a region, as well as touristic attractiveness and economy of the region. Pruning has generally been found to be an ineffective solution because, within the same year, the symptoms typically spread to other areas in the tree. Current methods may also involve replanting with varieties that show resistance and/or tolerance to *Xylella fastidiosa*. However, this method can take decades to develop these varieties, plant them, and obtain yields comparable to the trees that need to be replaced without any certainty of success in the first instance. In addition, these new varieties are unlikely the same as those currently certified as Protected Designation of Origin or Protected Geographical Indication (also known as Indicazione Geografica Protetta in Italian), which may hinder the ability to sell at a certain premium by olive oil producers. Furthermore, mutations in the *Xylella* bacterium might break the resistance and/or tolerance overtime. Other methods may involve foliar spraying of Dentamet®. However, a large volume of the formulation is typically needed to cover tree canopy. This method has generally been found to be ineffective because only an estimated 10-30% of product actually land on the tree's foliage. Such methods also have been observed to be less effective in older trees (for example, trees older than 100 years), and when symptoms are in advanced stages (for example, when more than 50% of the tree is affected or when 50% or less of the canopy foliage left).

Thus, what is needed in the art are alternative systems and methods to deliver active ingredients to a plant that can be executed on a commercial scale and minimizes risk of trunk damage and wounding the tree.

Overview

Summary

In an aspect, the present disclosure refers to a multiport injection tool, comprising: a base including a plurality of inlet ports; a penetrating distribution body extending from the base, and having a wedge type body profile extending along a longitudinal body axis, wherein the penetrating distribution body includes: a cutting edge along the front face of the penetrating distribution body directed distally away from the base, a penetrating element that extends from the cutting edge and proximate to a distal portion of the penetrating distribution body to a proximal portion of the penetration distribution body, and a distribution element that includes distribution ports and distribution reservoirs, wherein the distribution ports are connected to the inlet ports.

In another aspect, the present disclosure refers to a plant injection system, comprising: a

multiport injection tool of the above aspect, wherein the plurality of inlet ports includes at least a first inlet port and a second inlet port; a fluid delivery system; and a fluid receiving system, wherein the fluid delivery system is operatively connected to the first inlet port of the multiport injection tool, wherein the fluid receiving system is in fluid communication with the second inlet port of the multiport injection tool.

In another aspect, the present disclosure refers to a method for improving the strength of a plant whose xylem or phloem or both are invaded by, or are at risk of being invaded by, bacteria, fungi, virus and/or other pathogens, wherein the plant has a trunk or stem, and wherein the plant further has an active vasculature that runs through the trunk or stem to other parts of the plant, wherein the method comprises: injecting a liquid formulation into the trunk or stem, and no further than the active vasculature of the plant, to treat the plant.

The present disclosure provides systems for administering fluids, for example liquid formulations including one or more active ingredients ("AI fluid"), directly into the interior of a plant ("plant injection systems"). In some examples, the injection systems include an injection tool and a fluid delivery system. The fluid delivery system may include a source of liquid supply. The injection systems may also include a fluid receiving device. In use when the injection tool is installed in the trunk of a plant and the fluid delivery system is activated, fluid flows from the fluid delivery system through the injection tool and into the trunk of a plant.

The present disclosure also provides components for use in such plant injection systems, for example housings for integrating components of the plant injection systems, injection tools and fluid delivery devices.

In some examples, the disclosure provides housings for integrating one or more of the system's components. For example, one such housing may be configured to receive a pressurized canister (the fluid delivery system), which delivers AI fluid when activated, while

also integrating the injection tool and componentry for operatively connecting the injection tool to the pressurized canister. In another example, the housing is configured: to integrate the injection tool and componentry for fluidly connecting the injection tool to the fluid delivery system; and, to install the injection tool and maintain it in position in the trunk of a plant. In some such embodiments, the housing has a clothespin shape.

In some examples, the disclosure provides injection tools including a tool body, at least a portion of which is designed to be lodged into a plant, for example the trunk of a plant. The tool body has a channel system (having one or more channels) through which fluid can flow, terminating in an entry port through which fluid enters the injection tool and one or more distribution ports through which fluid is delivered to the interior of the plant. In some examples, the lodged portion of the tool is sized and shaped to minimize damage to the target plant when inserted into the plant, while maintaining efficient functionality of the injection tool in delivering the desired dosing of AI fluid over the desired time period directly to the sapwood and not the heartwood of the trunk of the plant.

In some examples, the injection tool is a multiport injection tool including a first access port, a second access port, the one or more distribution ports, and the channel system, which establishes fluid communication between the first and second access ports and the one or more distribution ports. In use, when the multiport injection tool is used in a plant injection system having a fluid receiving device, the multiport injection tool is positioned in the trunk of a plant in fluid communication with the fluid delivery system, and the fluid delivery system is activated, fluid flows from the fluid delivery device through the multiport tool from the first access port to the distribution ports for delivery into the trunk of a plant and to the second access port.

