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A challenging job: Plant pathology in the urban environment

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SUMMARY. – Plants in the city guarantee multiple benefits and satisfactions, but they are exposed to a variety of site conditions, environmental factors, and physical disturbances which influence their survival. Human activity creates urban soils that are distinct from their natural counterpart for physical, chemical and biological features. Surface crusting is water- and gas-repellent, with restricted aeration and water drainage. Vertical and spatial variability is great. Anthropogenic materials and contaminants are present. Soil structure is modified leading to compaction. Nutrient cycling is interrupted and soil organism activity modified. Environmental chemical pollution is a key stress factor for plants in urban areas. The objective of pruning urban trees is to produce safe, strong, healthy, attractive plants, but wounds produced by topping and improper pruning may serve as entry points for decay organisms. There are particular cases where individual trees, because of their condition and location, pose an unacceptable risk to people or property. Trees or tree parts can fail particularly during loading events such as wind and snow storms. Trees fail when the load (weight and motion of the crown) exceeds the mechanical strength of their stems, branches or root systems. This is true for both sound and defective trees, but defective individuals can only withstand a fraction of the load that sound trees can withstand. The failure of limbs or entire trees, however, is often predictable, detectable, and preventable. Tree risk analysis has evolved over time from a qualitative art to a quantitative science. Modern techniques and procedures can be used to minimize the risks associated with tree failure and to identify structural defects. So, the mission of urban plant pathologists is to verify if a tree has what it takes to stand up in a secure way. This is based on the evaluation of the acceptable safety factor (safe shell limits). Trained and able staff must be available for periodical tree inspections. University courses of Agricultural and Forest Sciences should discuss and deepen these crucial issues.

INTRODUCTION. – According to AGRIOS (2005), "*Plant pathology is a science that studies plant diseases and attempts to improve the chances for survival of plants when they are faced with unfavorable environmental conditions and parasitic microorganisms that cause disease*". So, it is a discipline that has a practical and noble goal of protect-

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ing the food (quantity and quality) available for humans and animals. Nowadays to this crucial task at least another mission must be added: "*to ensure the presence of well performing and safe plants (especially trees) in our cities*"; this because plant diseases, by their presence, menace the survival, shorten life expectancy and make dangerous the plants in the urban environment and represent a limiting factor for citizen's security.

Rapid increases in human population and economic development have led to tremendous urbanization: in Europe, around 75% of the population lives in urban areas and this is projected to increase to about 80% by 2020 (EEA, 2006). At world level, more than 50% of the human beings currently live in an urban area and 70% will do that in the year 2050. Cities are similar to an organism in that they consume resources from their surroundings and excrete wastes: "*Cities transform raw materials, fuel, and water into the built environment, human biomass and waste*" (KENNEDY *et al.*, 2011). Urbanization concentrates people, materials and energy into relatively small geographical areas (cities and towns are estimated to be less than a mere 3% of the total land of our planet), whose environmental conditions are often critical. Quality of life in cities relies on a range of components such as social equity, income and welfare, housing, social relations and education and a healthy environment. The environmental elements of a nice quality of life include good air quality, low noise levels, clean and sufficient water, fair urban design with sufficient and high quality public and green spaces, and a good local climate or opportunities to adapt to climate change. Urban trees provide a number of important (but not easily quantified) aesthetic, economic, and psychological benefits for humans: they increase property values, promote tourism, provide educational opportunities, encourage healthy life styles and outdoor activities, improve the visual appeal of urban areas, mitigate stress and encourage biological diversity. But trees, just as all other plants, may be sick and attacked by biotic and abiotic stress factors, and a diseased tree may represent an intolerable risk factor for human welfare.

