Trees and Management: Advances in Research

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Abstract
In the coming decades, arboriculture and urban forestry will have to face many challenges as populations increase and demographics change, natural resources are strained, environmental degradation persists, climate continues to change, and globalization increases. At the international level, urban green areas are increasingly being perceived as vital spaces for the development of important ecological, social and economic functions. Therefore, there is a strong need for research in all of the areas addressed in this article if the benefits brought by trees are to be maximized. The presentation will review the recent advancement in tree management in the European scenario.

Presenter Biography

Francesco Ferrini, Ph.D.
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Scientific activity focused on:

- Impact of plant selection and nursery production practices on root regeneration and tree growth after planting
- Physiological and growth aspects of different species as affected by different cultivation techniques after planting in the urban environment
- Evaluation of morpho-physiological and biochemical parameters to study urban stress tolerance on tree species.
- Evaluation of the ability of shrub and tree species to mitigate the effect of pollution in the urban and periurban environment
- Planning the green city in the global change era: urban tree functions and suitability for predicted future climates (TreeCity)

From 1990 he has published more than 210 scientific and technical papers in Italian (112) and in English (101) in international referred and nationwide journals. He has given more than 100 talks in several international and national congresses.

In 2010 he received ISA's **L.C. Chadwick Award for Arboricultural Research**

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- **Member of the ISA Board of Directors**
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Introduction

In the present and future urban scenarios sustainable tree care and maintenance represent the preservation of the long term efficiency of the urban ecosystem in an environmentally conserving and safe manner coupled with economic viability, social justice and equity for the citizens. Although urban green areas have been acknowledged globally to be of outmost importance, the term "sustainable arboriculture" is often used loosely and in a general manner as a label, brand or icon to make it acceptable to all types of stakeholders and under various environments.

In the coming decades, arboriculture and urban forestry will have to face many challenges as population increase and demographic changes, reducing per capita natural resources, environmental degradation, climate change and globalization. At international level urban green areas are more and more perceived as vital spaces for the development of important functions such as the strictly ecological-environmental and the social and economic ones. Also, in many urban areas, lack of proper training and maintenance results in much higher tree mortality rates that cannot be sustained over the long term. Therefore there is a strong need to set up research projects in all the different contexts and on different topics to gather as much information as possible to maximize the benefits brought by trees.
Some of the aspects regarding sustainable planting and management techniques will be considered in this paper.

Concept of Sustainability

There are several definitions of sustainability in the urban forestry sector. Sample (1993) stated that sustainable arboriculture comprises management and practices which are simultaneously environmentally sound, economically viable and socially responsible. Actually, in urban areas, we focus on sustaining net benefits of trees and forests at the broadest level. We are therefore sustaining environmental quality, resource conservation, economic development, psychological health, wildlife habitat, and social well-being (Clark et al., 1997).

The sustainable approach to urban greening

Sustainable arboriculture implies several steps which are listed below and which start from site design and must follow trees until the senescence phase.

- Design: focused on plant needs and on site potentiality
- Contract: all details must be specified in order to meet plant requirements
- Site preparation: to ensure that site conditions are appropriate for the plants
- Tree supply: plant material must be of the highest quality possible (morphological, physiological and phytosanitary) and to have the right fitness (in biology fitness is "The extent to which an organism is adapted to or able to produce offspring in a particular environment")
- Planting: to ensure that all the necessary interventions are provided before, during and after planting
- Establishment: to anticipate the typical problems of the urban environment like water scarcity, weed competition and man damages
- Maintenance: keep on caring trees for the time need according to plant material type and "don't think that once planted trees can live on their own"
- Monitoring: monitoring trees for an early detection of stress and diseases

All these steps have to be in close relation among them and, in time course, readjustments can be necessary to reorient them to a new steady state because without readjustments no system is infinitely sustainable. This is especially true for urban green areas which are not static but they change and evolve through a highly variable set of quasi-stable conditions over time, in tandem with changing demand scenarios such as population growth, demographic transition, evolving tastes, economic strength, technological development, awareness and attitudes.

