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Trunk Injection Technology **2018**

Abiotic Disorders; Diseases & Pests;
Active Ingredients & Formulations; Markets;
Company Profiles; Future Trends & Applications

Contents

List of Tables

List of Figures

Executive Summary

Chapter 1: Introduction

The opening chapter of this report covers concepts fundamental to trunk injection as a basis for the rest of the report. This includes summaries on trunk anatomy, physiology and classification to help understand the challenge of effective trunk injection. The chapter also discusses the history of the technology, the factors to consider when choosing an injection method, benefits of trunk injection over more common application methods and its limitations.

Chapter 2: Trunk injection technologies

Chapter 2 is a discussion of all commercially available trunk injection systems. The discussion is separated into trunk interfaces developed and also the delivery systems offered. Methods of trunk interface are further split into plug interfaces, no-plug interfaces and no-drill interfaces, whilst delivery systems are split into macro-injection systems and micro-injection. A further segment is included on novel injection systems recently patented but not commercially available.

Chapter 3: Tree abiotic disorders, diseases and pests

This chapter provides information on the pests, diseases and abiotic disorders which have been successfully treated using trunk injection. Trunk injection has become standard practice for many of these tree issues in North America. Information includes pest and disease behaviour, geographic history and distribution and the role of trunk injection in their treatment.

Chapter 4: Injectable ingredients & formulations

Chapter 4 looks at the active ingredients and formulations used in trunk injection. It first discusses the physical factors that determine whether a formulation can be injected and goes on to look at the active ingredients used in injectable products including insecticides, fungicides, antibiotics and plant growth regulators. A profile is given for each active, including chemistry, history and its role in trunk injection.

Chapter 5: Trunk injection markets

This chapter presents a figure for the size of the global market which includes trunk injection systems and injectable formulations. It goes on to discuss the size of markets in key countries and discusses the nature of the market and the main suppliers. Information is also provided on the registration of trunk injectable formulations in each country.

Chapter 6: Industry information

Chapter 6 provides profiles of companies involved in the trunk injection industry, including trunk injection specialists and agrochemical majors. Where available, information for each company includes company history and figures, R&D activity in trunk injection, the level of training offered to end users and the company's view on the future of the trunk injection industry.

Chapter 7: Trunk injection in agricultural fruit trees

The final chapter looks at recent field studies on the use of trunk injection in agricultural fruit trees and discusses the implications of these on the potential for greater commercial use in fruit tree applications. Where available, the discussion covers the efficacy of the injected compound on treating the fruit tree issue of interest, distribution and fate of the compound in the tree following injection and its residue in the fruit.

to their tree-like form are commonly referred to as trees. Tree classification is an important factor in choosing a trunk injection strategy due to differences in internal tree structure, hydraulic behaviour and wounding.

Table 2: Tree classifications and characteristics
Hardwoods
• Angiosperm ("closed" seeds with fruit / flowers)
• Non-coniferous, i.e. any species not pine, spruce or fir
• Deciduous at temperate latitudes; evergreen in the tropics
• Usually broad-leaved, i.e. it has leaves rather than needles
• More complex structure than softwood; has pores/vessels
Softwoods
• Gymnosperm ("open" seeds)
• Coniferous, i.e. pine, spruce or fir species
• All evergreen except Bald Cypress and Larch
• Needles instead of leaves
• Generally lower in economic value

Angiosperms (hardwoods)

Angiosperms are a taxonomic classification of plants wherein the plant's ovules (seeds) are surrounded by an ovary, for example fruits of the apple tree or "conkers" found on horse-chestnut trees. Within the plant kingdom, angiosperms are the most diverse group of land plants with nearly 300,000 different species.

Angiosperms (or 'hardwoods') are further classified by the size of the pores in the wood. Most hardwoods are 'diffuse-porous', that is the size of pores throughout each ring of the trunk do not change significantly regardless of position. 'Ring-porous' hardwoods on the other hand grow much larger pores at the beginning of the growing season and therefore have a distribution of pore sizes decreasing from large on the inside of each ring to smaller at the outside. These differences can have an impact on the choice of trunk injection approach used.

push the plug out over time. Plug systems have been used since the 1970s but have fallen out of favour in some applications due to setup time and also due to complaints of non-healing wounds creating sites for infection. This may be the case with certain species of tree or due to incorrect plug installation.

Table 4: Plug interfaces

Name	Supplier	Year
Arborplug / Viper needle	Arborjet	2007
ACECAP implantation	TreeCare	1972

Arborjet's Arborplug has an internal rubber septum which is pierced by the injector needle. It is 15 mm in length and 7 or 9 mm wide. Drilling 15 mm deep provides a volumetric capacity of 0.6-1.1 cm^3. When set correctly (at the sapwood-bark plane), the plug provides a flat surface for callus and woundwood development and wound closure. This encapsulation is the survival strategy of trees following injury.

Figure 6: Arborplugs, plug positioning and example of minimal tree scar

Other early systems still employed today include the ACEAP gelatine capsule implants containing the active ingredient in almost pure form (e.g. 97%). The capsules are housed in a plastic plug that is inserted into the drilled hole. Water from the tree's transpiration stream dissolves the gelatine capsule releasing the chemical.

Figure 7: TreeCare ACECAP implant system

Arbocap

Arbocap is another pre-filled bottle system. However, rather than pre-pressurising by the manufacturer, the bottle is pressurised to 0.2-0.5 bar in-situ by the operator using a small built-in manual pump.

