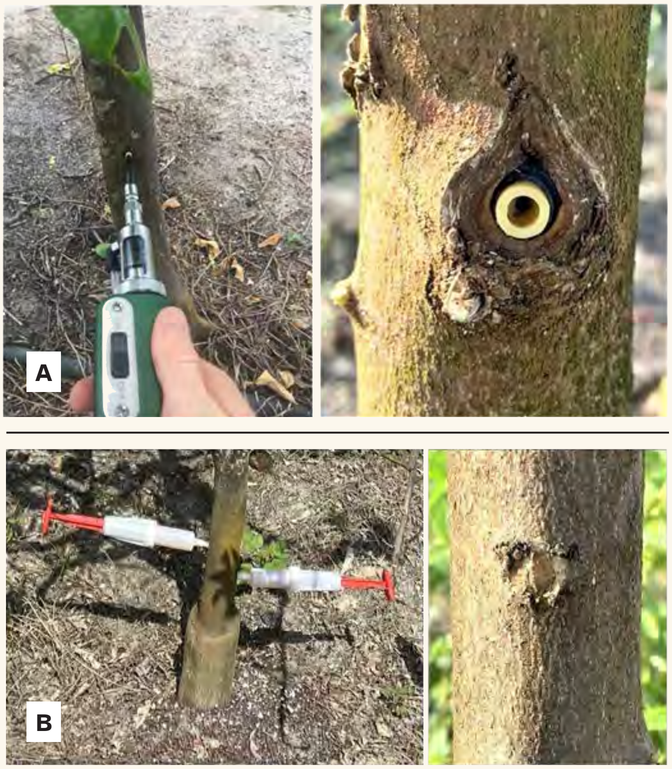

Figure 1. High-pressure trunk injection (A) requires the use of a plastic plug, which causes more damage at the injection site than medium-pressure injection (B).

Principles and risks of trunk injection for delivery of crop protection materials

By Ute Albrecht and Leigh Archer

Trunk injection is a targeted delivery of materials into the stem or trunk of trees as an alternative to spraying or soil drenching. It is practical for disease and pest management in high-value forest trees and ornamental plants where aerial applications are problematic because of environmental and human health-related concerns. Interest in using the injection technique to protect agricultural crops has emerged more recently in areas where foliar applications and soil drenches have proven ineffective or pose environmental hazards.

"Injection" is defined as the act or process of forcing a liquid medicine or drug into someone or something, usually by using a special needle. In botany, this term is used in a wider sense and applies to introducing any materials into a plant organ through cuts or holes with or without force.

The earliest evidence of plant injection is from the 12th century when Arabic horticulturists applied perfumes, spices, dyes and other substances through wounds to affect the smell, color or other qualities of flowers and fruits. Modern research on the use of trunk injection to deliver protection materials was incited by the devastation Dutch elm disease (a vascular fungal disease) wreaked in Europe and North America during the 1900s. This method is still used predominantly for forest trees and ornamental plants, but also to treat diseases in some fruit tree crops.

TRUNK INJECTION METHODS

Different devices are available for delivering liquid materials into tree trunks. Many of them require drilling a relatively large hole, followed by injecting the desired material using pressures up to 100 pound-force per square inch or more. High-pressure injection usually requires inserting a plastic plug into the drill hole and is therefore only suitable for large-size trees.

Other devices require less pressure or no drilling and are less damaging and more suitable for smaller trees (Figure 1). University of Florida Institute of Food and Agricultural Sciences (UF/IFAS) field experiments show that some pressure is necessary to effectively deliver the necessary volumes of material into a tree.

TREE PHYSIOLOGICAL PRINCIPLES

Trunk injection delivers materials into the xylem (wood) of trees. The xylem is the part of the vascular system that is responsible for transporting water and nutrients from the roots to the rest of the tree. It is mostly composed of non-living tissue that forms a pipe-like system. Transport in the xylem is passive and occurs with the plant transpiration stream. Because injected materials are easily distributed through the xylem and are spread relatively homogeneously throughout the canopy, trunk injection is primarily used to target xylem-related diseases such as wood-boring insects or xylem-inhabiting fungi and leaf chewing, piercing or sucking insects.

The urgent need for an HLB cure and the discovery of novel therapeutic compounds have sparked interest in using trunk injection for effective delivery of materials into citrus trees. In contrast to pests and diseases commonly targeted by trunk injection, HLB is associated with a phloem-limited pathogen.

While the xylem occupies most of the trunk, the phloem is a thin layer of tissue located in the inner bark. The phloem is a living tissue that transports sugars and other organic substances throughout the plant. Phloem transport occurs from source tissues with a high sugar content (usually

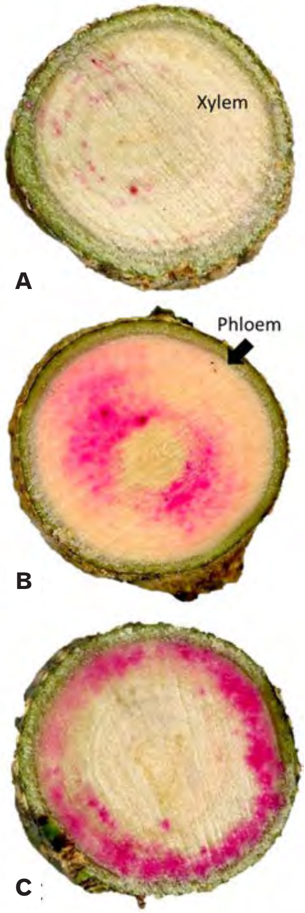

Figure 2. Trunk distribution of three dyes with different chemical properties: A) dye with low mobility, B) dye dispersing throughout much of the inner trunk and C) dye moving predominantly in the outer wood beneath the bark. Dyes were injected 8 inches below the stem sections shown.

photosynthetically active leaves) to sink tissues where sugars are needed, such as roots and developing fruits. It is not possible to inject large amounts of materials directly into the phloem.