In some examples, the fluid delivery system is a single unit formulation cartridge that stores, pressurizes and delivers the fluid. In some such examples, the unit is a canister containing the liquid and a piston that pressurizes the liquid. The piston is loaded by a spring that is held in a compressed position by a plunger. When, for example, a pin is removed to release the plunger, the piston pressurizes the fluid and when the canister is in the open position providing fluid communication between the canister and injection tool, fluid flows from the canister to the injection tool.

In other examples, the fluid delivery system comprises a formulation cartridge which delivers formulation into a plant without active operation by the installer or technician (e.g. operating a plunger, syringe, injection device or the like). Instead the plant injection systems comprising the formulation cartridge provide a quantity of active ingredient formulation and a

mechanism for delivery the quantity of formulation to an injection tool for distribution to a plant. In some examples, the injection tool has a distribution shaft and a tool adapter configured to couple with a complementary cartridge adapter of the formulation cartridge. The distribution shaft of the injection tool has one or more distribution ports and a delivery channel (including one or more component channels) extending between the tool adapter and the one or more distribution ports. The tool adapter is accessible from the plant exterior while the one or more distribution ports and the associated portion of the distribution shaft are installed within the plant.

In some examples, the formulation cartridge includes a formulation reservoir including a quantity of an active ingredient (AI) formulation. The formulation cartridge includes a cartridge adapter complementary to the tool adapter of the injection tool. A seal port is proximate to the cartridge adapter, and coupling of the formulation cartridge with the injection tool (e.g., including direct or indirect coupling) opens the formulation reservoir through the seal port. The AI formulation is communicated through the seal port and the cartridge adapter through the delivery channel of the injection tool to the one or more distribution ports for delivery to plant. In one example, the seal port automatically reseals when not coupled with the injection tool to minimize leaking or distribution of the AI formulation to the environment exterior to the cartridge when not coupled with the tool. Accordingly, AI formulations that are rated, certified or labelled for internal (as opposed to external, sprayed or topical formulations) are readily administered with the plant injection system including the formulation cartridges and injection tools described herein while leaking and corresponding external distribution are minimized (e.g., reduced or eliminated).

In some examples, the formulation cartridge stores the AI formulation and drives the formulation into the injection tool when coupled with the injection tool. For instance, a bias membrane is provided with the formulation cartridge that applies a delivery pressure to the AI formulation for delivery to the injection tool. The delivery pressure is optionally generated through one or more mechanisms including, but not limited to, elastic deformation of an elastic bias membrane, a pressurized driving fluid in an opposed cavity to the formulation reservoir, combinations of the same or the like. The bias membrane thereby drives the AI formulation to the injection tool upon coupling and with minimal interaction (e.g., reduced or none) from the installer or technician. In one example, the formulation cartridge provides the AI formulation and the delivery mechanism for the AI formulation in a consolidated package that is readily coupled with the installed injection tool. Further, formulation cartridges are readily coupled, decoupled and replaced with fresh cartridges through the complementary cartridge and tool adapters to ensure AI formulations are delivered from the formulation cartridges to the plant interior (e.g., vasculature) with minimized leaking or external distribution.

In the context of coupling between the formulation cartridge and the injection tool the interconnection between the cartridge and the injection tool includes direct and indirect coupling. Accordingly, the formulation cartridge may still be used as the fluid delivery device even if the injection tool does not include a tool adaptor and/or the formulation cartridge is not fitted with a complimentary cartridge adaptor. For instance, the adapters described herein are optionally provided with the respective formulation cartridge or injection tool in one example. In another example, the adapters (which may simply be ports) are provided with one or more intermediate components to facilitate indirect coupling between the formulation cartridge and the injection tool (e.g., with intervening tubing, manifolds or the like). The connection between the cartridge and tool adapters includes various mechanisms. For example, the adapter arrangements include, but are not limited to, clips, clamps, complementary threading, interference fittings, bayonet fittings, detents or the like. Optionally, the adaptors are configured to interfit with a robust coupling (e.g., with a detent, bayonet fitting or the like) to minimize incidental decoupling between the cartridge and the injection tool.

In certain examples, the present disclosure provides injection systems or components thereof as depicted in the figures herein. In some examples, the systems are configured to administer liquid formulation comprising one or more active ingredients to a plant or a part thereof. In certain examples, such systems are mounted onto a post portion of a plant, for example to a stem or trunk of a tree.

