Trees in the urban environment: response mechanisms and benefits for the ecosystem

Ferrini, F. [1,3], Fini, A.[1], Bussotti, F.[1], Tattini, M.[2]
Presenting author's e-mail: Francesco.ferrini@unifi.it
[1] *Department of Agri-Food Production and Environmental Sciences, section Woody Plants - University of Florence, Italy*
[2] *Institute for Plant Protection, National Research Council of Italy, Florence, Italy*
[3] *International Society of Arboriculture - Board of Directors, Champaign, IL (USA)*

Introduction - The " Urban Forest "

It is known that the "urban forest" has in itself the characters of the "forest" and those of "urbanity". The term "urban forest" is, however, still under discussion, so that many researchers still don't accept it. Perhaps it would be better to speak of "forest", if we really want to use this word, enclosed into the urban structure. In fact, together with the development and with the economic, social, political growth and changes, many forests have begun to "urbanize", hence the term "Town Forestry".

The process of acceptance of the term "urban forest" has roots far back in time. Already in the sixties, it was a topic of discussion in the United States and in the early 90's, it was introduced the term "urban green structure", a concept which therefore goes well beyond the single tree, also regarding tree avenue, gardens, parks, etc. enclosed in the urban areas.

With the present knowledge one question occurs: can we relate the concept of "urban forest" to the "ecosystem"? Odum (1971), summarizing his thoughts, defined the ecosystem as a set of living organisms in a given area, which interact among themselves and between them and the physical environment in which they are inserted, resulting in energy flows and material transfers through the various levels of the food chain.

From the comparison of the two systems comes the consideration that human activities cause artificiality of the system thus affecting the presence, frequency, assembly and relationships of potentially pathogenic living entities (mainly fungi and insects) of urban trees.

Consequently in the "urban system" negative situations for plants can become dominating:

- Digging, paving, asphalting;
- Loss of soil fauna and flora;
- organic matter cycle is altered or interrupted;
- modification of the vegetative cycles of plants depending on the urban climate;
- direct action of pollutants on the plants and on the parasite/plant relationships;
- planting in the wrong and harsh places;
- altered physiology and phenology

Therefore the conditions of the urban system beyond determining adverse conditions for tree growth and physiology often have favoured the establishment and development of numerous parasites (mainly fungi) and insects which, sometimes, were already present in natural systems but limited by natural enemies and/or conditions. Because of this the relationships between the two entities, trees and building, can change in the city, as well as population dynamics, sometimes resulting in very serious situations, much more difficult to control compared to natural systems.

Trees, urban environment and climate change

The report by the UN's climate panel (IPCC, released at the end of September, 2013) details the physical evidence behind climate change. On the ground, in the air, in the oceans, global warming is "unequivocal”. It adds that a pause in warming over the past 15 years is too short to reflect long-term trends. The panel warns that continued emissions of greenhouse gases will cause further warming and changes in all aspects of the climate system. To contain these changes will require "substantial and sustained reductions of greenhouse gas emissions" and take actions to diminish or at least, to stabilize, their quantity in the atmoshpere. We know that one the best methods to combat climate change effects is planting trees whether around your home and property, in your community, or in our national forests. Through the natural process of photosynthesis, trees absorb CO_2 and other pollutant particulates, then store the carbon and emit pure oxygen.

But what we know about the effects of climate change on trees and how they will guide our choices?

In order to specify the future effects of climate change on arboriculture, reliable predictions of the transient changes in regional and global climate are required because we need to select plants that will tolerate the climate change which is also predicted to result in altered rainfall patterns with an increase in the frequency and severity of summer drought across different areas in both Hemispheres and, probably, in extreme weather events (heavy storms, tornadoes, etc.). Drought is predicted to be the most significant factor not only in the Mediterranean-like climates and this will strongly affect survival and growth of newly planted trees and will probably influence the development of diseases and tree pest resistance. Not only are the short-term effects on growth or survival in extreme years important, but also the long-term impacts on tree growth have to be considered in selecting planting material. With impending water shortages in many urban areas leading to prohibitions of irrigation or watering, planting trees that are more tolerant to prolonged drought conditions is the best long-term solution to a healthier, low-maintenance landscape.