THE DISEASE TRIANGLE IN THE URBAN ENVIRONMENT. – Three are the classical components of a disease and their interaction is often visualized as a triangle (Fig. 1). In other words, a susceptible plant becomes diseased when it is attacked by a virulent living pathogen, or when it is affected by an abiotic agent, but the interaction between these two components must occur with environmental conditions within a favourable

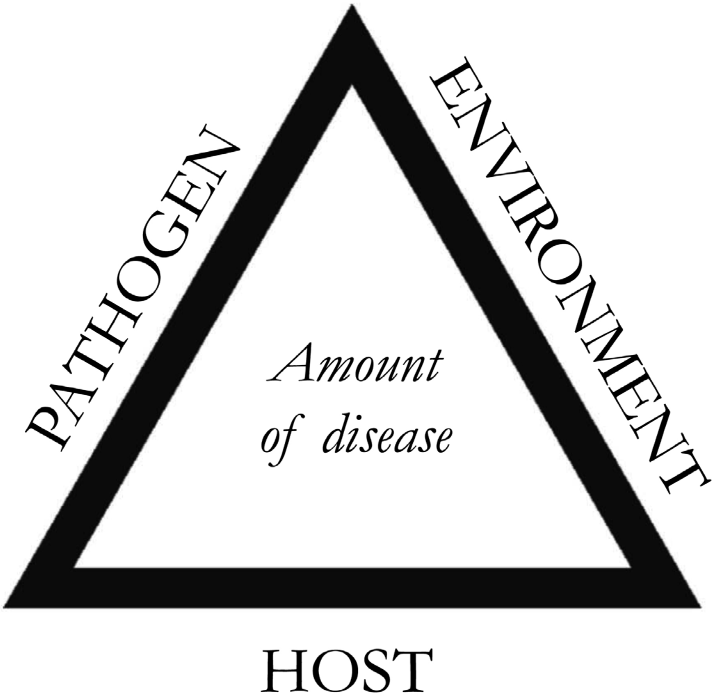

Fig. 1. – The plant disease triangle, the combination of a susceptible host, a virulent pathogen and a favourable environment in a given time. The area of the triangle is related to the 'quantity' of disease.

range. Each side of the triangle represents one of the three components. The length of its side is proportional to the sum total of the characteristics that favour disease and therefore the area of the triangle would represent the 'amount' of disease in a plant or in a population (AGRIOS, 2005). In the urban environment all the three players of a plant disease are peculiar.

(a) *The environment in the city*. – Urban soils are naturally-occurring soils that have been disturbed by development in a way that affects their functioning and properties. Human activity, by modification of the natural soilscape, is the predominant active agent. This is in contrast to the natural agents of wind, water, ice, gravity and heat that are the active agents in the placement of parent material within which the resultant soil-forming processes occur in the natural environment. Because urban soils are always associated with human activities, their characteristics are determined by their previous construction history and by the degree of disturbance they have undergone. So, they have characteristics that are distinct from their natural counterparts. The peculiarities of urban soils have been described since long (Craul, 1985). For instance, they typically show great variability in vertical profile, as well as horizontally across the landscape, due to the cut and fill, backfilling, and resurfacing that occur during the process of land shaping. Heavy compaction is a rule and "sealed" soils are repellent to water and gases. Soil structure (the balance of solids and pores) has been crushed out by mechanical compaction that chokes off water and air exchange. As a consequence there is less oxygen and more carbon dioxide in soil. Organic matter is scarce: these substances are periodically deposited on natural soils by trees and shrubs in the form of leaves and branches and organic remains are decomposed by various soil-inhabiting organisms, but in urban soils these cycles are interrupted by various factors. Leaf litter is often swept up as trash, or very little litter falls on urban soils because of the low amount of biomass produced by the plants. As a result of the shortage of organic matter, the diversity and activity of soil microorganisms (e.g. mycorrhyzal fungi) are reduced well below optimum levels. Most urban soils contain various forms of man-made materials, such as metals, glass, plastic, asphalt, and masonry. Contamination arises from the deposition, mixing, and filling of materials not found, or in concentrations greater than those found, in natural soils. These materials have several negative effects on soil and on the vegetation it may support: they can physically obstruct root penetration, water movement, and gaseous diffusion. In some cases, these man-made materials may harbor products that are toxic to plants and soil organisms. Occasional pipeline leaks must be considered as contaminants as well. Water that reaches urban soils (and plant roots) is often of bad quality and polluted (mainly hydrocarbons and heavy metals). Urban soils tend to have reaction (pH) higher than their natural counterparts. De-icing salts may be applied to the streets during the cold season and reach the plant substrate and roots.

