Trunk injection for delivery of HLB therapies

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Trunk injection – definition

- The targeted delivery of crop protection materials into the stem or trunk of a woody plant as an alternative to spraying or soil drenching ("endotherapy")

- Injection occurs into the **xylem** (not phloem) from where the materials are then distributed throughout the plant with the transpiration stream

Modern areas of use

- Forest trees, non-crop-bearing ornamental trees, and palms in residential and commercial landscapes
- Few crop-bearing agricultural crops (e.g., avocado, peach, pear)

→ *20% of the commercial avocado acreage (~6000 acres) in Florida is managed for laurel wilt by trunk injections*




Trunk anatomy

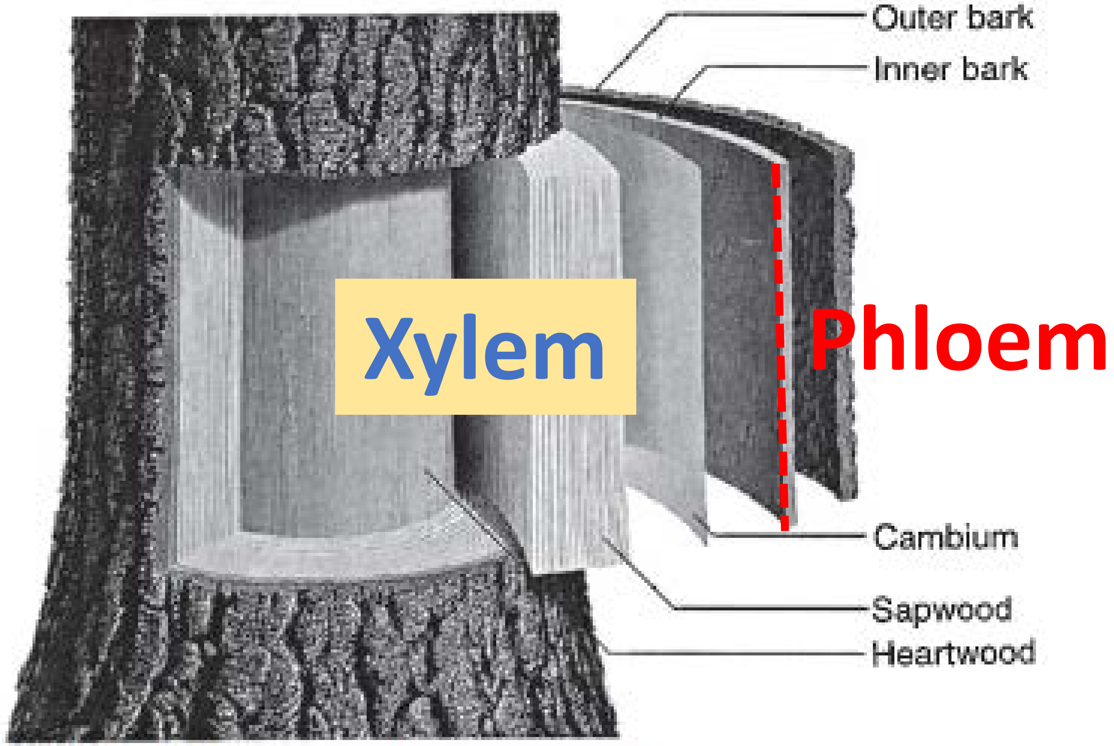
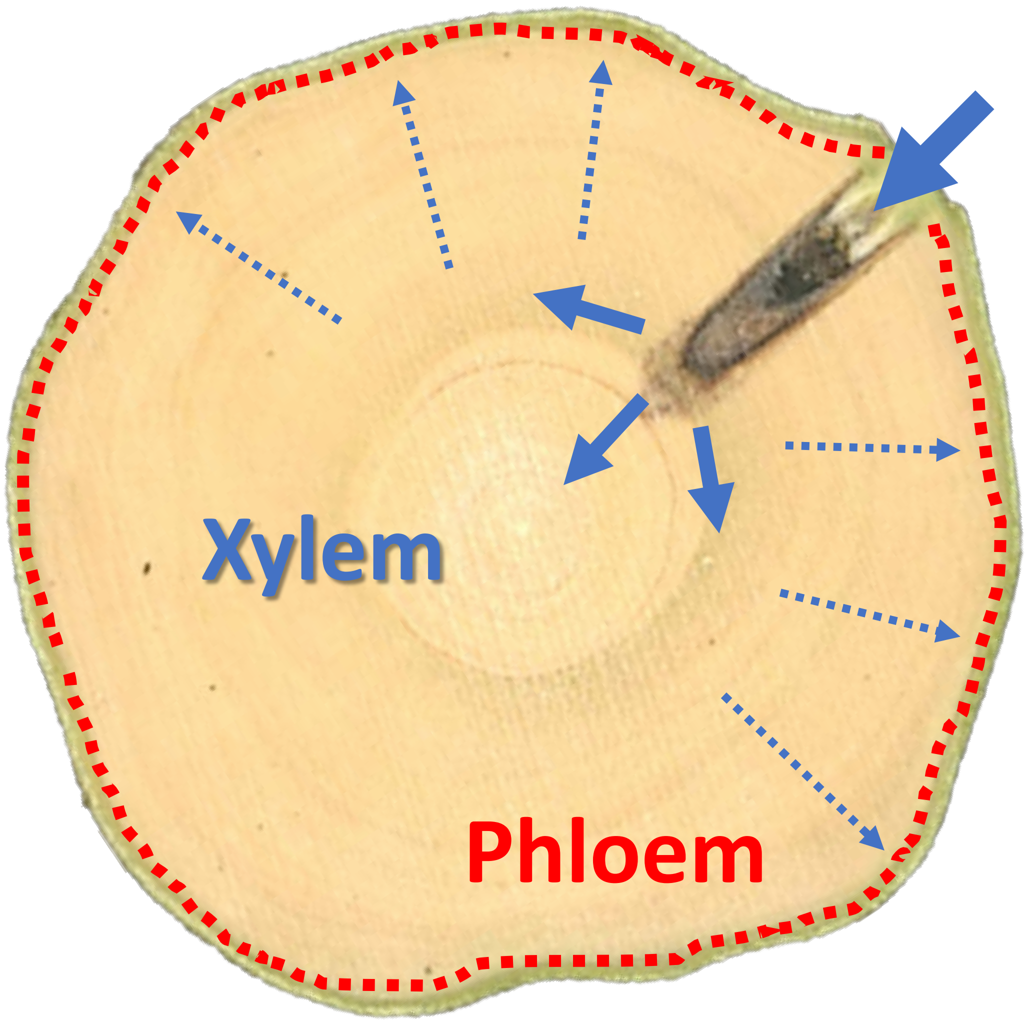
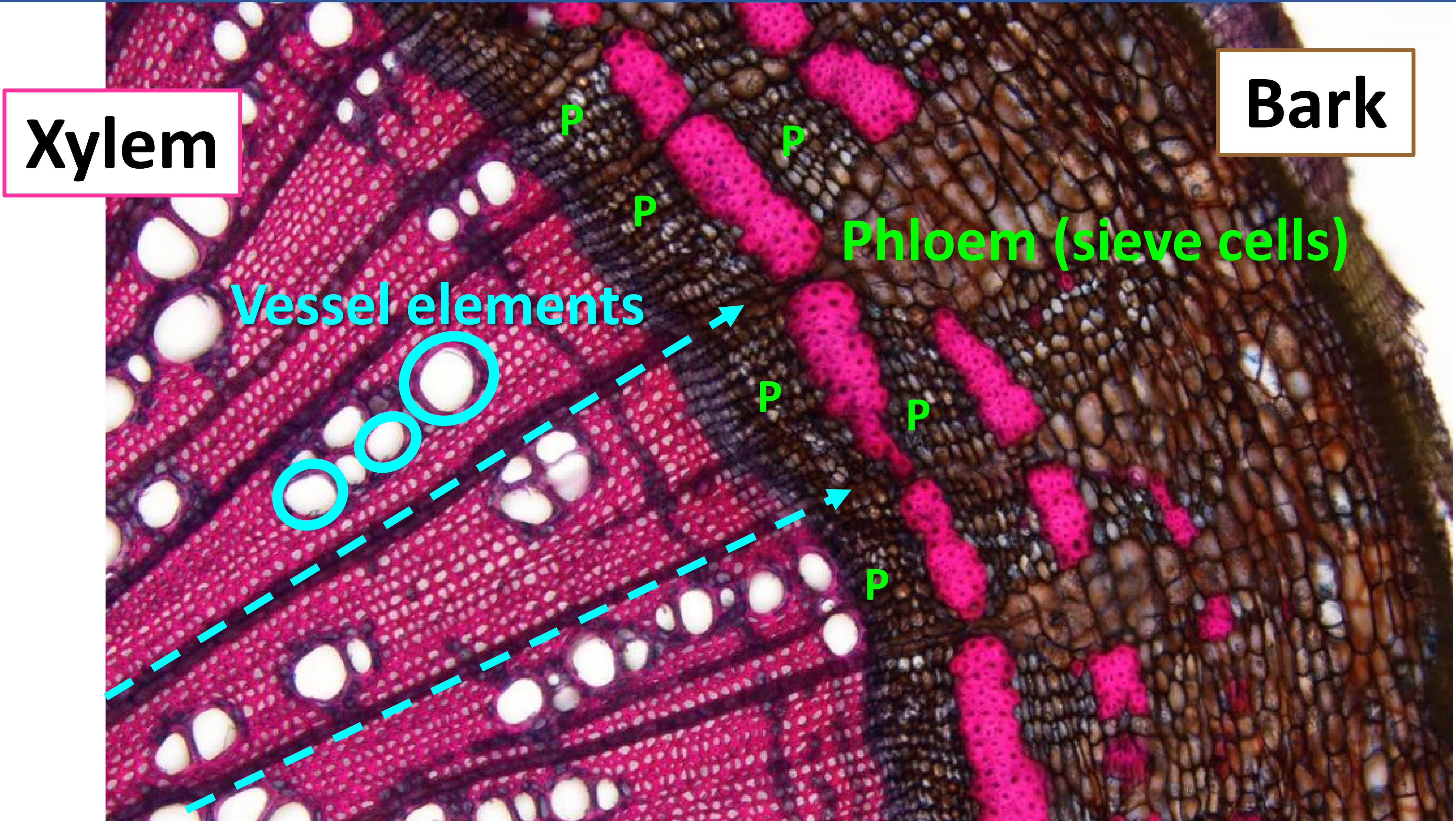


