Video Article

A Venturi Effect Can Help Cure Our Trees

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Abstract

In woody plants, xylem sap moves upwards through the vessels due to a decreasing gradient of water potential from the groundwater to the foliage. According to these factors and their dynamics, small amounts of sap-compatible liquids (*i.e.* pesticides) can be injected into the xylem system, reaching their target from inside. This endotherapic method, called "trunk injection" or "trunk infusion" (depending on whether the user supplies an external pressure or not), confines the applied chemicals only within the target tree, thereby making it particularly useful in urban situations. The main factors limiting wider use of the traditional drilling methods are related to negative side effects of the holes that must be drilled around the trunk circumference in order to gain access to the xylem vessels beneath the bark.

The University of Padova (Italy) recently developed a manual, drill-free instrument with a small, perforated blade that enters the trunk by separating the woody fibers with minimal friction. Furthermore, the lenticular shaped blade reduces the vessels' cross section, increasing sap velocity and allowing the natural uptake of an external liquid up to the leaves, when transpiration rate is substantial. Ports partially close soon after the removal of the blade due to the natural elasticity and turgidity of the plant tissues, and the cambial activity completes the healing process in few weeks.

Video Link

The video component of this article can be found at http://www.jove.com/video/51199/

Introduction

In recent times, trunk endotherapy has progressively replaced traditional air spray methods in woody plants[1-6], but this is not a recent idea. In the 15th century Leonardo Da Vinci described in detail how he was able to intoxicate apples by injecting arsenic solution into the trunk of an apple tree through deep holes made with a gimlet[7]. Little has changed since then: chemicals easily available in nature have gradually been replaced with more efficient synthetic active ingredients (insecticides, fungicides, bactericides, fertilizers, plant growth regulators and desiccants). Atmospheric pressure injections evolved into high pressure, and hand-driven gimlets have been replaced by modern battery drills[8-10]. Unfortunately, even the sharpest drill bit tears and overheats the cambial tissue responsible for the hole closure. Consequently, wound closure is delayed and large sections of the adjacent woody tissues lose their functionality ("discolored wood") from the injection site to several feet above and below[11]. Furthermore, unplugged holes can easily be colonized by bacteria and fungi attracted by the bleeding sap and leading to long-term internal decay, with a consequential loss of wood strength and stability[12,13].

Realizing that 1) a group of longitudinal fibers separates according to a lenticular biconvex geometry (**Figure 1a**), and 2) sap movements into vessels fulfill the Bernoulli's principle on fluid dynamics, in 2011 the University of Padova designed a new[14] drill-free endotherapic instrument with an essential lenticular, biconvex and hollow blade that enters the wood separating its fibers. In this way, inner xylematic vessels are reached with minimal friction (**Figure 1b**), and the temporary reduction of their section increases sap velocity, accelerating the natural uptake of an external liquid (**Figure 1c**, **Video 1**)[15,16].

Protocol

1. Perform treatments preferably between bud break and late summer, in sunny and breezy days, according to general rules in tree endotherapy[17].
2. Wear gloves, protective glasses and any other safety device according to regulations in force.
3. Get familiar with the instrument, disassembling and reassembling it. Its main components are reported in **Figure 2.**
4. Get familiar with the method, described in the following steps and in **Video 2**. Start practicing infusion technique using water in an un-pruned tree with smooth bark, fully developed canopy and very broad leaves (*i.e. Platanus* spp., *Quercus* spp.).
5. Use only toxic liquids (insecticides, fungicides, desiccants, *etc.*) authorized for tree injection according to local or national rules, and diluted according to the producer information (see label).