The present disclosure also provides methods of administering fluid to plants using the systems and components of the disclosure. In some examples, the method includes installing an injection tool in the trunk, stem, root or limb of a plant, operatively connecting the injection tool to a fluid delivery device, and activating the fluid delivery device to initiate the flow of fluid from the fluid delivery device through the injection tool and into the plant. In some examples, the injection tools described herein are installed in plants having relatively small and large sizes or diameters (e.g., trunk or stem diameters). In one example, the portions of the injection tools installed in plants have dimensions of around 5 mm or less (e.g., width) and 1 mm or less (e.g., height) and accordingly the tools are configured for installation in plants with stems, trunks, roots, limbs or the like of 5 mm or more in size, such as diameter. In other examples, two or more injection tools are installed into one or more of the stem, trunk, roots, limbs or the like of a plant to minimize trauma to the plant (e.g., by minimizing the size of a unitary hole in the plant or spacing the tools apart along the plant). In some such examples, the two or more injection tools are operatively connected to the same fluid delivery system. In other such

examples the two or more injection tools are operatively connected to independent fluid delivery systems.

The present disclosure also provides methods for validating fluid flow through the installed injection tool. In some examples, the method includes installing a multiport injection tool in the trunk of a plant, connecting a first access port of the injection tool to a fluid delivery device, connecting a second access port of the multiport injection tool to a fluid receiving device having an on position allowing fluid to flow through the device and off position in which fluid is retained in the device, activating the fluid delivery system with the fluid receiving device in the off position to prime the injection tool, placing the fluid receiving device in the on position and verifying that fluid is flowing through the fluid receiving device, thereafter placing the fluid receiving device in the off position so that fluid is not drained from the injection tool into the fluid receiving device.

Example injection tools described herein include a penetrating distribution body configured to penetrate a plant and administer liquid formulations. In some examples, the injection tools distribute the formulations to the plant tissue while at the same time minimizing damage to the plant. In some examples, the injection tools include a penetrating element that penetrates the plant, for instance, along a longitudinal body axis of the penetrating distribution body. The penetrating distribution body includes a distribution element, such as one or more distribution ports, along the body. The one or more distribution ports open laterally along the penetrating distribution body, in one example, relative to the longitudinal body axis. As the plant moves around the penetrating element, for instance during insertion in a reversed direction along the longitudinal body axis and toward the proximal portion of the body, the one or more distribution ports are recessed from the distal portion and remain open for delivery of the liquid formulation. Without being bound by theory, it is believed that because the one or more distribution ports administer liquid formulations along a different vector relative to the longitudinal body axis of the penetrating distribution body, the ports remain open (e.g. clear of plant tissue) and minimal pressure (relative to pressure applied with a driven plunger and cylinder) administers the liquid formulation. For example, the one or more distribution ports open, extend laterally, distribute the liquid formulation or the like in a misaligned orientation (e.g., transverse, along an offset angle, orthogonal, greater than 5 degrees, greater than 10 degrees or more) relative to the longitudinal body axis to thereby minimize clogging from plant tissue.

In other examples, the one or more distribution ports are recessed from an exterior of a body profile of the penetrating distribution body, and accordingly remain clear of plant tissue.

For example, the one or more distribution ports are provided along the troughs of anchor elements (e.g., threading, flutes, serrations, cleats, scalloped surfaces or the like), within distribution reservoirs within the body profile of the penetrating distribution body or the like. The one or more distribution ports are within the body profile and with penetration of the plant tissue the ports are not engaged with plant tissue in a manner that promotes clogging. Instead, the one or more distribution ports are recessed from the penetrating element and, at least in some examples, the plant tissue itself. Accordingly, liquid formulations delivered to the injection tool are readily received in the plant and delivered with minimal pressure or effort. Further, in examples including cavities as described herein the proximate walls, surfaces or the like of the injection tool in combination with the surrounding plant tissue provide reservoirs within the plant, and the liquid formulations reside in these reservoirs for gradual uptake by the plant.

The injection tools, injection systems having the injection tools, and methods described herein facilitate the continuous application of liquid formulations including active ingredients to a large variety of plants, including, but not limited to, perennial plants with any kind of trunk or stem size. In some examples, the systems, components and methods of this disclosure enable administering active ingredients to plants at a reduced dosage rate as compared to foliar application. Reduced dosage rate is attractive because it may reduce the negative environmental impact of foliar application in which a high amount of the employed chemicals is not reaching the target plant or pest but is release into the environmental where it may effect beneficial organism (e.g., bees) and or causes environmental pollution (e.g., ground water). And lower dosage rates may enable replacing chemical pesticides with biological control agents which are approved for human consumption but have high costs of goods which make a foliar use by spray applications in plantations of trees and other plants like banana, coffee, or cocoa punitively expensive.

In some examples, the present disclosure provides a process for modulating the phenotype of a plant or a multitude of plants by installing a plant injection system according to the disclosure in the plant or multitude of plants and administering a liquid formulation of an active ingredient to modulate the phenotype of the plant. In other examples, the present disclosure provides a method to modulate phenotypes of plants, for instance to treat, prevent, protect and immunize, which means induce local and systemic resistance to plants from pathogenic attacks and pest attacks. The injection tools described herein distribute liquid formulations directly to the interior of the plant without spraying and the commensurate loss of errantly applied sprayed formulations. The subject matter described herein places the formulations in direct contact with plant tissues and in some examples, the formulations are