FIGURE 2.16. Generalized structure of a tree stem showing orientation of major tissues including outer bark, cambium, sapwood, and heartwood. Photo courtesy of St. Regis Paper Co.

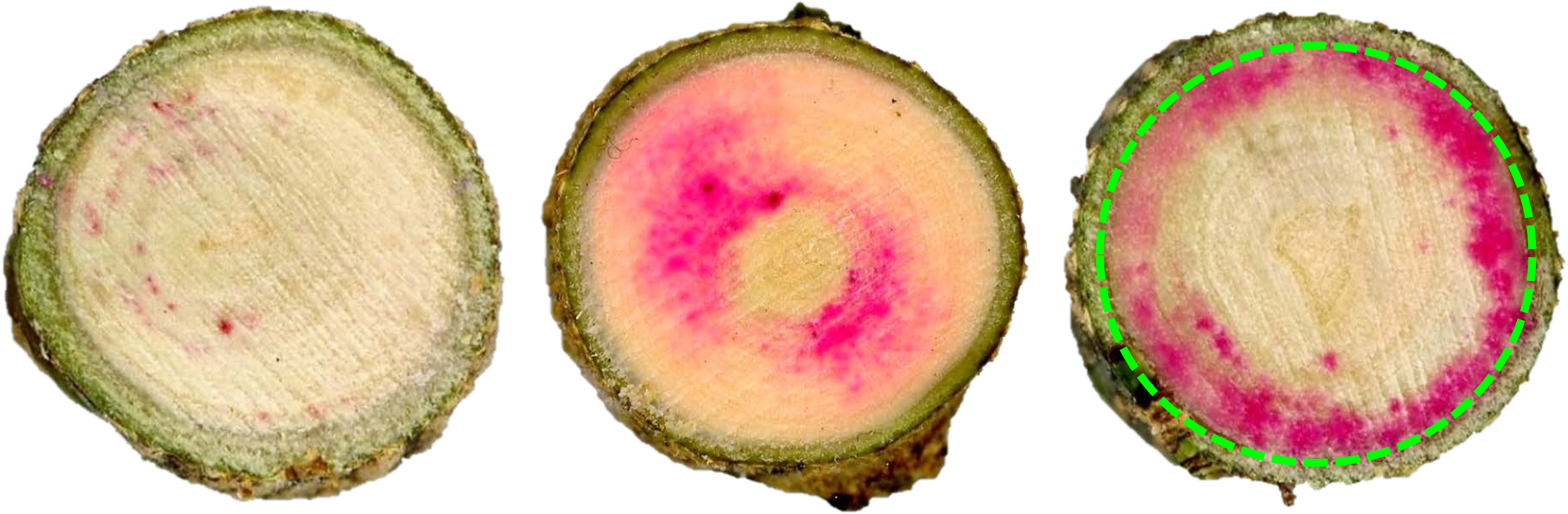


Trunk anatomy



Formulation

Compound mobility (formulation) matters!



Registered crop production materials

Company	Product	Content	Use	Frequency	Registered crop
Arborsystems	Boxer	Emamectin Benzoate 4%	Insecticide/miticide	Annual maximum application rate of 8.5g a.i. per tree	None
Arborsystems	Greyhound	Abamectin B1 1.9%	Insecticide	1 or 2 per year	None
Arborsystems	Pointer	Imidacloprid 5%	Insecticide	1 per year	None
Arborsystems	Retriever	Acetamiprid 8.5%	Insecticide	As needed	None
Arborsystems	Shepherd	Propiconazole 14.3%	Fungicide	1 per year	none
Arborsystems	Whippet	Potassium salts of Phosphorous Acid 45.8%	Fungicide	Preventative application	Almond, apple, avocado, maca-damia, pineapple, stone fruit
Arborsystems	Terrier	OTC Hydrochloride 4.3%	Antibiotic	1 per year	None
Arborsystems	Springer	OTC Hydrochloride 4.3%	Antibiotic for palms	As needed	None
Arborsystems	Pinscher	Dikegulac-sodium 18.5%	Plant growth regulator	1 per year	None
Arborsystems	Greentree Pro Nutribooster	NPK 0-15-10	Nutritional	1 per year	None
Arborsystems	Iron/Manganese Nutribooster	Fe 8.5%, Mn 3.5%	Nutritional	As needed	None
Arborsystems	Manganese nutribooster	Mn 5%	Nutritional	As needed	None
Sorbus International	EnerBite	Phosphonic Acid and potassium salt	Nutritional	Every two years	
Rainbow Treecare	Bacastat	Oxytetracycline 18.3%	Antibiotic	As needed	None
Rainbow Treecare	Arbotect 20-s	Thiabendazole Hypopho-phite 26.6%	Fungicide	1 per year	None
Rainbow Treecare	Mectinite	Emamectin Benzoate 4%	Insecticide	1 every 2 years	
Rainbow Treecare	Alamo	Propiconazole 14.3%	Fungicide	1 per year	None
Tree Tech	Dendrex	Acephate 98%	Instecticide	As needed	None
Tree Tech	Vivid 2	Abamectin 1%	Insecticide/miticide	As needed	None
Tree Tech	Alsa Propiconazole 14.3%	Propiconazole 14.3%	Fungicide	As needed	None
Tree Tech	Systrex	Triadimefon .88%	Fungicide	As needed	None
Tree Tech	Tree Tech OTC	OTC Calcium Complex 4.57%	Antibiotic	As needed	Citrus*, nuts, pome fruits, stone fruits (*non- crop bearing)
Tree Tech	Snipper	Indole-3 butyric acid 4%	Plant growth regulator	1 per year	None
Tree Tech	Nutri-ject Supreme	NPK, Fe, Mn, ZN	Nutritional	As needed	
Tree Tech	Nutri-ject Fe Mn Zn	NPK, Ca, Mg, Cu, Fe, Mn, Zn	Nutritional	As needed	