6. Measure the circumference (crf = diam x 3.14) of the tree at breast height and calculate the quantity of solution according to the technical information provided by the liquid's producer (*i.e.* if cfr is 190 cm and dosage is 0.7 ml /cm, a total amount of 133 ml of diluted liquid will be injected).
7. Calculate the number of ports to be made according to the diameter (diam) or circumference (crf) at breast height, envisaging 1 port/25-30 cm crf and rounding the result to the following unit (*i.e.* 190 cm crf = 6.3 = 7 ports).
8. Recalculate the distance between ports according to the final number of ports (*i.e.* 190 cm/7 ports = 27 cm)
9. Calculate the final volume of liquid/port (*i.e.* 133 cc in total/7 ports = 19 ml/port).
10. When using pre-filled capsules, calculate the number of ports according to the manufacturer' instructions.
11. Select equidistant insertion sites (*i.e.* 7) along the circumference in the first 150 cm from the ground, preferring lightly convex, smooth locations above root flares.
12. Avoid any part with anomalies able to interfere with sap dynamics, above or below the insertion site (*i.e.* knots, wood decay, pruning cuts).
13. If necessary, superficially smooth the bark with a knife to allow the external gasket to make a perfect seal with the bark. If the site is too rough or too curved, move a few cm to one side.
14. Choose a blade with a length compatible with both bark thickness and tree diameter and screw it to the body. In broadleaves, at least 2 cm must enter the woody tissues; in conifers and palms, longer blades are preferable to overcome the resin vessels or because of the monocotyledonae anatomy, respectively.
15. Fill a disposable pharmaceutical syringe (the cheapest and most effective solution) of suitable volume with the solution required for a single insertion (*i.e.* 17.14 ml), keeping the plunger in for at least 3 cm deep (*i.e.* a 20 ml syringe).
16. As an alternative to the syringe, use any container for tree injections (*i.e.* drip bags, refillable syringes, pre-filled capsules, external tanks) fitting with the conical hole (female hypodermic needle standard) or the 1/8" thread located on the tool's arm.
17. Hold the body firmly with a hand, directing the blade to the tree's center. The blade's edge must be directed parallel to the fibers (*i.e.* vertically).
18. With the other hand strike the sliding hammer on the body until the external latex gasket is completely squeezed.
19. Insert the syringe in the conical opening and gently draw out the plunger: air that entered the instrument during the percussion will flow out through the liquid. The resistance of the plunger indicates the perfect insertion of the blade. Note: with different couplings air cannot be drawn out and treatment will be slower.
20. Wait for total uptake.
21. If infusion is quick (*i.e.* 10 ml/1 min), to decrease the total number of ports refill the container before it's empty and then recalculate the number of ports. Note: to ensure a good distribution of the liquid to the canopy, at least one port /40 cm along the circumference is suggested.
22. If infusion takes too long (more than 1 ml/min; *i.e.* on cloudy days or in conifers and palms) turn to light injection mode, re-inserting the plunger and applying a low pressure with the thumb, or connecting the tool to a pressurized tank (*ca.* 1.5 bar; **Figures 3a and b**).
23. If injection doesn't happen, postpone the treatment until suitable physiological and climatic conditions prevail.
24. When the container is empty, wait for the remaining liquid to exit the blade (8-10 sec), remove the syringe and extract the blade by striking the hammer in the opposite direction.
25. Move to the next port.
26. Use an inert wax or gum if protection of the wound is desirable or compulsory. Note: pruning or grafting gums containing pesticides can be phytotoxic for the cambium, slowing down the wound closure.
27. In case of plants affected by transmittable diseases, disinfect both the blade and the body after treatment. Where locally acceptable, use alcohol or hydrogen peroxide. In case of heat disinfection, remove both the external and two internal rubber gaskets and treat them separately, or substitute them.

Representative Results

Due to its small dimension and unique shape, the lenticular blade does not remove cambial and woody tissues, and when compared with traditional drill holes, the wound is visibly smaller (**Figure 4a**). Usually, the edges of the hole are slowly compartmentalized by cambial tissues (**Figure 4b1**), often because of overheating during drilling. Conversely, after treating the same tree with a lenticular blade, the woody fibers revert to their previous shape, and the cambium starts to produce meristematic tissues in a few days. Mainly in broadleaves, this is visible after detaching the bark (**Figures 4b2** and **c**). Usually, after few months, the wound is perfectly healed, with a small amount of underlying discolored wood (**Figure 5**), allowing further treatments if the tree is not used for high quality timber.

Because of its shape, the blade produces a "Venturi effect". This physical phenomenon takes place when the fluid's velocity inside a duct is substantial (**Video 1**), and in a tree the main variables affecting sap velocity are associated with leaf transpiration. According to our preliminary results, infusions are quicker in broadleaved species with annular or decreasing wood porosity, and when liquid is applied in convex or flat surfaces close to the base or on root flares (**Video 2**; **Figure 6**). The best performing environmental conditions are during daytime, with soil moisture content close to 60% and slight breeze **(Figure 7)**. In normal conditions, for instance, a London plane (*Platanus acerifolia*) can spontaneously uptake 10 ml of the insecticide abamectine in less than 1 min, and in ideal conditions around 1 L in 10 min[18].

