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Comparison of drill- and needle-based tree injection technologies in healing of trunk injection ports on apple trees

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ABSTRACT

Excessive tree wounding is a common concern regarding the use of trunk injection technology for tree protection purposes in landscapes and urban greening. We investigated the rate of healing of injection ports (points) in apple trees by monitoring parameters such as port diameters, the size of bark cracking, and port depths. We compared drilled injection ports from 4.4 and 9.5 mm drill bits, with latter being sealed with plastic-silicone plug (Arborplug®) or not, and the lenticular port from a double-edged blade. Depending on port size and type, port closure ranged from one to more than two years. Bark cracking around injection ports was more pronounced longitudinally. On the sealed 9.5 mm port, bark cracking was largely similar to all drilled ports. The depth of port wounds decreased faster on the port from the 4.4 mm drill bit and on lenticular injection port versus the unsealed port from the 9.5 mm drill bit. Plastic-silicone plugs, which simulate removed bark, slowed the healing of 9.5 mm drill port with callus and increased the port depths over time due to callus formation over the top of the plug. From fastest-healing to slowest-healing, on average the injection ports were: lenticular port from blade (70.8%), the unsealed 9.5 mm drill port (44.4%), 4.4 mm drill port (43.9%), and 9.5 mm drill port sealed with plastic-silicone plug (20.4%).

1. Introduction

Trunk injection for delivery of plant protective compounds and nutrients provides target-precise pest control and nutrient deficiency correction in landscape trees. Trunk injection as an *in planta* delivery method allows precise and confined compound delivery to trees (Ahmed et al., 2010; Guillot and Bory, 1997; VanWoerkom et al., 2014; Wilson, 1979; Wise et al., 2014). It is an environmentally safer alternative for pesticide application, which utilizes a tree's vascular system to translocate and distribute active compounds into the canopy (Percival and Boyle, 2005). Since injected compounds are enclosed within the tree, this method allows increased selectivity of exposure to pathogens and insect pests (Wise et al., 2014). Further, trunk injection is a superior delivery system because it enhances the activity of xylem mobile compounds such as oxytetracycline, which is used for fire blight control on crabapples and pears (Aćimović et al., 2015).

Tree injection developed primarily because ground- and air-spray applications were impractical due to large tree sizes, extensive drift-driven pesticide losses, reduced coverage, and proximity of urban areas (Düker et al., 2006; Guillot and Bory, 1997; Hillebrand et al., 1998). Over the past two decades, this method has gained increased use due to the development and availability of injectable compound formulations and new injection devices (Doccola et al., 2012 Doccola and Wild, 2012). These increase the efficiency of pesticides in pest control and the speed of the injection process (Dal Maso et al., 2014; Doccola et al., 2003, 2012; Doccola and Wild, 2012; Montecchio, 2013; Takai et al., 2003, 2004). Tree injection is steadily replacing seasonal spray treatments of trees and providing invaluable ecological service in landscapes and urban zones by reducing the exposure of applicators, environment, and wildlife to pesticide drift. Air-blast sprayers used in agricultural tree crops and pump sprayers used in landscape trees are rather inefficient in delivering pesticides to their target, with drift losses of spray solution into the environment of 44–71% (Perry, 1998; Reichard et al., 1979; Steiner, 1969; Zhu et al., 2006).

Despite widespread use of trunk injection technology in tree protection, trunk and bark wounding associated with the creation of injection points, i.e. injection ports, is an often-cited objection to the technique (Costonis, 1980; Doccola et al., 2011; Neely, 1988, 1979; Shigo, 1978; Smith and Lewis, 2005; Wasniewski et al., 1993a). An injection port is an opened point of access to trunk

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xylem. It allows direct delivery of a compound into the vascular tree tissues, which is then translocated into the canopy. Drill-based injection ports are most commonly used in landscape tree care and after injection can be left unsealed or are sealed with plastic-silicone plugs such as Arborplugs®. An Arborplug allows delivery of an exact dose of choice into the tree by preventing leakage of injected solution from the port. Further, it prevents wood tissue drying and exposure of cambium to the injected liquid, thus allowing undisturbed port healing i.e. closure with callus produced from cambium. Finally, the exposed surface of the plastic-silicone plug simulates trunk bark removed by drilling and purposely compartmentalizes injection port according the basic principles of tree healing i.e. wound closure through compartmentalization (Shigo, 1984). A primary common concern of arborists is that wounding by injection ports could have a negative impact on tree health and longevity due to physical damage and/or formation of entry points for pathogens or insects. This concern is especially justified if injections are repeated for sustained pest control.

Even though there is limited research on the impact of injection ports on trees, seemingly less-injurious delivery systems for trunk injection or infusion of plant protective compounds have been developed (Düker et al., 2006; Düker and Kubiak, 2009a, 2009b; Doccola et al., 2003, 2012; Shang et al., 2011a, 2011b; Düker and Kubiak, 2011a, 2011b; Montecchio, 2011, 2013). Some of these systems were specifically designed to create lenticular injection ports which may lead to minimal injury of trunk tissues.