Registered crop production materials

Company	Product	Content	Use	Frequency	Registered crop
Mauget	Stemix Plus 1-1-1	NPK, Cu, Fe, Mn, Zn	Nutritional	1 per year	
Mauget	Imisol	Debacarb 1.7%, Carbendazim .3%, Imidacloprid 5%	Insecticide/fungicide	Do not treat within 3 months of previous application	None
Mauget	ArborFos	Potassium salts of Phosphorous Acid 45.8%	Fungicide	Preventative application	Avocado, citrus, coconut, apples, pears, loquats, quince, tree nuts
Mauget	Dinocide	Dinotefuran 12%	Insecticide	1 per year	None
Mauget	Mycojet Ultra	OTC Hydrochloride 4.3%	Antibiotic ★	1 per year	None
Mauget	Imicide	Imidacloprid 10%	Insecticide	1 per year	None
Mauget	Abasol	Debacarb 1.7%, Carbendazim .3%, Abamectin .46%	Insecticide/fungicide	Do not treat within 3 months of previous application	None
Mauget	Inject-a-min Manganese 1%	NPK, Cu, Fe, Mn, Mo, Zn	Nutritional	1 per year	
Mauget	Abacide 2	Abamectin 1.9%	Miticide/insecticide	Preventative application	None
Mauget	Tebuject 16	Tebuconazole	Fungicide	Preventative application	None
Mauget	Inject-a-min Iron-Zinc	NPK, Cu, Fe, Mn, Mo, Zn	Nutritional	1 per year	
Mauget	Vigor 53	Soluble Potash 25%	Nutritional		Avocado, olives, citrus, grapes, nut crops, pome fruits, stone fruits
Arborjet	Ace-jet	Acephate 97.4%	Insecticide	As needed	None
Arborjet	IMA-jet (10)	Imidacloprid 5% (10%)	Insecticide	Preventative application	None
Arborjet	Tree-age	Emamectin Benzoate 4%	Insecticide	Preventative application	None
Arborjet	Arbor-OTC	OTC Hydrochloride 39.6%	Antibiotic ★	1 per growing season, repeat as necessary	Citrus*, nuts, pome fruits, stone fruits (*non- crop bearing)
Arborjet	Phospho-jet	Potassium salts of Phosphorous Acid 45.8%	Fungicide and plant resistance activator		Apples, loquats, pears, quince, avocado, citrus, coconut, mango, stone fruit, tree nuts
Arborjet	Mn-jet Fe	Potash, B, Cu, Fe, Mn, Zn	Nutritional	As needed	None
Arborjet	Palm-jet Mg	NPK, Mg, B, Fe, Mn, Zn	Nutritional	As needed	None

Methods of injection





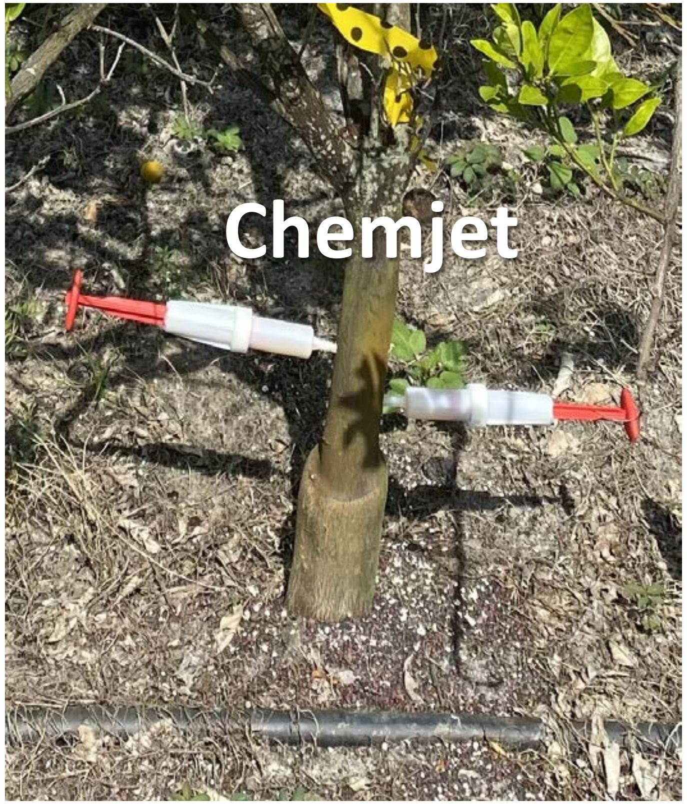



Most technologies are drill-based. Few are no-drill (needle)-based.
All require relatively large injection holes.

Injection pressure

INJECTION

High pressure



Medium pressure

INFUSION

Low pressure

No pressure

High pressure vs. medium pressure

HIGH PRESSURE INJECTION

Water

Oxytetracycline

Imidacloprid

MEDIUM PRESSURE INJECTION

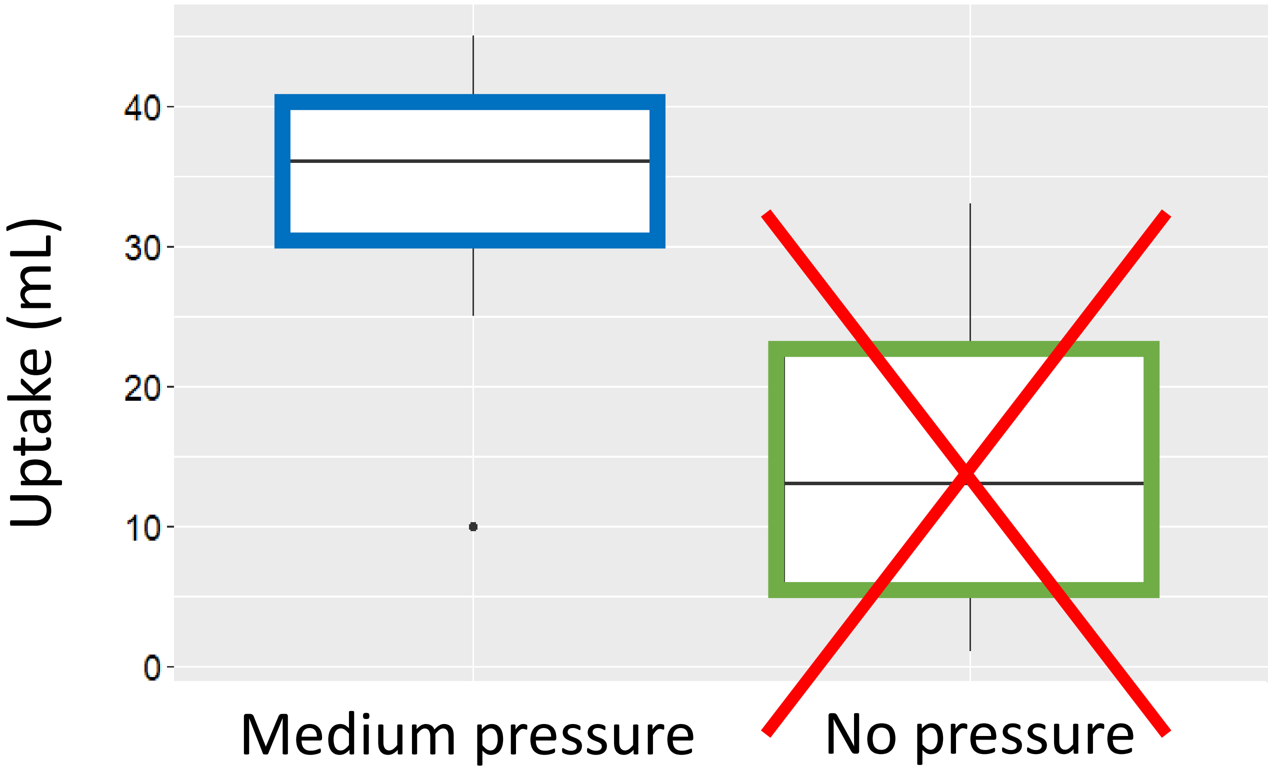
Water

Oxytetracycline

Imidacloprid

High pressure injection in combination with plastic injection ports causes greater injury