Due to human activity, the temperature in an urban microclimate is higher than that of the surrounding areas. City areas are said to be "urban heat islands" as under calm conditions temperatures are highest in the built up city centre and decrease towards the suburbs and countryside. There are several reasons why this pattern occurs (Landsberg, 1981). In urban areas, the building materials are non-reflective and therefore absorb heat. Also road surfaces such as tarmac and concrete have a high thermal capacity therefore also absorb large amounts of heat due to their dark colour. This heat is absorbed during the day and then released slowly at night, increasing the temperature. Further heat is given off by the presence of factories and increased car use within the city, causing pollution which causes smog and a pollution dome to form. This pollution dome allows short-wave insolation to enter, but traps outgoing terrestrial radiation due to its longer wavelength, therefore increasing the amount of heat obtained. Due to these reasons, the mean winter temperatures are on average 1-2°C higher in urban areas, in comparison to rural areas. The mean summer temperature may be on average 5°C higher than surrounding rural areas. Climate change has the potential to influence almost all components of the urban environment and to raise new, complex challenges for the quality of urban life, health and urban biodiversity. Some cities will experience droughts and higher temperatures; others will be subjected to floods. In the near future climate change will deeply affect many microclimatic aspects of urban living. In addition, heat waves as well as droughts are mainly associated with the southern parts of Europe, where cities are already under water stress and have the highest population growth (LORENZINI *et al.*, 2014).

(b) *The host (plant) in the city.* – Woody ornamental plants in the city are special plants: usually they are forest plants (under the botanical point of view) which are treated as fruit plants (under the agronomic point of view), compelled to live in an hostile environment (*see above*). So, natural defences against biotic and abiotic stresses are limited in comparison to individuals growing in the natural environment. Probably the most important practice which differentiates urban trees from those living in the natural environment is the recurrent pruning. There are several good reasons to prune an ornamental tree: maintain health and reduce the risk of failure, provide clearance, reduce shade and wind resistance, improve flower production, improve a view, enhance aesthetics. The best and most effective pruning that can be done on trees is corrective structural pruning when trees are young, especially soon after planting. If structural defects such as co-dominant stems are corrected when trees are young and vigorous, the pruning cuts and associated wounds are small and tend to seal over well and with little risk of decay. Proper pruning of adult trees generally does not remove more than 25% of the canopy at one pruning and in one growing season, but over-pruning is very common. Topping is the practice of indiscriminately cutting back large diameter branches of a mature tree to some predetermined lower height, to reduce the overall height of the tree. Improper pruning cuts cause unnecessary injury and bark ripping. The wounds and associated decay caused by a large and improper pruning wound may be cause the tree to be hazardous (Shigo, 1982). Branches – living, dying, or dead – should be cut as close as possible to the collar at the branch base, but the collar should not be injured or removed.