When sap velocity is too low (sub-optimal environmental conditions, tree species with intrinsically slow sap, like conifers and palms), the up-take can be gently forced by applying some slight pressure from outside (injection).

As a general rule in tree endotherapy, localized infusion of liquids along the trunk do not guarantee rapid translocation to leaves. **Figure 8** reports the up-take time to leaves in Pedunculate oak (*Quercus robur*) demonstrating that, with no external pressure applied, water needs at least 6 hr to reach leaves, and that uptake times can be doubled using active ingredients, although formulated for endotherapy. However, the velocity and not the delivery method is the limiting factor: **Figure 9** demonstrates that up-take to the leaves by means of infusion happens also in palm trees, characterized by very slow sap dynamics. In this case, it takes *ca.* 24 hr, while the same result is reached through drill holes in *ca.* 3 hr, applying a 50 psi pressure.

Wide, statistically based tests on the efficacy of the injected chemicals against single pests were not performed, being related to many variables (*i.e.* tree species, physiological status, infestation degree, active ingredients and formulations), but preliminary trials using abamectine 6% to control aphids on *Prunus* spp. and *Cedrus libani*, *Cameraria ohridella* on *Aesculus hyppocastanum*, and *Thaumetopoea pityocampa* on both *Cedrus* spp. and *Pinus* spp., gave positive results[19].

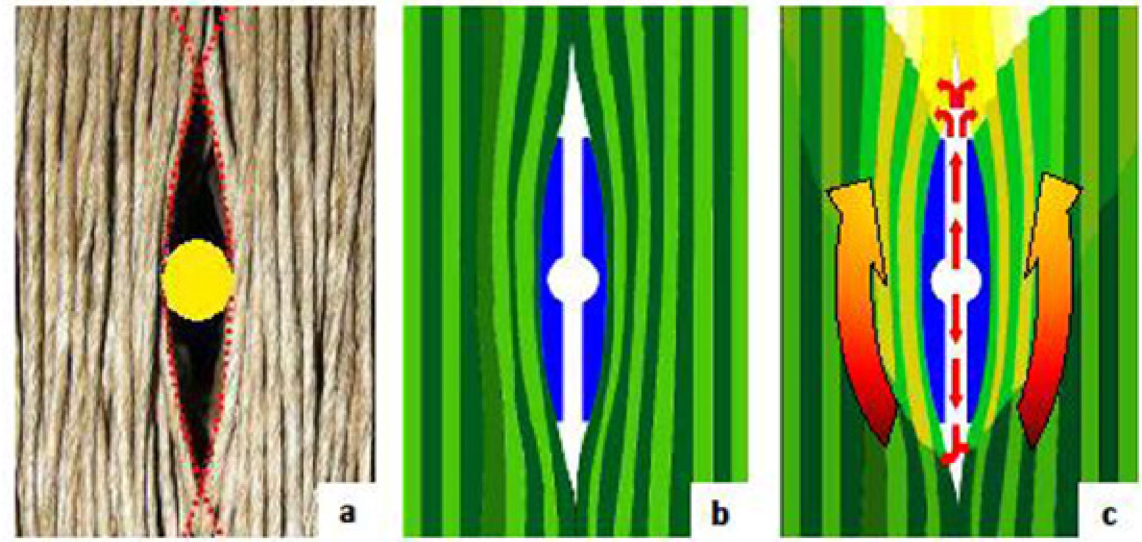

Figure 1. Advantages of lenticular blades. By introducing an object of any shape into a group of fibers, they separate according to a lenticular biconvex geometry (**a**). Differently from existing needles, a lenticular blade separates the fibers with minimal friction and damage (**b**). The blade shape causes a temporary reduction of the vessels' cross section, producing a "Venturi effect": sap pressure decreases and its speed increases. When the natural speed of sap is substantial, liquids from an external source are passively absorbed by the tree (**c**). Click here to view larger image.