OTHER CONSIDERATIONS

For trunk-injected crop protection materials to reach pathogens that reside in the phloem, such as the HLB-associated bacteria, the materials need to be able to move readily from the xylem to the phloem. The exchange of materials between xylem and phloem is not well understood but depends on the properties of the injected chemical.

Figure 2 demonstrates the different movements of three dyes with different chemical properties. For a crop protection material to be effective against phloem-inhabiting pathogens, it must be mobile enough to reach the phloem, but not so mobile that it moves back

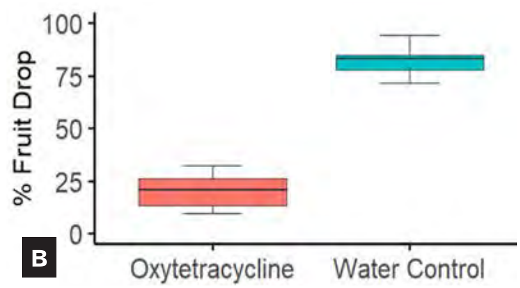

Figure 3. Effect of oxytetracycline trunk injections on tree health (A) and fruit drop (B) of 4-year-old Valencia trees. The tree on the right received one injection of oxytetracycline in October 2020; the photo was taken in February 2021. Fruit drop was assessed from December 2020 to March 2021.

out and is transported primarily in the faster-moving xylem.

Using antimicrobial compounds to cure HLB has been a discussion for many decades. So far, these materials do not have the desired levels of activity when delivered in a foliar spray. In contrast, experiments with tetracyclines conducted in the 1970s in South Africa and other countries, and more recently Florida, demonstrated that it is possible to reduce bacterial titers and HLB severity through trunk injection.

Preliminary results from UF/IFAS ongoing field experiments support these findings and demonstrate that injecting oxytetracycline can improve tree health and dramatically reduce fruit drop in citrus trees that are severely affected by HLB (Figure 3). It is important to note that any materials injected into the trunk move readily into the fruits and that oxytetracycline is not labeled for trunk injection in bearing citrus trees. Nevertheless, these experiments show that trunk injection is effective for systemically delivering therapeutic materials and restoring health and productivity to HLB-affected trees.

WOUNDING

Another concern regarding the use of trunk injection is its effect on tree health. Drilling or otherwise injecting materials into the trunk wounds the tree and provides entry points for opportunistic pathogens. Furthermore, upon injury, xylem vessels embolize and become dysfunctional, affecting the water- and nutrient-transport capability of a tree. Similarly, the phloem will be destroyed, affecting sugar transport.

Trees are generally very effective in compartmentalizing wounds. Figure 4A (page 17) shows the effective compartmentalization of a wound created after injecting water. During the next growing season, new xylem and phloem form, rendering the injured area functional again. As xylem transport is usually most active in the outer (newest) wood, the tree may fully regain its transport capacity in the season following injury.

It is imperative to determine any potential phytotoxic effects of the crop protection material before its use. For example, oxytetracycline prevents the closure of wounds after injection and causes considerable structural damage inside the tree (Figure 4B, page 17). The long-term effects of this are yet to be determined. Figure 4B also shows that a tree's ability to compartmentalize wounds is less effective in the up-and-down direction than in the left-to-right direction.

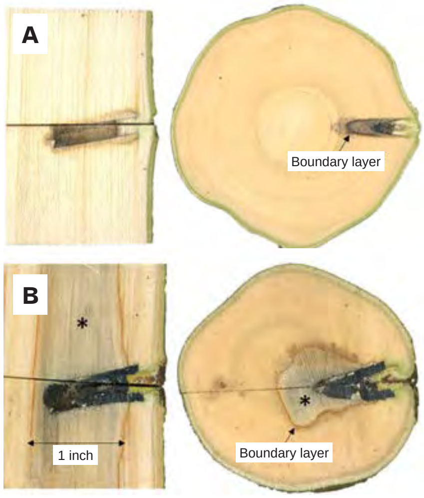

Figure 4. The wound is effectively compartmentalized after water injection (A), and new wood is visible above the injection site. In contrast, necrosis and ineffective compartmentalization is observed after oxytetracycline injection (B) as indicated by a broad zone of discoloration (*). The boundary layer marks the border of effective encapsulation of the wound area that prevents entry of opportunistic pathogens.

CONCLUSIONS

Trunk injection is an effective method for delivering crop protection materials systemically and with minimal impact on human health and the environment. However, trunk injection comes with risks ranging from residual chemicals in the fruits to the impact of wounding on long-term tree health. Trunk injection of most registered crop protection materials is not labeled for bearing citrus trees.

Currently, the cost associated with trunk injection impedes its widespread use in commercial citrus production. It is expected that automated delivery methods will be available soon that reduce cost and render trunk injection more practical for delivering novel therapeutic compounds currently being developed.

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