(c) *The plant pathogens in the city.* – Of course, plant pathogens occurring in agro-ecosystems and in forest stands may infect urban plants as well. But phytopathology in the urban environment has a special and peculiar pathogen to deal with: man! In addition to the well-known crucial role in diffusing noxious organisms from a continent to another (mainly trading off infected plant material), in the city man has other responsibilities, mainly related to agronomic practises (i.e. pruning, *see above*) with infected instruments. As a case study the pandemics of canker stain of plane trees may be summarized (Panconesi, 1999). It is a wilt disease caused by the fungus *Ceratocystis platani* (*C. fimbriata* f. sp. *platani* in the past) (*Ascomycotina*, *Ophiostomatales*), and is a typical wound-pathogen. When the wound has been colonised, the mycelium of the pathogen advances into the conducting tissues of the underlying sapwood, where it develops both longitudinally and tangentially. A single infection can kill a mature tree in a couple of years. The fungus is spread through root anastomoses between neighbouring trees and during pruning operations, if instruments are not properly cleaned and disinfected. Figure 2 depicts a typical scenario in an infected *Platanus* population. Canker stain is probably indigenous to forests of North America, where it is not very dangerous because it seems to have few natural means of diffusion and because local native genotypes are fairly resistant. The role of humans in spreading the disease is dual: (*i*) the pathogen was unknown in Europe until the Second World War, and was introduced (long-distance transfer) in Italy with wood from infected trees used to package material coming from the USA; (*ii*) successive spreading (short-distance transfer) was assured by pruning operations with infected work implements. Now canker stain is present in the whole of Italy, from Alps to Sicily, with the sole exception of some areas where however plane trees are uncommon. Without the help of man this pathogen would be strictly confined to localized areas: on the contrary, it has spread through southern Europe in a dramatic manner, posing a strong menace for the survival of its host.

There is another important item when dealing with man-made plant diseases: anthropogenic environmental pollution. Air pollution, in par-

Fig. 2. – A typical scenario in a boulevard lined by London planes (*Platanus* sp.) in the presence of an epidemics of canker stain (*Ceratocystis platani*). Several dead trees have been fallen (infection is spread through root anastomoses); adjacent plants have been infected, are dead but still standing; remaining plants are healthy (so far). Uncontrolled infection is doomed to further spread via root grafting.

ticular in urban area has a long history of at least 2000 years: Seneca, for instance, complained about the oppressive atmosphere in Rome. It is not surprising that effects of air pollutants on plants have been investigated in more detail in rural than in urban situations, because the economic implications for agriculture and forestry are of more widespread concern than the fate of amenity value. However, for instance, in the years before the First World War, a series of experiments was carried out to measure the effect of the air in Leeds on plants, by growing them in a standard soil at various locations in and around the city. Their results showed very substantial effects of the city air. Lettuce plants, for instance, grown at a village 11 km far from the city, weighed three or four times more than similar plants grown in an industrial area, or in the city centre (Fig. 3). Since that time there has been a huge shift in the chemical composition of lower atmosphere (the concentrations of sulphur dioxide have dramatically declined, and today photochemically produced ozone is the major problem and urban transport is the chief source) and air pollution is probably the most important unnatural stress factor affecting the growth and survival of trees in urban areas. Ozone-induced injury in trees shows up primarily as foliar injury, including leaf or needle discoloration and premature loss. Reduced growth rates may precede or follow foliar injury. But important physiological effects of ozone exposure may take place even in the absence of visible symptoms (LORENZINI and NALI, 2005); these subliminal ("hidden") effects include alteration of stomatal behaviour, reduced photosynthesis and increased respiration, increased turnover of antioxidant systems, damage to reproductive processes, lowered carbon transport to roots, which implies an increase of the above