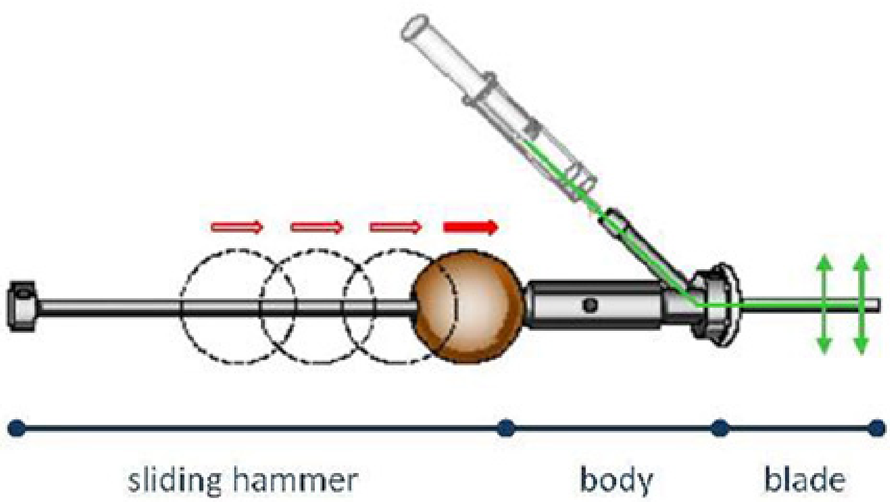

Figure 2. Components. The instrument is totally manual and has interchangeable blades of differing lengths, a body for connection to the liquid container, and a sliding hammer for axial insertion and extractions for the least damage to the tree (figure modified from [16]). Click here to view larger image.

Figure 3. Low pressure injections. Thumb pressure usually is sufficient to turn from infusion to injection when natural sap velocity is too slow (**a**). Multiple connections to pressurized tanks speed up the treatment (**b**). Click here to view larger image.

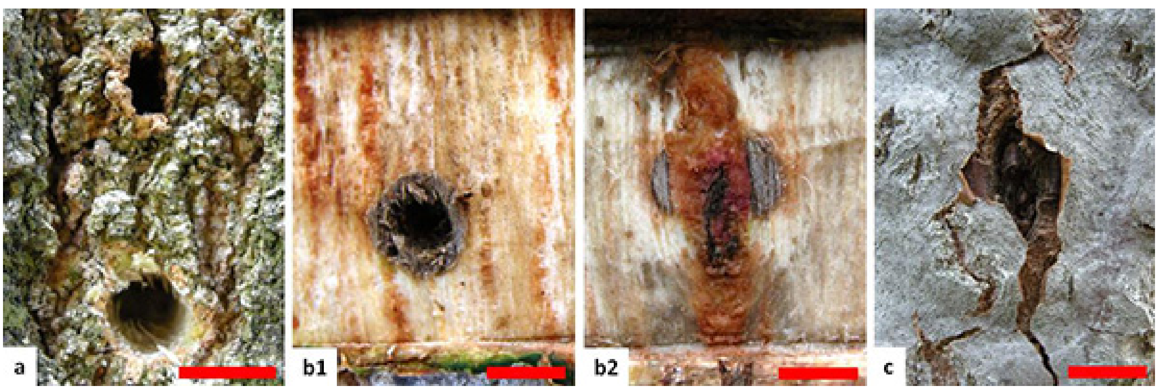

Figure 4. Closure times. Comparison between a traditional 4 mm diameter drill hole and blade wound before treatment (**a**; *Betula pubescens*). Removing the bark 4 weeks after treatment, the edge of the hole is smaller but noticeably necrotic (**b1**), whilst the bigger blade but less traumatic wound, is perfectly closed by meristematic tissues (**b2**; two diametrically opposite treatments in the same *Populus nigra*). Full closure after 1 month (**c**, *Aesculus hyppocastanum*). All treatments at bud break with abamectine 6%; bar: 5 mm. Click here to view larger image.