Together with drought and actually sometimes influencing and being influenced by it, soil compaction and waterlogging are among the main causes of death in urban environment. They limit root growth and nutrient absorption and, by consequence, leaf gas exchange. This makes trees more sensitive to pathogens, especially those affecting the root system. Increase in soil and air temperature, due to wide use of asphalt and concrete, is another cause of death for trees. High soil temperature limits root growth and causes high fine-roots mortality, loss of turgor, cell membrane denaturation while high air temperature causes a reduction of whole plant gas exchange.

In this scenario possible adaptation measures include changes in the establishment practices and tree management, better matching of species to site, both under current and future climates, and the planting of non-native species and provenances in anticipation of climate change. Current opinion is to encourage the planting of local provenances of native species, citing their adaptation to local conditions, and the requirement to maintain biodiversity and a native genetic base. However, indigenous or naturalized species may not be able to adapt to a changing climate, particularly given the rate of change predicted (Bussotti et al., 2014). Sourcing planting stock from regions with a current climate similar to that predicted for the future may provide one option, although care must be taken to ensure that suitable provenances are selected which are not at risk from, for example, spring frost damage as a result of early flushing.

Recent studies on some species have shown that due to climate change the spring phenological events are already delayed of two-three days (even 7-10 in some particular species and sites) due to mild winters and this is much more evident in the urban environment due to the urban heat island effect. Reversely other studies on four tree species widely present in England (*Quercus robur, Fraxinus excelsior, Aesculus hippocastanum, Tilia x vulgaris*) have shown how the rise of temperature can drive new leaves ahead in time of 2-4 days. This earlier regrowth can seriously put on risk young stems, above all for cold countries such as in the northern latitudes where late frost is common. Moreover, deep changes in temperatures can affect the length of the growing phase, in term of activity of foliage. It has also been demonstrated that different species are responsible for different entities of shifting dates. It is indeed possible that in a long term, phenological responses from different tree species to temperature changes could lead to permanent changes of the geographical distribution of the same species.

Though not directly related to climate change also the light environment can be a parameter to be considered in the urban stand where two light environments are commonly found: 1) urban canyons, defined as those environments where trees are heavily shaded by buildings for several hours per day and that may not be exposed to direct sunlight for entire weeks in late fall, winter or spring; 2) urban plazas defined as those locations where no shade is provided by buildings or other structures and trees are exposed to continuous direct sunlight throughout the year. This latter situation is worse than that experienced by trees in forest gaps, because of urban heat island, limited volume of the planting pit and reflection of sunlight by pavements.

In these typical urban conditions plants have often to respond to simultaneous stresses (e.g. drought, plus excessive light and heat) and their response is usually not predictable from single factor studies. Drought spells in urban conditions are often accompanied by strong light and the interaction between high irradiance and drought has been investigated in a number of studies which shown, in general, that water deficits predispose the photosynthetic apparatus to photoinhibition, and drought-induced inhibition of photosynthetic activity is exacerbated when leaves are dehydrated under strong light. In this case we can assume a positive effect of shading on photosynthetic activity under drought conditions, but it is conceivable that the depression in the capacity of the leaves to produce carbohydrates may limit the recovery of growth rate after drought stress relief. In contrast, some research reported that the capacity of plants to withstand a severe drought might be decreased under shade conditions, rather than being enhanced. This is particularly true in Mediterranean-like climates, with high irradiance and long period of drought, all conditions that strongly limit carbon assimilation and promote photoinhibition of the photosynthetic apparatus.

Further, it must be underlined that drought can interact not only with excessive light, but also with limiting light in understory habitats, which has deserved significantly less research. Plant tolerance of combined shade and drought, typically considered irresolvable due to trade-offs in morphology and physiology, potentially determine important vegetation patterns, especially as droughts are becoming more severe world-wide.

Existence of inverse correlations between ecological requirements of species involves the ad hoc hypothesis that being tolerant to a certain environmental factor involves a cost such that the plant cannot adjust simultaneously to multiple environmental stresses. In fact, shade and drought tolerance involve conflicting requirements for biomass investment in foliage and branches for efficient light capture vs. biomass investment in roots for efficient water uptake, and reductions in total foliage area and enhanced leaf clumping to reduce evaporation.