Efficacy

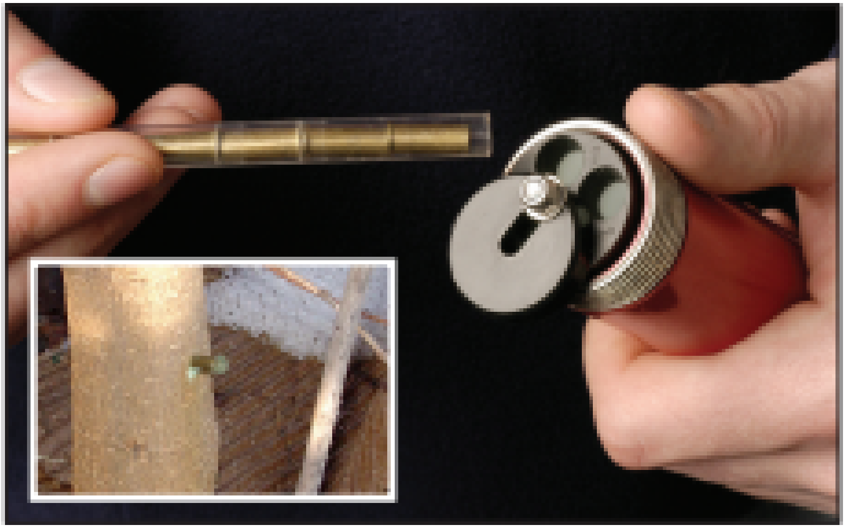


Uptake (mL)
40
30
20
10
0
Medium pressure
No pressure

Medium pressure

Methods of injection

EZ-Ject™
HERBICIDE SYSTEM

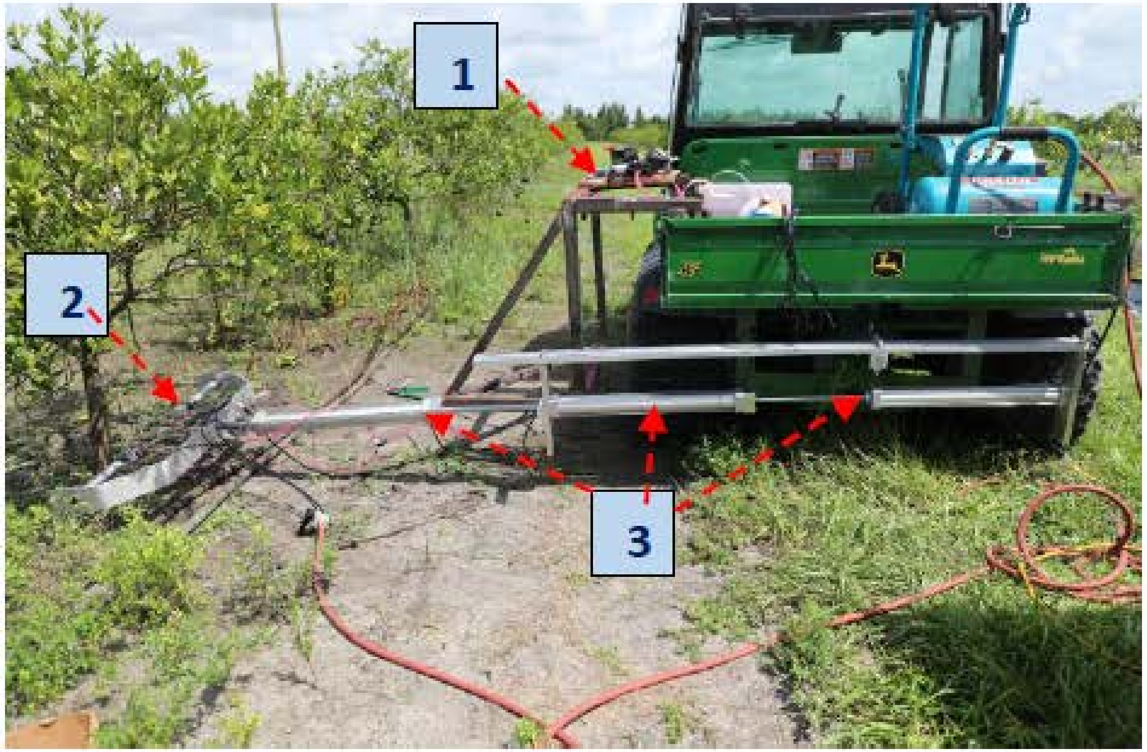


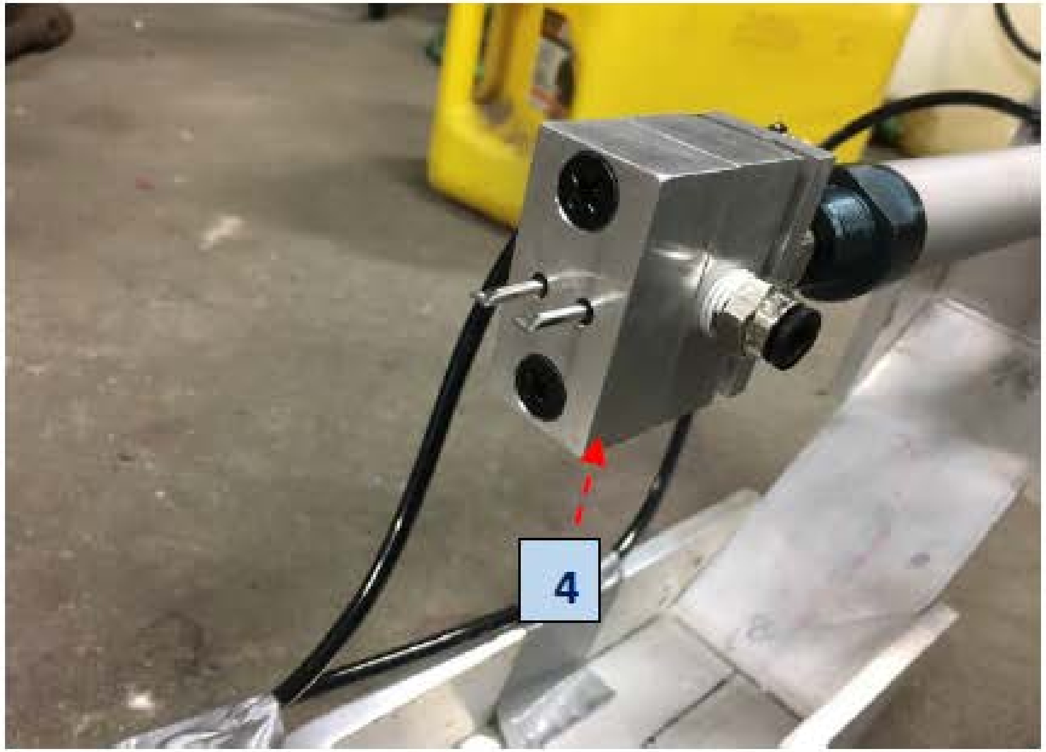
Simply load shells into lance end, screw on end cap, and begin injecting. Lance shaft contains four chambers into which shells are loaded. Fully loaded, the lance weighs less than ten pounds.

Herbicide shells are packaged 25 to a tube with 48 tubes contained in each 1200 shell box.

Distribution of chemicals is passive!

Automated delivery





Credit: Dr. Yiannis Ampatzidis and lab members

1: Pumping system
2: Actuator + Needle Hub
3: Pneumatic actuators in series to push the punching mechanism forward and backward
4: Needle hubs with 2 needles each to punch and create holes from both sides

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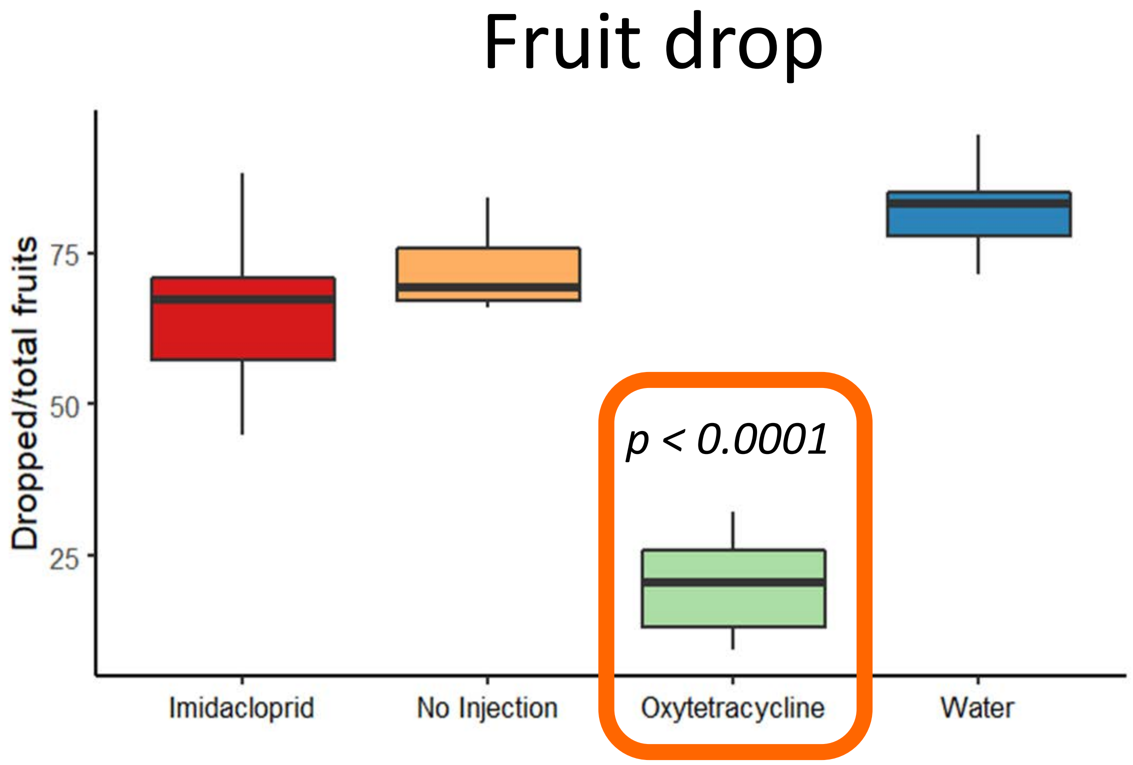
Sweet orange field trials