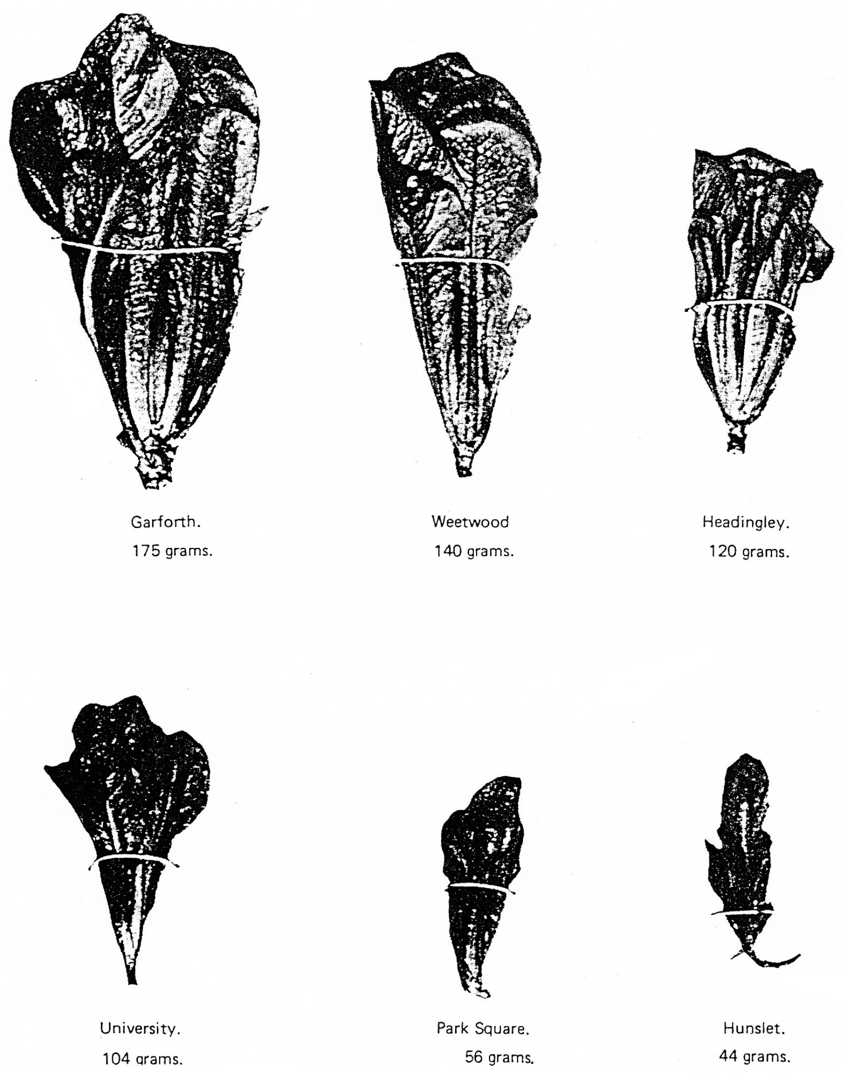

Fig. 3. – An experiment carried out in 1911 to demonstrate the effect of the air in Leeds and its suburb on plants. Lettuce plants were grown in a standard soil at various locations in/around the city. Dramatic differences in final weight were detected amongst plots and were correlated with "the freedom from sulphur" in the ambient air at each site (after LORENZINI and NALI, 2005).

ground/roots ratio. Moreover, increased susceptibility to diseases and other stresses (such as drought) may result from reduced photosynthesis and decreased allocation of carbohydrates to roots.

WHAT ABOUT HAZARD (AND POTENTIAL KILLER) TREES? – Tree fall in a forest stand may be an irrelevant phenomenon, but it is unacceptable in an urban environment. Tree custodians, who have both civil and criminal (as well as moral) responsibility for the actions and consequences of falling trees, have a duty to monitor the risk factors and minimize the probability of such damage occurring. Trees fail and represent hazards to property and people when the load (weight and motion of the crown) exceeds the mechanical strength of their stems, branches or root systems. This is true for both sound and defective trees, but defective individuals can only withstand a fraction of the load that sound trees can withstand. So, trees rated as low in their risk for failure can fail during extreme windstorms, while highly defective trees and tree parts can fail during calm days. External indicators of decayed wood are not often present, such as fungal fruit bodies, cavities, cracks, and fluxing material, so trees may contain a large amount of decayed wood without having obvious external indicators. Most defects can be linked to past wounding (including improper pruning, *see above*), but trees may began to break up while they are in good conditions. Molecular methods, such as polymerase chain reaction (PCR) (MCCARTNEY *et al.*, 2003), are routinely used in the diagnosis of plant pathogens (mainly wood decay agents) in the urban environment: however, they only can detect the mere presence of the pathogen, but not the extent of the damage it is causing to wood and the menace it represents for tree stability.