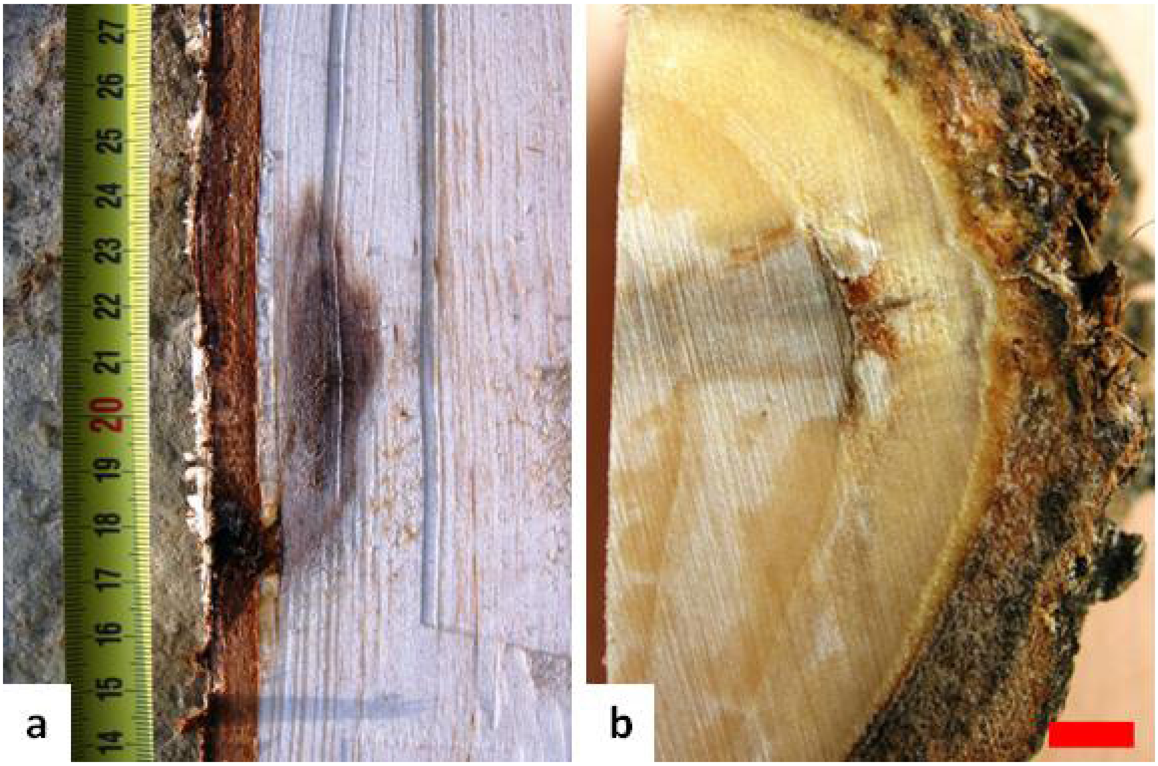

Figure 5. Discolored wood. Twelve months from treatment, extension of discolored wood (**a**, *Populus nigra,* bar: 5 mm; **b**, *Betula pendula*; potassium phosphates 25%). Click here to view larger image.

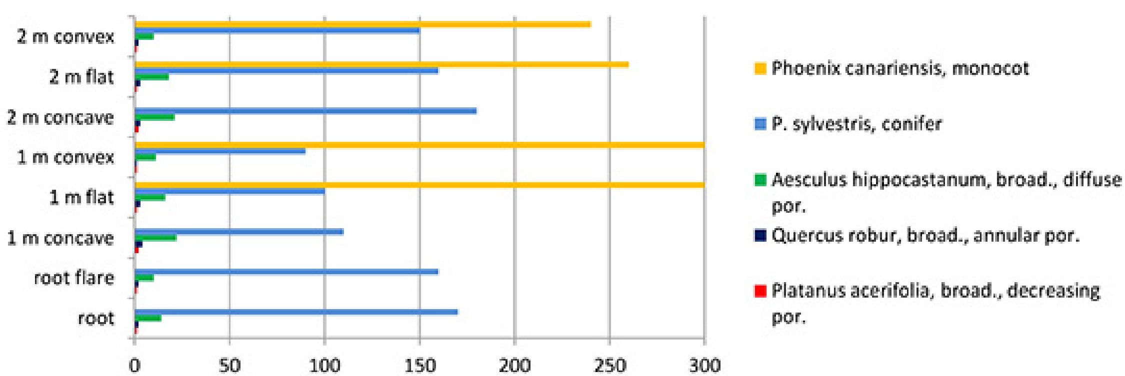

Figure 6. Injection times change with injection position and wood porosity. According to preliminary results, the quickest infusions happens in healthy broadleaved species with annular or decreasing wood porosity, in convex or flat surfaces close to the base or on root flares (min/10 ml of abamectine 0.1%, soil humidity 60%, wind 4 knots, fully developed leaves). Click here to view larger image.