Whereas aesthetic and beautification assumed top priority until the last part of the past century, the environment and socioeconomic equity have now become greater concerns, and alternative paradigms seeking sustainable and holistic development have become more relevant.

Sustainable tree care

With increasing population expansion, poor soil physical and chemical conditions are becoming more common in the urban environment; therefore, enhancing soil characteristics and organic matter content on a sustainable basis is one of the most vital problems we face. For this reason, it is of outmost importance to enhance our knowledge of the properties and behavior of the soil system in relation to different cultivation techniques. Organic mulching with different materials (mainly shredded wood, chipped wood, pine bark, and composted materials), correctly applied, is an environmentally friendly way of establishing, protecting, and managing young trees at a low cost in a new plantation. A recent review compared the costs and benefits of landscape mulches as reported in the technical and scientific literature, emphasizing how plants and soil can both benefit from weed suppression, evaporation reduction, and other environmental modifications (Chalker-Scott 2007). Even if mulching is a world-wide practise in urban green areas and different materials can be used for this purpose (Rakow 1989), little research has been done to determine the effects of this practice on tree physiology and on soil chemical, physical and biological characteristics in the actual urban stand.

Positive effects following organic mulch application have been obtained by previous research which has shown beneficial effects on soil physical and chemical properties (Fraedrich and Ham 1982; Litzow and Pellett 1983; Watson 1988; Appleton et. al. 1990; Himelick and Watson 1990; Smith and Rakow 1992; Iles and Dosmann 1999, Tiquina et. al 2002, Dahiya et al. 2007) and on plant growth and physiology (Watson, 1988; Green and Watson 1989; Appleton et. al. 1990; Himelick and Watson 1990). Also the invertebrate diversity can be positively affected by mulching (Jordan and Jones 2007). However, sometimes the results from mulching are variable being affected by the different environmental conditions and by the different tree species (Whitcomb 1979; Iles and Dosmann 1999). Moreover, if the quality of the mulching materials supplied by the producers is not satisfactory, tree performances can be affected in a negative way. This can be related either to its quality or to its misuses, i.e adding too much material which can negatively affect soil oxygen content (Gilman and Grabosky 2004; Hanslin et al. 2005), though Watson and Kupkowski (1991) found no detrimental effect from the application of 0.45 m (18 in) of wood chip mulch over the soil in which the roots of trees were growing. The application of bark mulch can sometimes decrease growth in the first year, but the effects on plant growth are positive when examined in the long term (Samyn and de Vos 2002). This can be caused by a temporary nitrogen depression until the microorganisms are able to decompose a sufficient amount of organic material to provide the needed nitrogen (Craul 1992).

In a study carried out on two common landscape species, Fini et al. (2011) found that mulching with compost is a useful practice to improve plant growth, leaf gas exchange and leaf chlorophyll content. In this study, the use of compost on the row also mitigated the effect of competition with turf and reduced soil temperature. Plots mulched with compost were 13°C, 10,8°C and 7,2°C colder than bare soil, tilled and turf plots respectively. This significant reduction in soil temperature contributed to create a more favorable environment for root growth: soil temperature in mulched plots didn't exceed 35°C, which is considered the threshold temperature above which root growth is hampered and root mortality increased (Coder, 1996; Fini and Ferrini, 2007). Soil oxygen content was slightly reduced by mulch application. The oxygen content didn't fall below critical levels for root growth, which was found around 10% but this data confirm the importance of a correct mulch application, as described in Saebo and Ferrini (2006). On the basis of results obtained in this study, mulching can be considered an environmentally-friendly and sustainable alternative to tillage and chemical weeding for managing plants in the urban environment.