Trees or tree parts can fail and cause damage or personal injury, particularly during loading events such as wind and snow storms. The failure of limbs or entire trees, however, is often predictable, detectable, and preventable. It is crucial to identify when and where a tree has become an unacceptable risk. Trees vary in their level of risk for failure and trained people can best determine these risk ratings. Modern techniques and procedures can be used to minimize the risks associated with tree failure and to identify structural defects. Steps underlying risk assessment protocols include: (*i*) the evaluation of the probability of mechanical failure; (*ii*) the severity of impact in the event of failure, and (*iii*) the probability of people or particular items of property being present at the time.

Tree risk inspections provide a systematic method of examining trees, assessing defects present, and estimating the degree of risk trees pose to public safety. Visual tree assessment (VTA; MATTHECK and BRELOER, 1994), using the 360-degree walk-by method (POKORNY,

2002) is often sufficient for detecting most visible defects and assessing the probability of tree failure (LONDSDALE, 2001). In most cases the tree gives out a silent sign in its body language: it is up to the professional to interpret and evaluate biomechanically these symptoms (e.g. holes and cavities, adaptive growth, cankers, cracks, stem girdling roots, weak branch unions, included bark, leaning). As above described, however, some defects do not have external signs or symptoms and their identification requires in-depth inspections and the use of specialized diagnostic tools. Many devices are available to detect internal decay and other defects in standing trees. Traditional, low tech devices include the steel rod, rubber mallet (but, remember, "*sounding is an art!*" – the tonality of wood changes only when there is extensive decay inside the trunk) and increment borer (Pressler borer). The core of wood removed can be examined for the presence of discoloration or decay. Strength and elasticity of this core may be evaluated by means of a fractometre, which analyses the fracture moment and angle of failure. Another low-tech approach is represented by decay sniffing dogs, but in urban areas their use may limited by many odours much stronger than those given off by fungi (NICOLOTTI and MIGLIETTA, 1998).

Tree risk analysis has evolved over time from a qualitative art to a quantitative science. Utilizing modern techniques, it is possible to more accurately quantify the uprooting stability and breaking resistance of a tree and provide a more thorough analysis of risk than it was possible only a couple of decades ago. Most popular high-tech devices include sonic/ultrasonic detectors and dendropenetrometers (NICOLOTTI and MIGLIETTA, 1998). Sonic devices are acoustic instruments that measure the time taken for a shock wave to pass a tree trunk. The stress wave is initiated by a hammer blow that is delivered to a start probe located on one side of the trunk to travel to other sensor probes located diametrically opposite on different sides of the trunk, on the same or on different levels. The time required to travel to the various sensor probes ("transit time") is measured. The instruments work on the principle that transmissibility of sound waves through a body is determined by the body's density. Damaged wood is usually less dense, so transmission of the sound takes longer than if the tree was free of defects. A computer analyses the speed of the waves to determine areas with the same density ("sonic tomography", digital phytoimaging) (Fig. 4). Penetrometers are self-powered drills which record the resistance encountered by a very thin probe as it is impelled into the wood rotating at high and electroni-

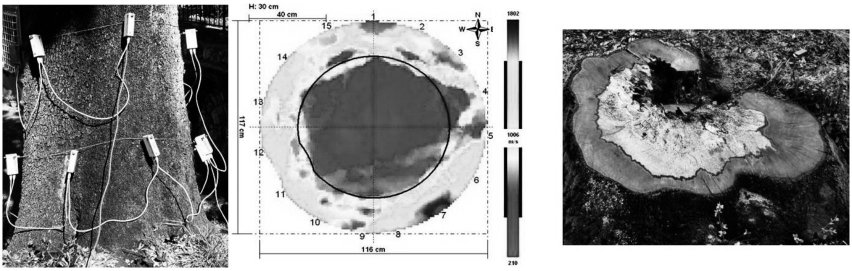

Fig. 4. – *Left*: sensors of a sonic detector around the basal portion of the trunk of an adult holm oak (*Quercus ilex*) tree; *middle*: plot of the sonic tomography (digital phytoimaging) analysis of the lower stage, based on a PC-processing of the speed of the waves (right side); *right*: cross section of the tree after felling: damaged wood is clearly visible.

cally controlled constant speed. They work on the premise that during the wood decay process, wood density decreases and, correspondingly, wood hardness and drilling resistance declines. So, severely decayed wood is less dense, softer in texture, and has a reduced drilling resistance than sound wood. The power demand of the motor during penetration expresses the density of wood and is converted into graphic signals (dendrograms) that both reveal and quantify decay in the wood (Fig. 5).