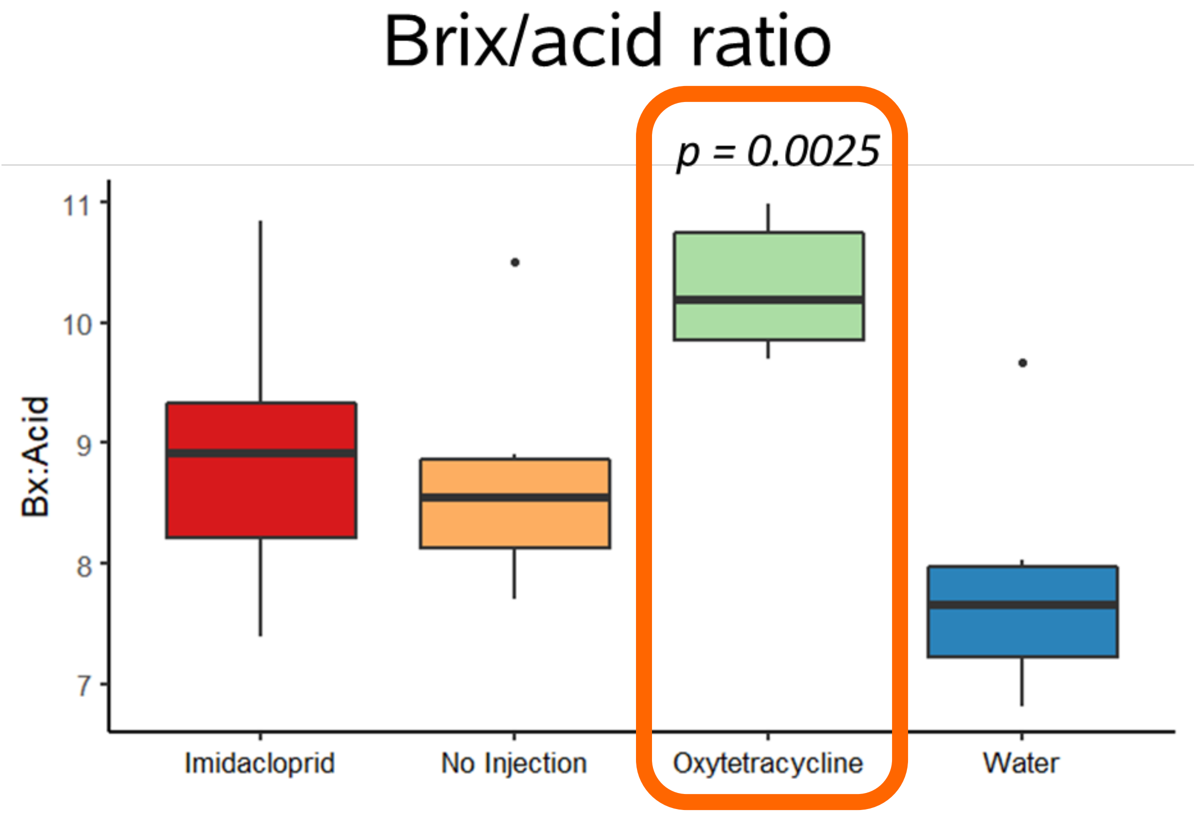
Injections performed in Oct 2020:

1. Oxytetracycline (OTC)*
2. Imidacloprid (IMI)
3. Water
4. No Injection

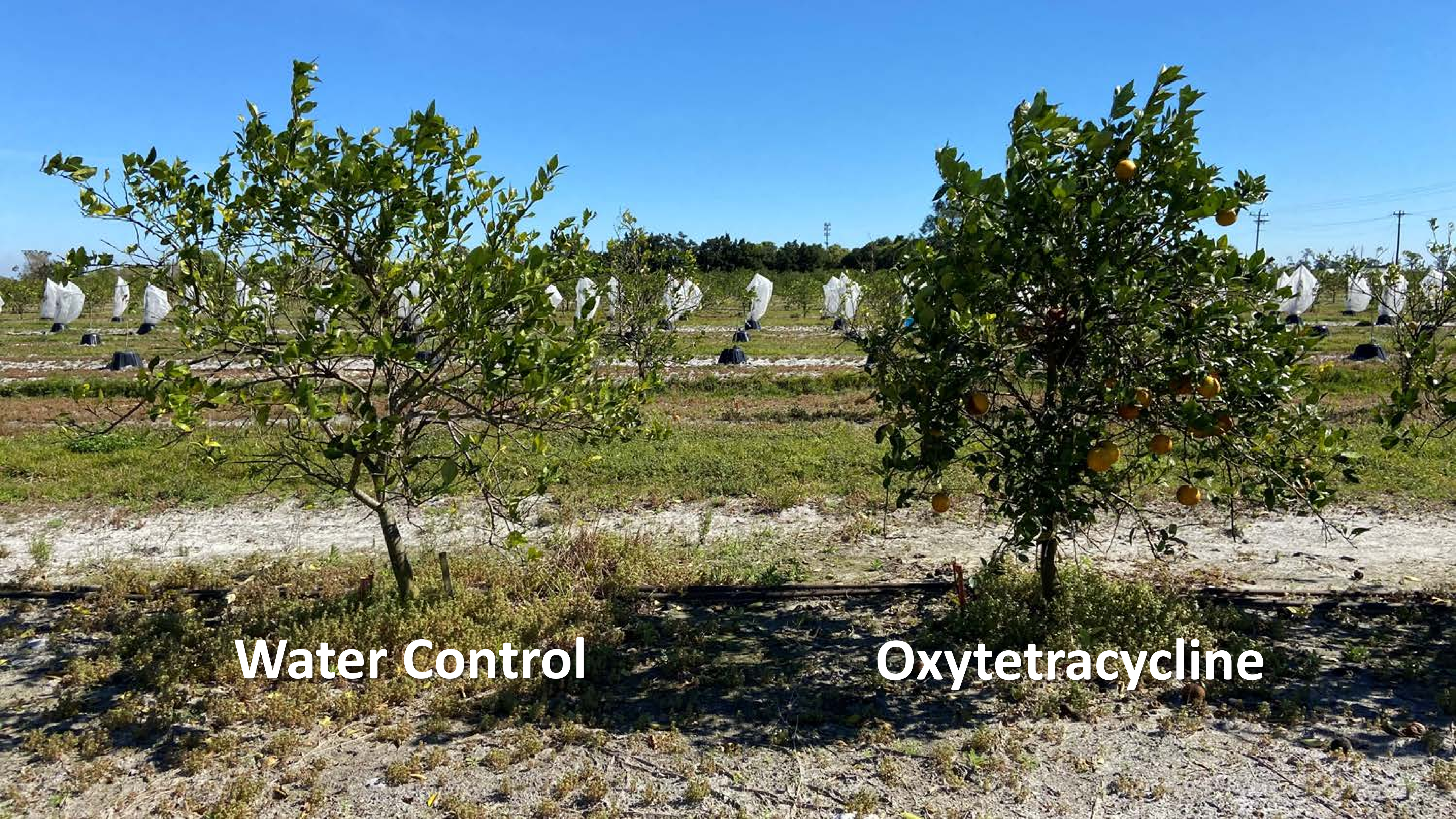
*Arbor-OTC (Arbor-Jet): OTC Hydrochloride 39.6%. *Injections were performed > recommended label rates using chemjets (2 per tree on opposite sides).*