In a more recent study (Fini et al., in press) found that newly planted elm trees mulched with compost generally had greater height, trunk diameter, and current-year shoot growth, while limited effects were found with regard to carbon assimilation when considered on a single-leaf basis. Due to the fact that mulched trees were bigger with longer shoots, whole plant leaf gas exchange was greater in the first season and also probably in the following ones when trees were already too big to measure their total leaf number and area. Mulching also affected chlorophyll content.

As far the composted material as concerned, it has to be remarked that it needs to be well characterised for nutrient values, stability and other properties for the support of tree growth and effect against weeds. In a review of the use of composts for mulching and soil amendments, Sæbø & Ferrini (2006) suggest designing the composts as to fit the specific effects that are wanted. For example composts for mulching should consist of layers of compost of different particle sizes, so that both nutrients can be supplied and weeds are not given good germination conditions. Organic compost materials generally have long term beneficial effects on soil physical properties, though in the short term these benefits are less evident (Watson 2002; Ferrini et al. 2005; Ferrini et al., 2008). Some research projects have shown that organic amendments have a potential role in ensuring quality restoration works (Hornick and Parr 1987) and their application is beneficial and relatively inexpensive (Vetterlein and Huttl 1999). This works well with the European Union countries which target is to decrease the quantity of organic waste going to landfill sites.

Besides soil quality, other important components of planting sites are the open soil surface and the surface treatment over the rooting zone (Coder 1996; Trowbridge and Bassuk 2004). In many urban sites, the soil surface is covered after planting; typical coverings of paving stones, asphalt and concrete are impermeable to the water and oxygen required by both the tree roots and the soil for proper functioning (Bradshaw et al. 1995). Metal grids or grates used in conjunction with concrete, allow water and oxygen exchange only if the soil is not compacted and are also expensive.

Planting the area around the trees with small shrubby cover seems to have a very beneficial effect on soil humus and microrganisms (Bernatzky 1978). Benefits are probably due to the fact that with ground cover the risk of being walked on is much reduced. A research carried out on Norway maple showed that after three years, trees with larger and mulched planting areas had higher leaf gas exchanges, leaf chlorophyll and mineral content, than those grown under pavement (Ferrini and Baietto, 2007). Other research trials done in Denmark showed that super-planting pits (>12m2/129.7 ft2) were superior to the other planting techniques (structural load-bearing soil, sand-based load bearing soil)(Bühler et al., 2007)

Irrigation management

Global environmental conditions have changed during the last century and, based on current trends and according to IPCC (IPCC, 2007), temperature will rise by about 1-3.5 °C over the next 70 years; rainfall will also be affected by a decrease in the frequency and an increase in intensity of rainy events. Water limitation may prove to be a critical constraint to primary productivity of plants under future scenarios of more arid climates due to climate change (Fisher et al., 2001).

The primary reason for irrigation is to provide water to a crop when the frequency and amount of rainfall is not sufficient to replenish water used by a crop system. Water requirements of the crop system depend on growth and development needs as well as environmental demands. The levels of water used by the plant in growth and development are usually small compared to the atmospheric demands.

One question needed to be answered in order to schedule irrigation in a sustainable way: how can I reduce the amount of water to apply without limiting growth of the new planting? Efficient water use in the new landscape will contribute substantially to the conservation of this resource. Water use efficiency can be achieved by supplying only the amount of water sufficient to meet plant needs. The potential for plant injury caused by water deficits or excess can be minimized by identifying and meeting plant needs. Also control of water application uniformity and amount in relation to evapotranspiration is the key to efficient, effective water management.

In order to take full advantage of an irrigation system the following technical points need to be known or/and are recommended:

- The irrigation system should be well designed and maintained in order to apply water uniformly and efficiently.
- The approximate rooting depth and water holding capacity of the soil should be known so that the soil water reservoir can be estimated
- The application efficiency of the irrigation system should be used to figure the amount of water to apply to replace that evapotranspired or the amount desired.