In sum, the mission of urban plant pathologists is to verify if a tree has what it takes to stand up in a secure way. This is based on the evaluation of the acceptable safety factor (safe shell limits, e.g. t/R ratio; MATTECK *et al.*, 2006). If this is not the case, the tree becomes an unacceptable risk, and must be corrected (e.g. pruned, cabled and braced) or removed (Fig. 6). In the alternative, the area should be closed to the public (*target removal*) (Fig. 7).

CONCLUSIVE REMARKS. – Trees are integral to the character of many urban areas, offering benefits and services, softening the landscape, making it more attractive and boosting property values. People also benefit from the shade and shelter which they provide and their ability to screen out noise and light. In addition, trees can have significant ecological benefits, providing wildlife habitats and corridors, moderating the urban climate, storing carbon dioxide and intercepting rainfall, which reduces erosion and flooding. In “conventional” agriculture and crop production, uncontrolled plant diseases may result in less food and higher food prices, or in food of poor quality; in addition, diseased plant produce may sometimes be poisonous or unfit for consumption. But in the urban environment a diseased tree may be a killer and for the

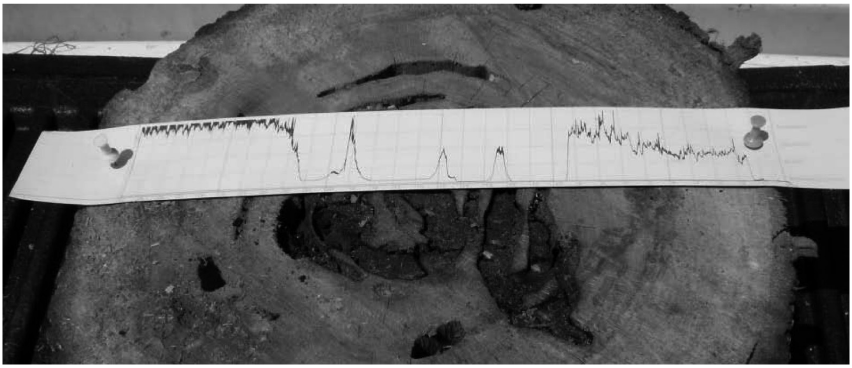

Fig. 5. – *Above*: a dendropenetrometer in action on the root of a tree. *Below*: a graphic signal (dendrogram) obtained with a dendropenetrometer: it shows the power demand of the motor during penetration (*ordinate*) as a function of drilling depth (*abscissa*).

three-quarters of Europe’s population that live in cities and towns, the presence of well-performing trees and plants is a precondition for a good quality of life.

No doubt that plant pathology in the urban environment is not an easy task: several factors make this discipline very peculiar. For instance, pesti-

Fig. 6. – This tree has a canker and associated decay that affects more than 50 per cent of tree circumference: it does not meet safe shell requirements and should be removed.

cides use is banned in most cases. Special applications could be injections into trunks: chemicals may be injected, infused, or implanted into trees, but at the moment the availability of registered fungicides for this special treatment is very low and no practical use is predictable. The key issue for urban phytopathologists is the "operational chain" [(improper) pruning-wood decay-tree (or branch) fall-injury to persons/damage to property], which is almost absent in conventional (open field) plant pathology. Tree