One of the important parameters for measuring the degree of harm from trunk injection wounds is the time needed for injection ports to heal. Only a handful of studies address or mention injection wound healing (Neely, 1979, 1988; Costonis, 1980; Wasniewski et al., 1993a; Percival and Boyle, 2005; Düker et al., 2006; Doccola et al., 2011; Smith and Lewis, 2005; Cooley et al., 1992; Shigo et al., 1977; Shigo and Marx, 1977). Overall, no research compared the levels of injury after creation of different types of injection ports and it is unclear whether tree wounding by injection leads to economically important damage to trees and impairment of tree longevity and functionality. To address this knowledge gap, using apple tree as a model, our objective was to compare the rate of injection port closure after the creation of different types and sizes of trunk injection ports. We chose apple tree due to thin and smooth bark, making measurements of wound closure rate easier.

2. Materials and methods

2.1. Creation of trunk injection ports

An experiment was conducted during 2012 and 2013 at Michigan State University's Plant Pathology Farm in East Lansing, Michigan (GPS: N42° 41′ 34.93″, W84° 29′ 31.657″). On 14 April 2012, 13-year-old 'Jonathan' apple trees, *Malus domestica* Borkh., were wounded with the four most common types of trunk injection ports: (1) drilled port 4.4 mm in diameter after using 4.4 mm wood drill bit, (2) drilled port 9.5 mm in diameter after using 9.5 mm wood drill bit, (3) drilled port 9.5 mm in diameter sealed with a plastic-silicone plug (Arborplug® no. 4, Arborjet Inc., Woburn, MA), and (4) lenticular port 1 mm wide, 28 mm high, after insertion of symmetrical double-edged blade 4 mm wide, 33 mm high, 50 mm long (Fig. 1). A similar lenticular port is created with needle-insertion injection device with a flat-blade screwdriver-like needle, called Bite® (Montecchio, 2011). All injection ports were 25.4 mm deep and created by drilling into the trunk xylem with a cordless 1500 rpm drill (DeWalt Industrial Tool Co., Baltimore, MD), or by insertion of a double-edge blade using hammer (Fig. 1). The blade was inserted perpendicular to trunk axis so that it separated vertically-oriented wood fibers and opened a lenticular injection port in xylem (Fig. 2D). To seal injection ports from 9.5 mm drill bit, we inserted plastic-silicone plugs 3 mm below the thin bark surface of apple tree and cambium. Thus, the orifice around the silicone septum for injection was in line with bark surface and cambium is exposed to air.

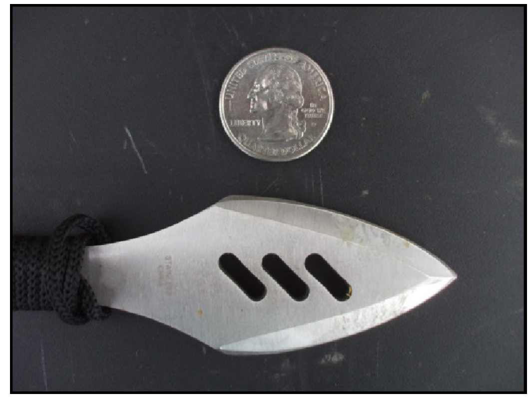

Fig. 1. Double-edge blade used to create lenticular injection port, 1 × 28 mm, by insertion into the trunk. Similar port is created by Bite® injection device with a flat screwdriver-like needle for infusion of trees (Montecchio, 2011).

For each type of injection port, we used three replicate trees arranged in a completely randomized design (CRD) and each tree was injected four times with a given injection port type. Trunk ports were oriented according to cardinal directions and positioned 30 cm above the ground surface. Opposing ports, at 0° and 180°, were offset vertically by approximately 5 cm of wood between them. In 2012, apple trees ranged from 7.1–10.2 cm in trunk diameter at 30 cm trunk height (average 8 ± 0.36 cm). In 2013, the same trees ranged from 7.8–11.4 cm in trunk diameter at 30 cm trunk height (average 8.8 ± 0.45 cm).

2.2. Measurement of injection port healing

All injection ports after creation on 14 April 2012 (Fig. 2A–D) were measured on 20 July 2012 (Fig. 2E–H), 14 April 2013, and 20 July 2013 (Fig. 2I–L). We measured the following parameters for each port type using digital caliper: depth of injection port from the bark surface (Fig. 2M–P), depth of injection port from the surface of plastic-silicone plug (Fig. 2O), horizontal and vertical diameters of port opening surrounded by callus tissue (Fig. 2R), and width and length of bark crack around the injection port (Fig. 2R). If the entrance to port cavity was closed by callus from cambium, we measured port depth as the depth from surface of the old, raised periderm on the bark, around the injection port, to the new periderm from callus which is below the old periderm (Fig. 2M). If the entrance to port cavity was closed by a plastic-silicone plug, we measured the port depth as the depth from the surface of old, raised periderm on the bark and the plug's surface (Fig. 2O). For measuring injection port depth from the surface of plastic-silicone plug we inserted a needle through the silicone septum for injection and measured this needle increment length (Fig. 2O).

2.3. Statistical analyses

Data were analyzed using MIXED procedure in SAS 9.3 (SAS Institute Inc., 2012). To normalize the residuals, we transformed data on horizontal diameter of port opening with callus with SQUARE ROOT (SQRT) function. For the data on length and width of bark crack around the injection port we used the COSINE (COS) transformation. We analyzed the effects of port type and time on horizontal and vertical diameters of port opening with callus, on the length and width of the bark crack, and on the injection port