When we specifically refer to shade trees planted in the urban environment, peri-urban forests and recreational areas, plant productivity may correspond with the ability of single plants or plant communities to provide benefits to the inhabitants. Healthy, long-lived trees provide environmental, ecological, economic, social, cultural and aesthetic benefits to the community (Akbari, 2002; Brack, 2002; Fini and Ferrini, 2007; Nowak et al., 2007; Elmendorf 2008; Escobedo et al. 2008). Mortality rate in the urban environment is usually very high and ranges from 10 to 50% with water stress playing a major role, especially where pavements, soil compaction and small planting pits prevent infiltration into the root zone (Kaushal and Aussenac, 1989; Miller and Miller, 1991; Whitlow et al., 1992; Pauleit et al. ,2002). This threat is very dangerous in the first years after planting, when mortality peaks up to 50% in the first year and up to 34% in the second (Gilbertson and Bradshaw, 1985; Nowak et al., 1990). Irrigation is an important factor to increase plant survival and quality during the establishment phase, but landscape water consumption is highly visible and provides a prime target for water restrictions and subsequent regulations (Scheiber et al., 2007). Despite the need to save water, water restrictions during landscape establishment can be detrimental to plants which have not had enough time to develop a sufficient root system to compensate for evapotranspirational losses (Montague et al., 2000). One way to increase water efficiency is to irrigate trees until they are fully established and then terminate irrigation unless there are periods of extreme drought. Establishment time can be estimated by comparing leaf gas exchange and growth rates of newly planted stressed (non irrigated) and unstressed (irrigated) trees (Scheiber et al., 2007).

As regards possible change in the climate, the whole strategy of coping with its impacts on the landscape, and especially in its effects on water supplies and water bodies, will need to rely on learning lessons from nature rather than trying to overrule it. Response to these alternating deficits and surfeits of water will require careful management of water flow and water quality. Techniques might include impounding run-off, recycling irrigation water and using grey water where possible, combined with land contouring, improving soil structure and better drain maintenance.

The impacts of climate change on water supply to the landscape will be significant, but can be reduced by sound water management using methods different method. Shortage of water in the summer can be made good by irrigation, preferably using stored water, and concentrating on the most important plants in the event of a prolonged hosepipe ban. Irrigation after dusk, using an ET controlled station to schedule irrigation will reduce evaporative losses.

In well managed gardens, surplus water in winter should infiltrate into good garden soil and runoff drives, paths and patios onto lawns or borders or into drains if levels are suitably designed.

Growing concerns for the future water supply and more stringent wastewater discharge standards to surface water bodies have contributed to increasing interest in using recycled wastewater for urban landscape irrigation. Increasing numbers of landscape facilities and development areas have been switched to or plan to use recycled wastewater for irrigation though there are still some limitations. While the environmental and conservational benefits of wastewater reuse in landscape and turfgrass irrigation are obvious, the major concerns associated with wastewater reuse include: 1) additional costs in installing irrigation pipelines and irrigation equipment maintenance (such as, prevention of nozzle plugging); 2) health risk due to the possibility of the presence of pathogens; 3) salt damage to landscape plants and salt accumulation in soil surface and soil profile; and 4) leaching of excess nutrients to ground water (Harris et al., 2004).

A preventive strategy to reduce drought-related transplant losses is to plant species/cultivars which show a certain degree of drought tolerance during the establishment phase. Even within a genus or species, great differences in water needs for establishment can be found among species/cultivars. A previous work ranked drought tolerance of *Fraxinus* genotypes on the basis of drought-induced changes in chlorophyll fluorescence, chlorophyll content and carbon assimilation (Percival et al., 2006). Other Authors found different responses to water shortage among different species of *Tilia* and cultivars of *Acer platanoides* which also adopt different strategies of coping with water stress (Fini et al., 2009). Since few studies have assessed drought tolerance among ornamental trees during the establishment phase, so more information is needed on this topic.