Sweet orange field trials





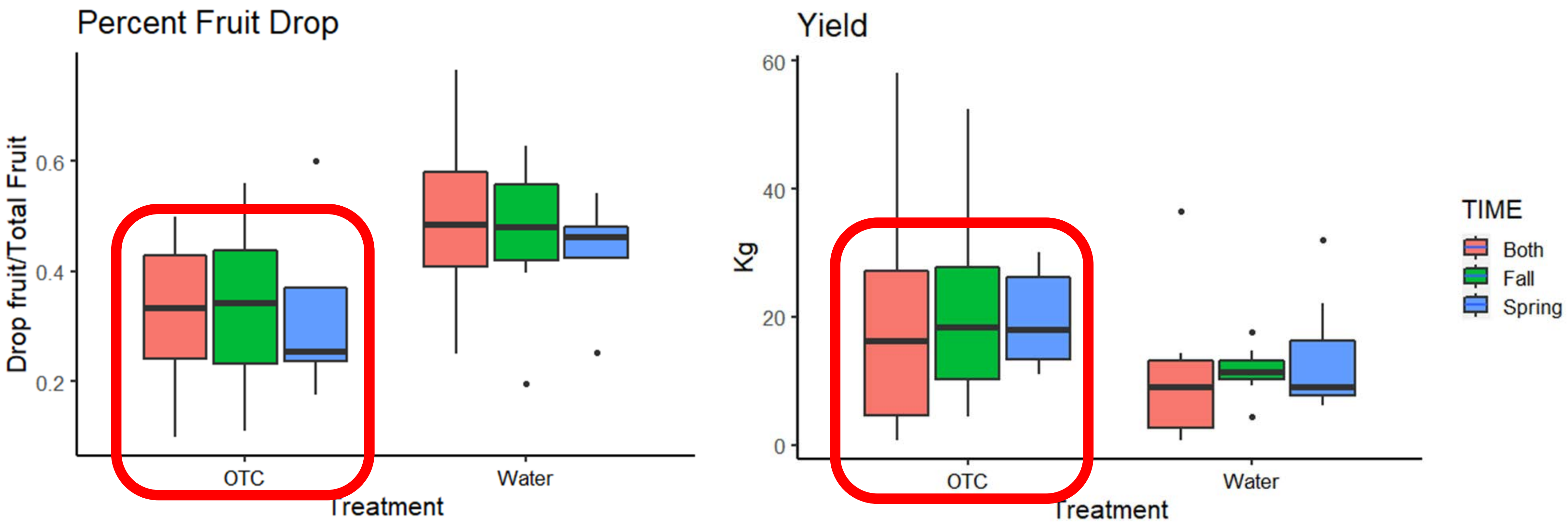
OTC reduced fruit drop and improved the fruit quality


Water Control
Oxytetracycline

Duncan Grapefruit Trial

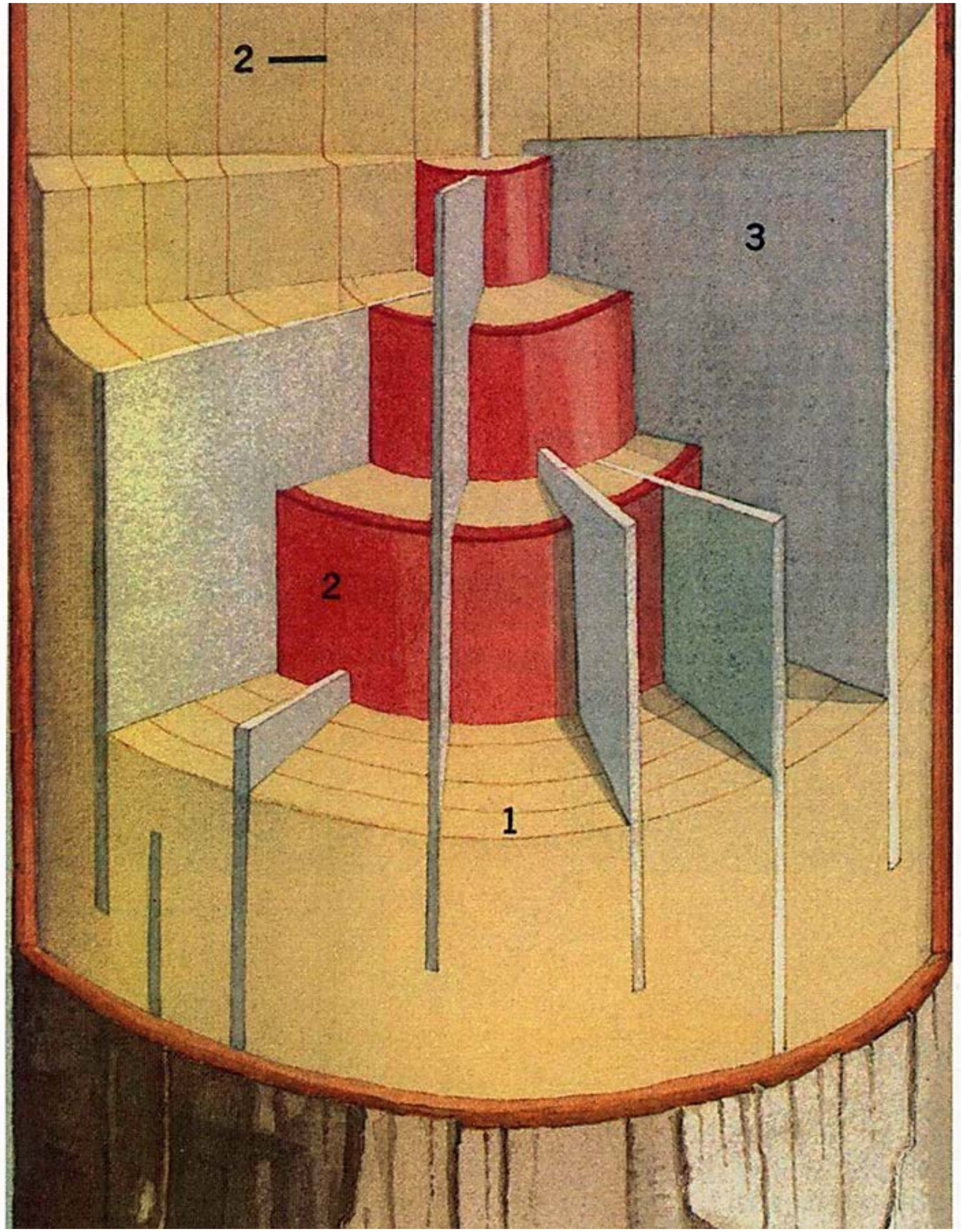
Injections performed in 1) spring 2021, 2) fall 2021, 3) spring + fall 2021

Duncan Grapefruit Trial



Fruit drop was reduced, and yield was higher, regardless of the time and frequency of injection

Tree Injury



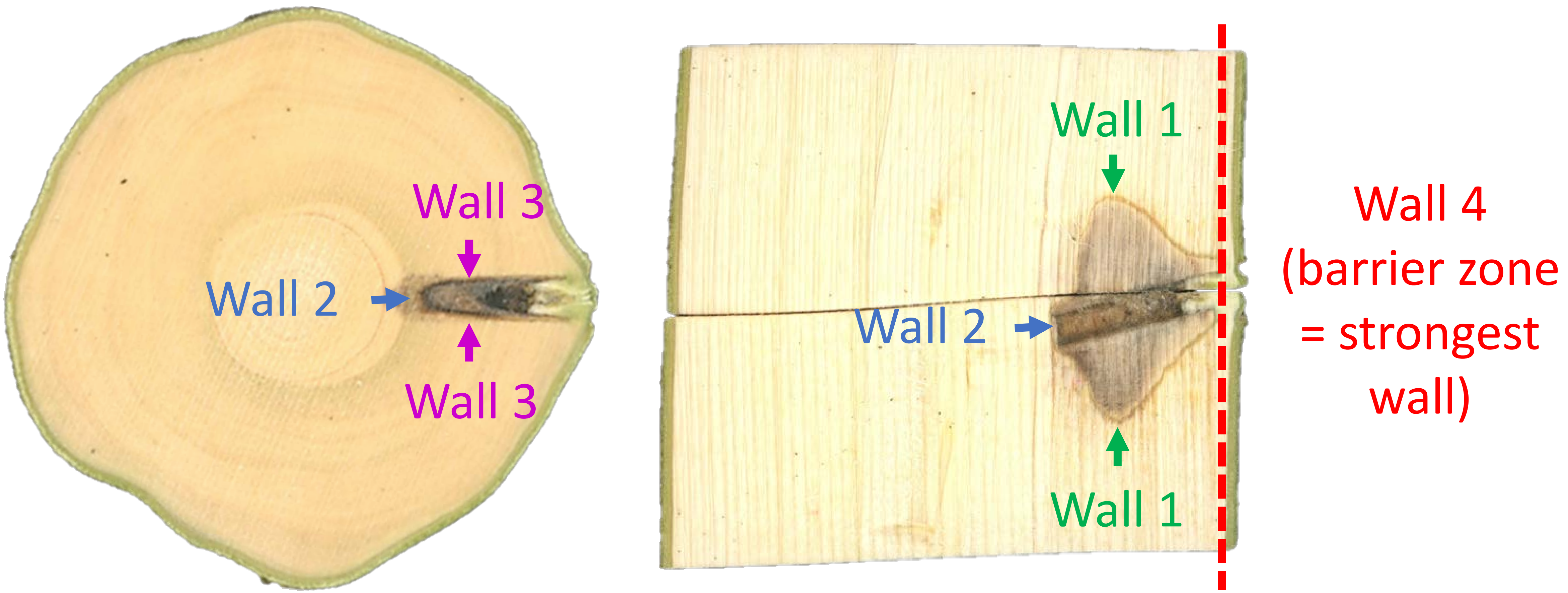
Compartmentalization of Decay in Trees (CODIT)

Shigo and Marx (1977)

Weak (wall 1) → Strong (wall 3)

Fig. 64: The CODIT Model depicts the tree as a chambered organism in which there are structural walls that can react to decay by compartmentalization. Wall 1 occurs in the axial direction. Wall 2 provides barriers in the radial direction (toward the center of the trunk) and wall 3 in the tangential direction (to the sides). In the model, wall 1 represents the weakest compartment and wall 3 is the strongest (Shigo & Marx 1977).