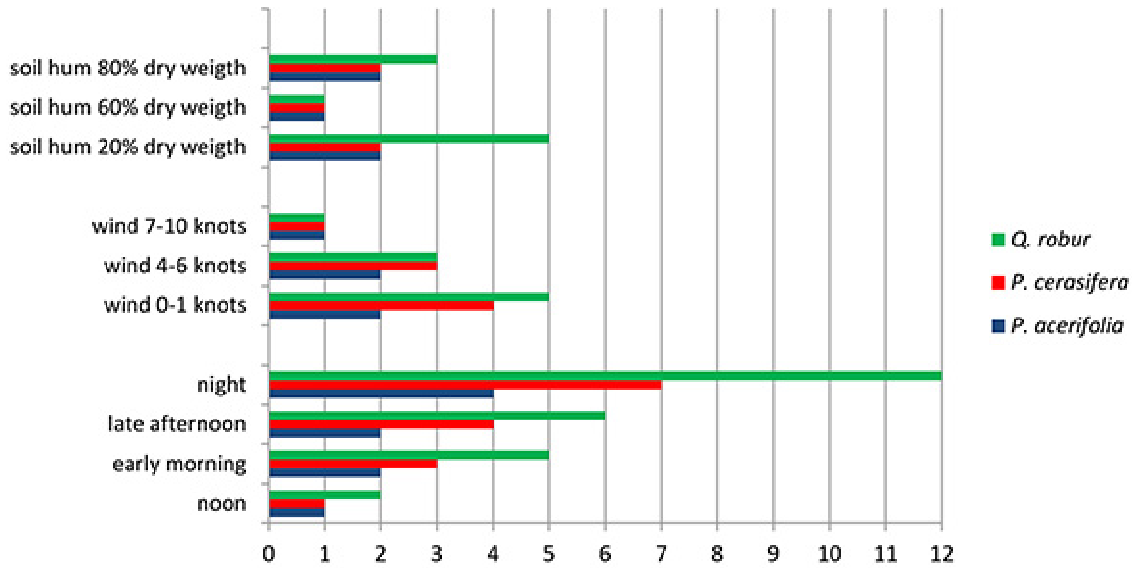

Figure 7. Environmental variables affect the up-take speed. According to preliminary results, best performing variables are daytime, soil humidity close to 60% and weak wind (minutes to uptake 10 ml of abamectine 0.1%, 0 psi, fully developed leaves). Click here to view larger image.

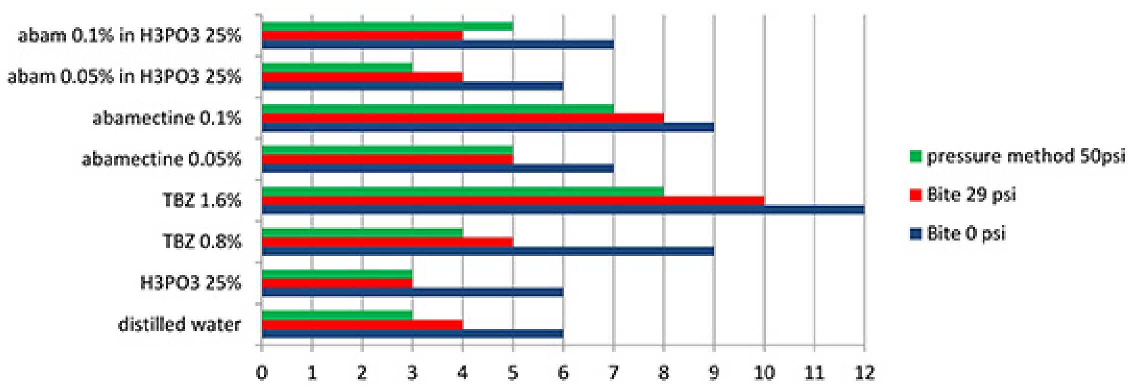

Figure 8. Up-take times to leaves. Using red safranin as a marker, liquids infused in Pedunculate oak (*Quercus robur*) takes significantly different times to be detected in leaf petioles, according to pressure applied and active liquid features (hr/10 ml of liquid, soil humidity 60%, wind 4 knots, fully developed leaves, abam = abamectine, TBZ = thiabendazole, H_3PO_3 = potassium phosphytes; all products commercially formulated for trunk injection). Click here to view larger image.