Tree Pruning

Pruning can be one of the best things an arborist can do for a tree and one of the worst things an arborist can do to a tree (Shigo, 1989). In the United States, the A300 Standard describes four conventional types of pruning to be used to satisfy a pre-determined pruning objective (American National Standard Institute, 2001). Pruning types and prescriptions have been developed mostly without the benefit of empiric tests on shade trees (Pavlis et al., 2008). In fact, main topics of pruning research include tree response to wounding (Shigo, 1984; Dujesiefken et al., 2005; Schwarze et al., 2007), interactions between trees and utility lines (Shigo, 1990a; Millet and Bouchard, 2003), and between trees and wind load (Gilman et al., 2008; Pavlis et al., 2008), while the effects of different pruning methods on tree health, structure and physiology has received much less attention and deserve further research (Clark and Matheny, 2010). A recent work carried out on *Acer pseudoplatanus* (Fini et al. 2011) showed that topping, when compared with other pruning methods, induced a greater alteration to plant structure and functioning: the lost of apical dominance causes the production of watersprouts which may become codominant, with a long-term loss of safety. At the leaf level, topping increased photosynthesis and chlorophyll content. Anyway, the effects found at the leaf level were short-lasting and disappeared quickly as summer progressed, while the effects of topping on tree structure are long-lasting. Moreover, since urban trees are repeatedly pruned along their life, the effects of repeated pruning intervention on tree health and structure should be addressed in future research.

Another study investigated the effect of different time of winter pruning on tree growth and wound healing in sycamore maple. The pruning times were selected to be representative of different dormancy stages, since plants pruned in December and January were endodormant, those pruned in February were ecodormant, and those pruned in March were in the "swollen bud" phonological stage. However, despite of slight differences between treatments in wound closure, diameter growth of the pruned branch and of watersprouts developed or released after the cut, and leaf chlorophyll content no plain indication of the preferred time to carry out winter pruning. Therefore, results of this study indicate that any time prior to bud-break is suitable for pruning a deciduous tree with high chilling requirements like sycamore maple (Fini et al., 2011).

Trees and street works

Trees in cities are subject to intense conflicts with buildings, roads and utility installations, and engineering requirements often take precedence over tree conservation (Jim, 2003). Moreover, the advent of optical-fiber and cable television infrastructures has required thousand kilometers of new trenching in the urban environment (Thompson and Rumsey, 1997). Construction activities and trenching near trees commonly cause extensive root damage, often resulting in tree decline and death, thus imposing additional replacement and maintenance cost (Hauer, 1994; Matheny and Clark, 1998; Jim, 2003). Root loss can be substantial, because roots usually spread up to 2.9 times beyond the dripline (Gilman, 1988). Therefore, a single trench can remove 18% to about 50% of a tree root system, depending on the distance from the trunk, the age of the tree, and soil characteristics (Watson, 1998; Wajja-Musukwe et al., 2008). Root severance has been reported to increase the risk of premature failing, even if stability loss following trenching was found to be lower than expected, probably because of the contribution of sinker roots (Smiley, 2008; Ghani et al., 2009). However, tree health can be seriously affected by trenching and construction activities. In fact, root severance affects plant hydraulic architecture, carbohydrate storage and hormone balance, and consequently, plant physiology (Jackson et al., 2000). Therefore, it is likely that root damage through trenching induces a physiological stress on plants, but this hypothesis has not been tested directly yet (Watson, 1998). Several papers evaluated plant survival and growth response to trenching and reported that root damage increased mortality over the next 8 years by 18-22% (Hauer et al., 1994). Furthermore, visible symptoms may not occur until years after the damage (Watson, 1998; Despot and Gerhold, 2003; Wajja-Musukwe et al., 2008). However, little attention has been given to the physiological reason of tree decline. The study of plant physiological responses may provide a useful tool for early diagnosis of excavation damage to trees, and provide a better understanding about the effects of root loss on tree health before visible symptoms develop. A study aimed to assess whether two degrees of root severance induce physiological stress in European linden and horsechestnut, two species supposed to differ in their tolerance in root manipulation indicated that, during the rainy years when the experiment was conducted, the two species responded similarly to root damage, showing reductions in growth and leaf gas exchange although linden showed a slightly greater capacity to recover the stress (Fini et al. 2012). However, results of this study may not apply to situation when root severance is followed by very dry growing seasons. Therefore, more observations are needed to determine whether trees will be able to recover from damage or will decline further, especially if dryer years will occur before complete root regeneration.

