in soil surface with the remainder as fine cracks within the soil [28]. Cracking affects thermal conductivity of the soil which is an important parameter in the analysis of water flow, evaporation and soil temperature [28].

With the fissures comes new sources of water and air as porosity increases [28] to allow root extension down the fractured horizon. This allows the active and vigorous species to exploit deeper reserves of water and to survive the periods of drought more effectively than other species.

Some species have the ability to take advantage of this new rooting environment and thus it is suggested that trees can best be classified according to their *rooting habit,* rather than any hypothetical *water demand* as follows:

Deep rooting trees. Oak (*Quercus* spp.) for example, will quickly take advantage of the increasing oxygen availability at depth and a second ephemeral absorbing root system will be produced. This will occupy the subsoil until precipitation causes re-hydration and the fissures close.

Intermediate rooting trees. Linden / Lime (*Tilia* spp.) will respond more slowly to the availability of the fissures, especially if they are in competition with the deep rooting species. They can produce the second root system but seem to require a higher degree of drought stress to initiate growth, possibly a second consecutive year of drought.

Shallow (non-deep) rooting trees. European Beech (*Fagus sylvatica*) seem to have limited genetic capabilities to pursue moisture at depth. These are also the first trees to show external signs of drought stress.

The basis for this suggestion lies in the fact that the best place for absorbing roots to be is close to the surface. In a closed forest stand, the precipitation that reaches the floor will be absorbed first by the most superficial roots. If anaerobic clay soils exist, then roots are unlikely to be present. If they are present they may be under a great amount of biological stress.

Discussion

Trees can survive in lower volumes of soil than current research suggests that they need [18,30]. They survive in hostile urban environments where water availability is very unpredictable. But they survive because they seem to have a differential requirement for water over time and have developed effective management strategies in periods of extreme drought. The existing UK models are oversimplified and unconfirmed. Much more fundamental research is required. However, there is published work that has not been previously referenced in the context of the problems being discussed.

The data from 43 scientific papers on water use by trees in forests have been collated [29]. Essentially, all of these data suggest that trees generally use similar volumes of water, i.e., have a similar "demand." The data cover species such as eucalyptus, pine, spruce, oak, poplar etc. and there seems to be no significant difference between these species on the basis of amounts of water used [10,11,14,31,32].

As trees are using/demanding broadly similar amounts of water from the soil, other explanations for the observed differences between trees are required. One explanation has already been proposed in this paper, i.e., the differential genetic capability of trees to root into clay subsoils in response to environmental changes. Another could be in the different capability of trees to intercept water. Eidmann [9] shows that over a 12 month period, European beech intercepts 93 mm of precipitation, while Norway spruce will intercept 314 mm in the same period.

Tree species seem to have adapted differently to the urban environment as opposed to the forest situation. Species such as poplar were selected for urban plantings because they coped well with poor soils, limited water availability and less than perfect atmospheres. While other 'forest' species struggled to grow and generate tissue (probably limited by water availability), poplar grew equivalent to its forest stand norm. Consequently, a difference in water demand might be attributable to a species *fitness* to survive poor soils, low water availability and poor air and still perform to optimum levels. An appropriate phrase may be termed *urban fitness*. Much more data are needed.

That vegetation extracts water from clay soils is not in dispute. Indeed a large specimen tree can contribute to substantial ground movements, which, if linked with foundation failure, can produce significant effects. However, the currently available practice and guidance notes and the legal precedents and attitudes mitigates against rational decisions based on sound arboricultural advice being made. Given that the published and accepted norms for mature tree heights, root spread indices and distance to height ratios have been set with a maximum level, then tree removals are inevitable in most situations.

An attempt to rationalise the approach to subsidence claims has been made recently by a working party of the London Tree Officers Association (LTOA) [20]. The London Boroughs have claims averaging £850,000 per borough (1988-92) against their policies for alleged damage by street and other publicly-owned trees. The LTOA Risk Limitation Strategy [20] for insurance claims produced the following recommendations:

(i) Identify those trees that are most likely to

cause subsidence damage and subject them to a regular and systematic pruning regime

(*ii*) Make the identification of the trees at (*i*) an on-going programme.

(*iii*) Avoid planting trees that are likely to cause subsidence.

(*iv*) When appropriate carry out prompt remedial pruning to implicated trees.

If public and private sector arborists are to implement the above proposals sensibly, then fundamental research is required Which trees are most likely to cause damage? Which species of tree should we avoid planting? What are the real effects of extended remedial pruning programmes? Do the current data provide answers to these questions? What "new" species or developing trees might cause the future claims?

Conclusions and Recommendations

Trees growing on clay soils contribute to building failures. This has been attributed to a differential "water demand" between species [26,27]. The published Tables of water demand are clearly in error and misleading and are based on limited scientific data. However, the differences between the effects caused by trees highlighted in these data can be explained by factors other than "water demand", i.e., differential genetic rooting capability, species interception indices, species urban fitness and individual species biology and physiology. Also to be considered would be hard surface interception and evaporation, total run-off, albedo, etc.

The current pressure from insurance companies, engineers and the courts for permanent, "one off" solutions and answers is not helpful. The education of both arboriculturists and the building professionals is obviously lacking. In England, colleges that teach arboriculture on a full-time basis contain little within Course Syllabi that prepare students to deal with this problem on even a rudimentary basis.

The need for trained experts in this area is obvious and the interdisciplinary aspects make this all the more important It is becoming increasingly clear that this is the most complex problem / challenge that faces the arboricultural professional working in the UK today [12]. We need help to address the issue and we need research monies to develop the knowledge The main beneficiaries will be the insurance and building industries.

Ultimately, given the tens of millions of pounds that have been expended to date in efforts to secure solutions to vegetation related structural damage, no attempt has been made to finance the management of the problem. The costs of remedial building works increase dramatically with each new dry-phase. The effects of climate change and selection of "new" tree species upon the housing stock in the future, cannot be predicted with any degree of accuracy at this time. This is particularly so if houses are built on inadequate foundations or if no attempt is made by the building profession to take arboricultural advice.

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Résumé. Les nombreux blâmes adressés aux arbres pour les dommages aux fondations des bâtiments au Royaume-Uni a résulté en un grand nombre de réclamations élevées d'assurance. Les arbres exercent leur influence en captant l'humidité contenue dans les sols argileux. Les données existantes n'expliquent pas de façon adéquate le problème. Une revue de la situation est présentée en regard des arbres, de la biologie, des relations de l'eau dans le sol et des effets du climat. Les données qui sont publiées se sont montrées être inadéquates. Un modèle de travail est proposé sur le comment un arbre affecte les sols argileux.

Zusammenfassung. Bäume werden in Großbrittanien für Schäden an Grundmauern verantwortlich gemacht, was zu einer großen Anzahl von hohen Versicherungsansprüchen führt. Bäume machen ihren Einfluß durch den Entzug von Feuchtigkeit in Tonböden geltend. Das vorhandene Datenmaterial reicht nicht aus, um das Problem zu klären. Hier ist ien Situationsüberblick gegeben, der Bäume, ihre Biologie, die Boden-Wasser-Beziehung und den Einfluß des Klimas miteinbezieht. Die veröffentlichten Daten erwiesen sich als unzureichend. Es wurde ein Model erarbeitet, um zu zeigen, wie Bäume Tonböden beeinflussen.