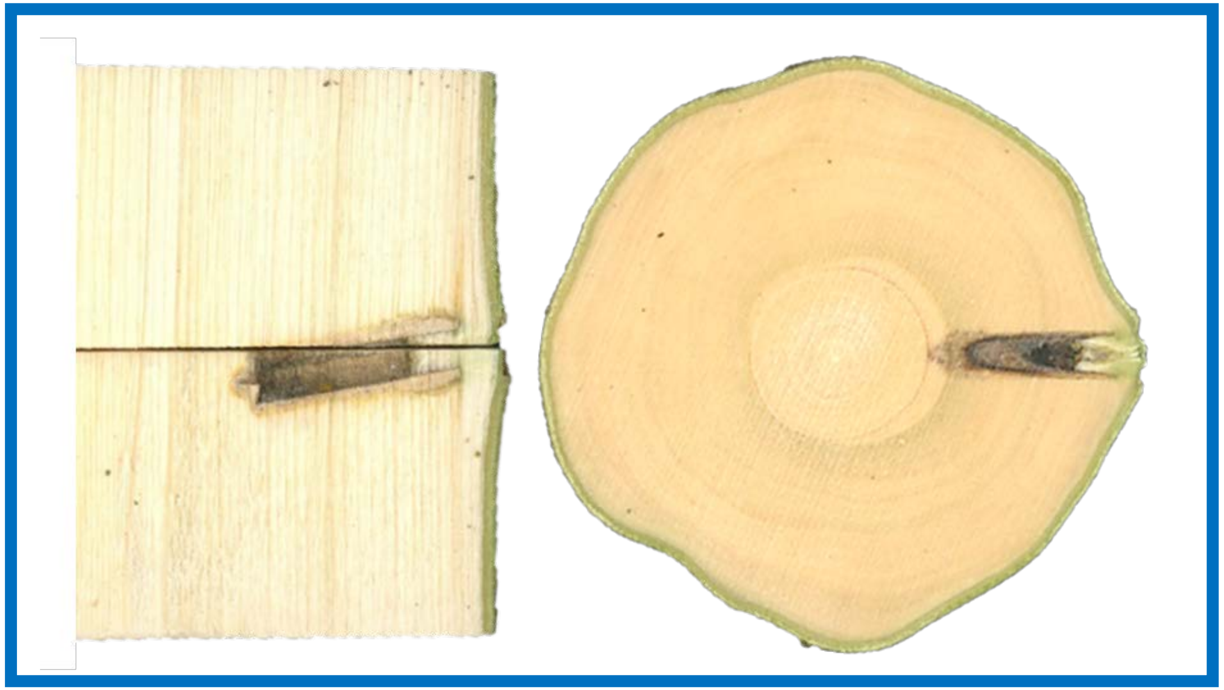
Tree injury



Effective wound compartmentalization in citrus trunk after water injection

Tree injury

WATER



OTC

OTC causes more extensive injury/discoloration

Summary

- Trunk injection can effectively and systemically deliver crop protection materials to target pests and diseases of citrus
- Citrus trees can effectively compartmentalize wounds
- Injected compounds may be phytotoxic and cause injury
- Wound healing is better in the spring
- Long-term effects on tree health need to be established

More information

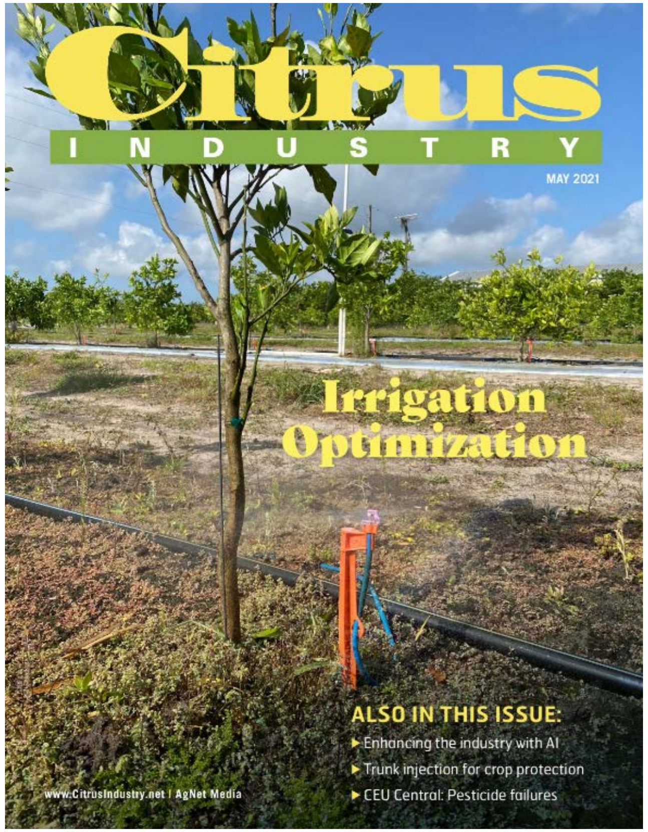


Figure 1. High-pressure trunk injection (A) requires the use of a plastic plug, which causes more damage at the injection site than medium-pressure injection (B).

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 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.

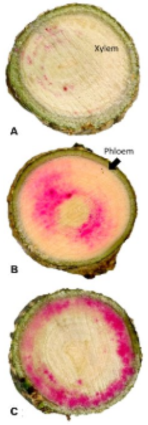


Figure 2. Trunk distribution of three dyes with different chemical properties: A) dye with low mobility, B) dye dispersing throughout much of the inner trunk and C) dye moving predominantly in the outer wood beneath the bark. Dyes were injected 8 inches below the stem sections shown.

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

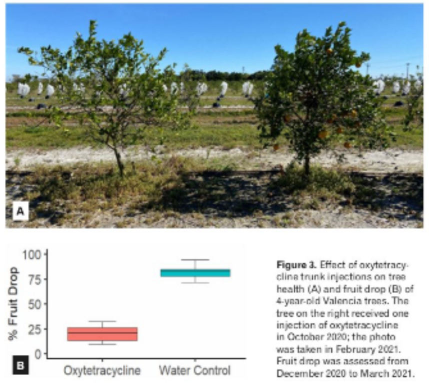


Figure 3. Effect of oxytetracycline trunk injections on tree health (A) and fruit drop (B) of 4-year-old Valencia trees. The tree on the right received one injection of oxytetracycline in October 2020; the photo was taken in February 2021. Fruit drop was assessed from December 2020 to March 2021.

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.

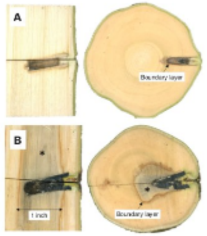


Figure 4. The wound is effectively compartmentalized after water injection (A), and new wood is visible above the injection site. In contrast, necrosis and ineffective compartmentalization is observed after oxytetracycline injection (B) as indicated by a broad zone of discoloration (*). The boundary 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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More information

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Trunk Injection to Deliver Crop Protection Materials: An Overview of Basic Principles and Practical Considerations[1]

Leigh Archer, Ute Albrecht, and Jonathan Crane[2]

Introduction

Trunk injection is a targeted delivery of crop protection materials into the stem or trunk of woody plants as an alternative to spraying or soil drenching. It is sometimes referred to as "endotherapy." Trunk injection occurs into the xylem of trees from where the injected material is distributed through the plant with the transpiration stream. There are several advantages that trunk injection provides over conventional spray or soil drenching of crop protection materials: (1) products are applied more precisely and used more efficiently; (2) spray drift is eliminated; (3) if properly applied there is a lower risk for worker exposure; and (4) nontarget organisms are less affected (Wise et al. 2014). Because there is less concern for human health and the environment, the method can be used in urban environments and residential areas where aerial sprays are not an option. Trunk injection is predominantly used in forested areas, landscapes, and nonagricultural areas. However, there is a long history of using plant injection to deliver crop protection to commercial avocado trees, e.g., phosphonate injection of avocado trees in Australia and South Africa (Dann et al. 2013). In the United States, most use in agricultural areas is in nonbearing crops, with Florida and California avocado trees being an exception. In California, injection of phosphonates to prevent phytophthora root rot has been implemented for decades. In Florida, approximately, 20% of the commercial acreage has been injected prophylactically to prevent (suppress) the laurel wilt pathogen (*Raffaelea lauricola*) on a 12-to-24-month basis since 2014 (Crane et al. 2020).