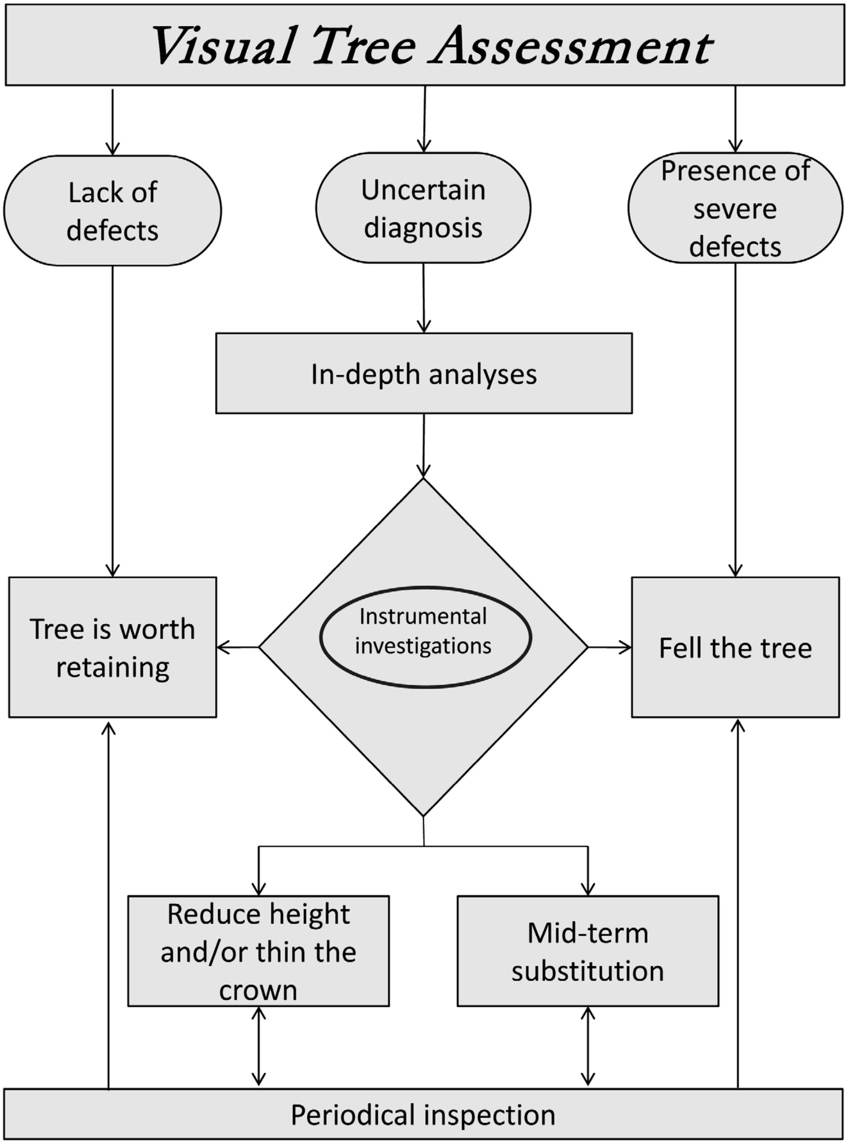

Fig. 7. – Decision tree for Visual Tree Assessment.

pruning is a key element and must be performed at due time and following the best available technologies. Pruning tools must be clean and sanitized as well as sharp. Most pathogens need some way of entering the tree to cause disease, and fresh wounds are perfect places for infection to begin. Microorganisms on tool surfaces are easily introduced into susceptible trees when subsequent cuts are made. Wound dressings are not necessary or recommended for most pruning cuts. Research has shown that dressings do not hasten wound closure or reduce wood decay (POKORNY, 2002). Another crucial point is that there still remains the difficulty of monitoring the extent and soundness of a tree's root system. The fall of trees in towns and cities, indeed, is frequently caused by root rot pathogens.

Urban forest pathology is a new and growing discipline and specialized professionals are deeply required, as trees of our cities are getting older and dangerous. Proper pruning is still the best thing we can do for our trees. At least the person supervising these activities should be licensed/certified and able to implement the best available technologies. University courses of Agricultural and Forest Sciences should discuss and deepen these crucial issues. Tree operators must be trained and qualified: the safety of the citizens depends on them!

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