Trees and pavement

We know that urbanization has a negative impact on water cycles. Much of this negative impact is due to the increase in impervious surfaces and the subsequent loss of mature tree canopy in the urban stand. Impervious surfaces, such as parking lots, roads and driveways, affect not only site hydrology but also affect plant physiology and contribute to urban heat islands.

Pervious pavements have a high infiltration rate, from 130 mm/h to up to several thousand mm per hour. This very high infiltration rate greatly reduces peak and total stormwater runoff rates, although the effectiveness strongly depends on the underlying soils. Pervious porous concrete is most effective at reducing or completely eliminating runoff from small rainfall events. As the stormwater from a parking lot is filtered through the pervious concrete and underlying soil, water quality can substantially improve reducing the total phosphorus and nitrogen load by approximately 50% or more. Low available water, low oxygen, and high root zone temperatures under paved surfaces present a significant challenge to urban tree health and survival. Pervious concrete may allow for easier infiltration of both water and oxygen to the root zone, which could greatly benefit root growth and production. Impervious pavements poured around mature trees generally result in a decline of tree health. Although several studies have focused on the performance of young or newly planted trees surrounded by different pavement types, most of them have provided only results mainly limited to a few plant growth parameters without going deeper to investigate plant physiology and the effect on soil physical and biological characteristics. A higher water availability, higher root zone oxygen and lower root zone temperature will likely improve the health and growth of nearby trees compared to a situation where standard concrete is installed. This will allow a higher carbon sequestration and storage of these plants. Measuring leaf gas exchange and plant physiology will allow to also provide scientific and precise data on this.

A project was started in 2012 on two shade tree species with the aim to provide information addressed to the improve survival and growth of trees planted in paved areas. To this purpose 24 plants of European hackberry (*Celtis australis*) and 24 of European ash (*Fraxinus ornus*) were planted in an experimental plot with single plots having an area of 5 x 5 m (17'x17'). Soil surface were covered with 3 different kind of pavement:

1) traditional asphalt largely used in Central-Southern Europe.
2) Self-blocking permeable cover.
3) Marmo Drain (formed by a mixture of grit and polyurethane resin
4) Some plots were left unpaved as control

Data about plant physiology, soil respiration and temperature, air temperature and humidity will be harvested.

Conclusion

The recently introduced concept of sustainable arboriculture represents the maintenance of the long term efficiency of the urban ecosystem in an environmentally conserving and safe manner coupled with economic viability, social justice and equity for the citizens. Although the importance of urban green areas has been acknowledged globally to be of outmost importance, the term “sustainable arboriculture” is often used loosely and in a general manner as a label, brand or icon to make it acceptable to all types of stakeholders and under various environments.

The experiences described before show the high potential of urban arboriculture to be part of a sustainable development for the future city environment. However, arboriculture and the promotion of its contribution to sustainable development at large require a comprehensive approach, since it needs to be linked to a broad range of issues and agendas.

Three directions for immediate action deserve to be underlined. First some new planting policies can be encouraged and funded since they have immediate environmental and economic benefits. It is well-known, even under present-day market forces, that great strides can be made towards energy conservation and improved energy efficiency by planting trees in the urban areas to reduce the heat island effect and to improve air quality.

Second, the process of identifying the full range of sustainable techniques for responding to the environmental, social and economic questions, should move forward without delay.

Third, there should be continuing, strong support for research on this topic, because as the scientific uncertainties narrow, the choices become easier to make.

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