The earliest evidence for plant injection is from the 12th century, when Arab horticulturists applied perfumes, spices, dyes, and other substances through wounds in plants to affect the smell, color, or other attributes of flowers and fruits (Roach 1939). The first documented experimentation on trunk injections is from the 15th century by Leonardo da Vinci (Roach 1939), who injected arsenic and other poisonous solutions in apple trees to poison the fruit, possibly to prevent thieves from stealing his fruits. Other experimentation until the early 1900s included injection of different nutrient solutions to overcome nutrient deficiencies and different organic and inorganic substances to control insect, fungal, and other diseases. An excellent

1. This document is HS1426, one of a series of the Horticultural Sciences Department, UF/IFAS Extension. Original publication date November 2021. Visit the EDIS website at https://edis.ifas.ufl.edu for the currently supported version of this publication.

2. Leigh Archer, graduate assistant; Ute Albrecht, assistant professor, Horticultural Sciences Department; UF/IFAS Southwest Florida Research and Education Center; and Jonathan Crane, professor, Horticultural Sciences Department, UF/IFAS Tropical REC; UF/IFAS Extension, Gainesville FL 32611.

xylem vessels and the speed of the transpiration stream. Compartmentalization in the vertical direction occurs through tyloses, which are balloon-like invaginations of the parenchyma cells surrounding the vessels. These plug the vessels above and below the wound site and prevent collapse of the transpiration stream as well as spread of invading organisms. After wounding, the cambium cells near the wound site start to divide, closing the wound and producing new vascular tissue outside of the wound.

The compartmentalization or healing of wounds depends on the plant species, wound depth and size, the time of the year, and the properties of the injected compound. Wounds heal faster during spring and summer, when trees are metabolically more active than during fall and winter. Also, wounds heal faster when they occur in the outer rings of the xylem (the sapwood) because these are metabolically more active than the inner rings. Some crop protection materials (e.g., oxytetracycline) can exert phytotoxic effects which prevents wound healing. When using trunk injection to protect agricultural crops, it is therefore important to determine crop-specific anatomical and physiological characteristics and determine potential phytotoxic effects of the material to be injected before commencing on a large scale.

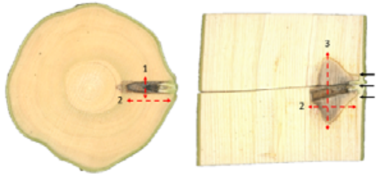

Figure 2. Cross section (left) and longitudinal (right) section of a tree injected with water. The wound caused by the injection is more effectively contained in the tangential (1) and radial (2) direction than in the vertical direction (3). Note the healthy tissue produced during the next growing season covering the wound site (black arrows).
Credits: Leigh Archer and Ute Albrecht, UF/IFAS

Trunk Injection Methods

Many different injection devices by which materials can be injected with different degrees of pressure are commercially available. High-pressure injection usually occurs through injectors that are attached via tubing to a portable canister filled with compressed gas (air or nitrogen). Low-pressure injection and passive infusion typically do not require a compressed air canister or other peripheral features.

High-Pressure Injection

The ArborJet Quik-Jet Air (ArborJet Inc, MA, Woburn, USA), is one example of a high-pressure injection device. This system uses 7.15 mm or larger diameter plastic plugs, which are inserted into the tree after drilling a hole. The plugs create a tight seal for injection, prevent leaking, and reportedly protect the wound from pathogens and insects. Injection of the compounds occurs through these injection plugs at pressures of 60–100 psi and requires compressed gas. Although the plugs enable the rapid injection of large volumes of material, they increase the size of the injection hole and, if left in place, interfere with the natural healing of the wound.

Figure 3. Equipment needed for high-pressure injection (left). High-pressure injection requires a plastic plug, which may remain in the tree after injection (center). Medium-pressure injection using a spring-loaded syringe that is removed after the material has been taken up (right).
Credits: Leigh Archer, UF/IFAS

Low-Pressure Injection

Alternatives to high-pressure injection are various syringe- or needle-based methods, sold by Chemjet (Kerrville, TX USA), Mauget (Arcadia, CA), Rainbow Treecare (Minnetonka, MN), and other manufacturers, that do not require a plug. Injection occurs at lower pressures (<60 psi) by manual squeezing or pumping, or automatically by a spring-loaded mechanism. Similar systems can be made through purchasing and assembling the necessary injection port parts (Crane et al. 2014). Tree uptake is slower due to the lower pressure; however, the smaller injection port size and absence of a permanent plug usually allow for quicker wound repair.

No-Pressure Injection (Infusion)

Implanted capsules such as the Acecap (Creative Sales Inc, NE USA), are no-pressure devices inserted into a drilled hole. Uptake of materials is through the natural transpiration-driven movement of sap in the tree and is greatly influenced by the ambient weather conditions and soil moisture available. Methods relying on passive infusion are slower and may not efficiently distribute materials. Once placed, these devices stay in the tree indefinitely, where they will be compartmentalized. Alternatively, a simple passive infusion system may be constructed using a disposable

1500 ml enema bag, tubing, and other necessary infusion port parts (Crane et al. 2014).

Figure 4. Wounds induced by low-pressure injection generally heal well and close completely (left). Wounds induced by injection of some materials (here oxytetracycline) and by high-pressure injection may not close and often result in extensive bark cracking (right).
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Physiological Implications of Trunk Injection

Higher pressure can increase the speed and volume of liquid taken up by the tree compared to lower pressure. However, this will increase the external and internal damage to the tree, and this risk needs to be assessed for each crop system.

Drilled-Based vs. No-Drill Injection

The greatest threat associated with a larger wound size is girdling the tree trunk or branches, especially when performing multiple or repeated injections. Smaller-diameter injection devices can be expected to reduce the likelihood of girdling. Drill injection causes the most wounding but is most widely used because liquids can be delivered more rapidly and in larger quantities than when using blades or needles.

High-Pressure vs. Low- or No-Pressure Injection

No-pressure systems may limit the volume of material that can be applied within a short time, while high-pressure systems increase the risk of vessel cavitation and girdling.

Pressurized devices allow for relatively large quantities of product to be injected into a tree in a short period of time. The extent and consequences of the physiological damage inflicted on the tree due to the high pressure needs to be established for each tree system. Injection systems with removable injection ports generally cause less damage and heal more quickly than systems where the ports are left in the tree. Implant-based injection devices are left in the tree indefinitely to slowly release compounds. The phytotoxic effects of this method for injection can be more severe because of the extended contact time between the chemical products and tree tissues.

Whether high- or low-pressure systems are used, the toxicity of the solution used may influence the extent of damage to the tree at or near the infusion or injection ports. In some instances, the wound caused by the injection ports does not heal well and allow wood-rooting organisms to invade the area, causing lasting wounds. Removable injection ports and technologies that reduce the size of an injection port but use a high-pressure approach have been developed for commercial avocado operations in Florida, although they are proprietary. Similar systems may need to be developed before injection methodologies can be adopted in other commercial tree-crop production systems.

Trunk Injection to Control Pests and Diseases

Trunk injection has been used to combat many different pests and diseases, including fungal and bacterial pathogens, chewing and sap-sucking insects, and wood-boring insects and nematodes. Modern research on injection has generally coincided with outbreaks of catastrophic tree diseases or pests.

Fungal and Oomycete Diseases

Modern research on trunk injection began in response to the catastrophic spread of Dutch Elm Disease (DED) caused by the fungal pathogen *Ophiostoma novo-ulmi* and spread by elm bark beetles (*Hylurgopinus rufipes* and *Scolytus* sp.). Fungicide injections have been used both preventatively and retroactively to reduce the impact of DED. Registered fungicides include propiconazole (such as Shepard by Arborsystems or Alamo by Rainbow Treecare, among others) or thiabendazole hypophosphite (Rainbow Treecare "Arbotect 20S").

In commercial avocado production trunk injection of fungicides has been used for decades. Historically, injection was primarily used for phytophthora management; however, the spread of laurel wilt (LW), caused by the fungus *Raffaelea lauricola* and spread by redbay ambrosia beetles, across the natural areas of the southeastern United States incited interest in managing this disease through trunk injection. LW is now endemic in Florida's avocado production area (primarily Miami-Dade County) and spread among avocado tree root grafts by at least four ambrosia beetle species (Crane et al. 2020). Currently, injection for laurel wilt management occurs on about 20% of the

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Questions

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