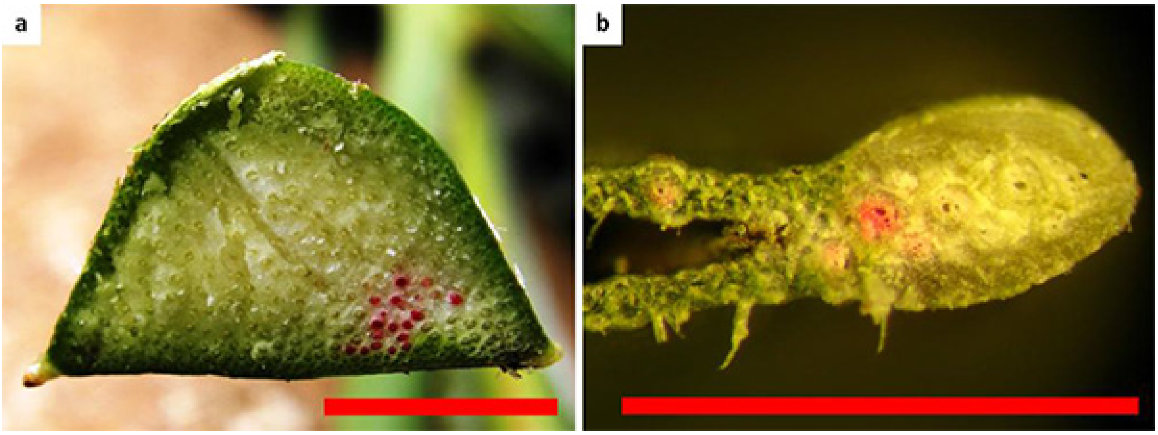

Figure 9. Up-take times in palms. Palm trees are known for their very slow sap velocity. The two pictures show the presence of stained insecticide in petioles (**a**) and leaves (**b**) *ca*. 24 hr from infusion (*Trachycarpus fortunei*, abamectine 0.1% and safranin, 0 psi; bar: 5 mm). Click here to view larger image.

Video 1. Click here to view Movie 1. The "Venturi effect". Action 1: once reduced the sectional area, when water velocity is substantial this physical phenomenon takes place. Action 2: according to natural sap velocity, the same effect happens with a lenticular blade temporarily reducing the vessel's section (video speed up 8x; Cherry tree, *Prunus cerasifera*; potassium phosphate 25%).

Video 2. Click here to view Movie 2. Infusion. Natural uptake in Cherry tree (*Prunus cerasifera*; potassium phosphate 25%).

Discussion

In spite of the acknowledged environmental advantages of tree endotherapy, up to now the main factor limiting a wider spread of this method has been related to the negative side effects of the drill holes used in traditional pressure methods (*i.e.* delayed wound closure, parasitic infections through the hole, production of inactive discolored wood).

In contrast with other methods, the described one was envisaged to work in compliance with host physiology, considering the delivery rate as of minor importance for the treatment success.

From the point of view of a professional operator, this is a limitation of the technique. In fact, with methods based on external pressure, delivery times are predictable also in sub optimal conditions, and number of plants to be treated per day can be easily planned. With the described technique, instead, uptake speed is directly related to the volume of water simultaneously dispersed through leaf transpiration, and in sub optimal conditions it can be slower than desired. In this case uptake can be encouraged by gently applying a low external pressure, not exceeding 1.5 bar. According to the project approach, waiting for better conditions is the suggested choice when leaf transpiration is not optimal.

One critical point relates to liquids distribution inside woody plants. In fact, while a huge amount of scientific data is available on pressure injections, little is currently understood about the dynamics leading to the best circulation of chemicals in the whole tree when applied by means of infusion. Investigations in progress at the University of Padova strengthen the hypothesis that, according to formulation, tree species and port location, minor changes in the liquid pH can significantly accelerate natural uptake.

According to the new trends of modern arboriculture[11,17,20], this paper suggests a different way to distribute pesticides and other sap compatible liquids into trees. This method is a suitable option when the side effects of the delivery method are more important than the operator's daily productivity. Lenticular bladed instruments, by enabling trees to absorb liquids according to their physiological status, represent a new step forward in developing less invasive endotherapic treatments.

Disclosures

Patent references of the described instrument are PD2011A000245, EP2012/063680, WIPO WO/2013/010909.

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