Selection of the right species is a primary requirement for successful tree planting. Pre-conditioning of nursery trees can be a supplementary tool to improve tree performances in the different urban light environments. It was shown that acclimation in the nursery to mild stress resulted in the production of hardened nursery stock, better able to tolerate transplanting and other environmental stress during establishment. Exposition to full sunlight during cultivation in the nursery may act as a mild stress and induce stress tolerance through increased leaf solute accumulation and enhanced photosynthetic, photoprotective and antioxidant capacities. Conversely, shading in the nursery of shade-tolerant trees to be planted in urban canyon can: 1) acclimate leaf anatomy and physiology to low light; 2) increase growth rate; 3) reduce water consumption.

Benefits for the ecosystems

Only in recent times, thanks to the research, the social, bio-ecological, cultural and economical benefits of green areas and of trees in particular have been reconfirmed. However, the most obvious microclimatic effect of a trees is on urban climate. Trees absorb and reflect solar radiation, they provide shade and the absorption and scattering of the visible portion of solar radiation and they play an important role in reducing glare from different surfaces (buildings, pavements, etc.). Trees also reduce wind speed by increasing the resistance to wind flow and provide some shelter by retaining and evaporating precipitation. Trees raise atmospheric humidity in summer because they transpire. Humidity is high under a tree canopy, but this adverse effect is more than counteracted by lower air temperature. The effect of trees on air temperature is well known. By transpiration trees dissipate energy that would otherwise be used in heating the air. Finally, planting vegetation to reduce air pollution and greenhouse gases is also increasingly used as an effective approach. Rising concentrations of greenhouse gases in the atmosphere are linked with the increased risk of global climate change, therefore the planning and the management of green areas have expanded from the notion of municipal street tree management to urban ecosystem management. Tree growth rate and survival influence the stream of benefits from CO_2 sequestration and energy savings. Large, healthy, fast-growing trees provide greater benefits sooner than small, slow-growing trees. Tree age fractions are also used to estimate the rate that CO_2 benefits change during the 40-year period relative to their maximum values.

It has to be stressed once again that because trees might be good alleys in the struggle against global change, they need to be in good health so to maximize gas exchange and wood biomass production, the main CO_2 storage site in the long term. At the same time trees are very vulnerable to the stresses induced by climate change. As complex and long-lived organisms they experience climatic impacts over a long time, sometimes centuries, and any impacts of the benefits or injuries imposed by long term climate changes or short term fluctuations in the weather, will be reflected with compound interest as time passes. Therefore tree protection from the adverse effects of climate change must lie in developing long term management and replacement programmes.

In urban landscapes, tree growth rates are highly variable according to the diversity of the urban environment and of urban forest: its many tree species, range of growing conditions, and levels of care that vary from neglect, to abuse, to professional pampering.

Conclusions

Beside climate change, other factors must be considered in order to ensure that the proper plant is placed in a specific site in the specific time and with the proper techniques. In general, these factors, which, however, are somewhat influenced by climate change, are divided into three major categories: design, site, and maintenance considerations. More specifically, factors to consider when selecting trees for city streets or park landscapes include pruning requirements and response, tree stability, disease resistance, catastrophic insect pests, soil adaptation, complementary planting, shade or sun tolerance, provenance, and adaptive cultivars.

Finally, the selection should be based on the potential benefits brought by trees in the urban stand though, while we are all aware of these, only in the last ten years some efforts have been done to select plants for this kind of use and to adopt management practices to maximize the net benefits of urban forests on atmospheric carbon dioxide. Anyway in the present scenario, planting strategies could be adapted to select species which are not only tough to face the challenges of the urban environment, but also very efficient in sequestering $CO_{2,}$ with a higher water use efficiency (WUE - ratio between net photosynthesis and transpiration rate), low emitters of volatile organic compounds (VOC which combined with nitrogen oxides can increase ozone level in the atmosphere) and with a lower LCA (Life Cycle Assessment also known as life-cycle analysis, ecobalance, and cradle-to-cradle analysis is a technique to assess environmental impacts associated with all the stages of a product's life from-cradle-to-cradle), so the ensure the highest ratio between benefits and cost.

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