Bioforest Technologies "Eco-ject Micro-injection System"

Infusion is applied in the Bioforest technologies "Eco-ject" system using canisters similar to the Mauget capsules described previously, but which contain a spring-loaded valve to infuse the liquid rather than air pressure (as in the Mauget capsules). The advantage of this system is the refillable and reusable design of the canisters. The Eco-ject consists of an air cylinder that can be pressurised used to re-fill a set of canisters once empty to allow the operator to move onto the next tree. Canisters can be used up to thirty times and can also be sent back to Bioforest Technologies for refurbishment and repair to allow further use.

2.3 Novel trunk injection technologies

A patent released last year by a South Korean inventor describes an automated trunk injection capsule. The device contains a spring-loaded mechanism to administer the compound automatically and to allow the operator to move on to further injections without waiting.

Table 6: Recent key trunk injection technology patents

Patent #	Year	Company	Key features
9,629,311	2017	-	Automatic spring-loaded trunk injection capsule
EP2731764 (A1)	2014	Uni. Padova	"Bite" lenticular blade injection tool
7,178,286	2007	ArborSystems	Needle with self-sealing holes so that needle may be left in tree

There is also a community of growers who develop home-made trunk injection systems for their orchards to better suit their individual needs. For example, avocado growers in Florida developed a retrofit to the Arborjet Quik-jet handgun which allowed delivery of liquids with far less damage to the trees.

The retrofit is a simple plastic adapter which is pushed into the drilled hole with a fitting on the back which corresponds to the output from the Quick-jet handgun. This approach avoids the need to use plastic plugs which the user found often remained in avocado trees for years or indefinitely and instead involves the tapping of a small wooden dowel into the hole to prevent infection from disease or entry of pests. A patent was submitted for this system in 2015; however, the developer whose orchards were hit hard by Storm Irma in 2017 has since decided to put the product development side of his work to one side whilst restoring his groves.

3.2.5 Anthracnose

Anthracnose is a general term used to describe disease caused by a range of host-specific fungi. The fungi cause a wide range of symptoms including leaf spots, blotches or distortion, defoliation, shoot blight, twig cankers and dieback in shade trees such as ash, birch, walnut, elm, maple and oak.

Table 7: Fungal pathogens responsible for anthracnose

Tree	Fungal Pathogen
Ash	Discula fraxinea
Birch	Cryptocline betularum, Discula betulina
Elm	Stegophora ulmea
Maple	Aureobasidium apocryptum, Discula campestris
Oak	Discula quercina

In most cases, anthracnose does not cause permanent damage to established trees. However, consecutive years of defoliation can decrease the tree's vigour, weakening the tree and thereby predisposing the plant to opportunistic pests that may further harm or damage the tree.

Treatment with trunk injection

It is generally not necessary to treat anthracnose with fungicides through trunk injection or spray unless complete defoliation has occurred several years in a row. If injection is necessary, most anthracnose fungi can be treated with propiconazole or thiophanate methyl which should be injected before the fungus becomes active.

Anthracnose occurs during early spring when the weather first warms up. It is a challenge to inject trees during the small window between the trees beginning to transpire and the fungus becoming active. Therefore J. J. Mauget offer anthracnose fungicides (Fungisol, Arborfos and Tebuject) which can be injected in the prior Autumn and remain active until the following spring before onset of the disease. Injecting in the Autumn also prevents overwintering of Anthracnose fungi in trees.

3.3 Insect pests treated with trunk injection

As a general rule, native insects are opportunistic, attacking stressed and declining trees. Invasive pests on the other hand are comparatively more aggressive and will attack and kill trees that are in full health. Most insect pests treated through trunk injection, particularly in North America are invasive pests.

Chapter 4: Injectable ais & formulations

A typical crop protection product formulation consists of an active ingredient, a base of water or oil and a balance of different inert ingredients often to aid in product stability and shelf life. There are a set of factors which determine how easily a formulation will be taken up and distributed throughout the tree, as follows:

- High active ingredient compound solubility in water
- Medium to low organic carbon-water partitioning coefficient (Koc)
- Water solution pH around 7
- Absence of penetrative or adhesive adjuvants
- Ability for systemic movement of compound

Water solubility

Water solubility is the ability to dissolve a certain amount of a compound in a certain amount of water whilst maintaining a homogeneous solution. High water solubility is critical for easier and faster uptake and translocation of a trunk-injected compound and its passage into the tree canopy and high efficiency against pests. Designing new formulations which allow higher water solubility is important for injectable formulations.

Organic carbon-water partitioning coefficient (Koc)

Organic carbon-water partitioning coefficient (ml/g or µg/g) or carbon adsorption coefficient (Koc) of a substance expresses the level of the substances adhesion to the carbon rich compounds within a given environment. It is usually discussed in relation to the adsorption of a substance as it passes through soil, and also has relevance to the passage of substances through trunk xylem.

Koc is defined as the ratio of the mass of a chemical that is adsorbed in a certain environment per unit mass of organic carbon in that environment (per the equilibrium chemical concentration in solution). Compounds with high Koc values bind strongly to the organic compounds in a given environment (e.g. soil, sap or xylem) and hamper the movement of the injected compound into the canopy. This leads to negligible compound accumulation in the tree crown resulting in poor compound distribution and low level of pest control. Compounds with low or moderate Koc values are not adsorbed and this property is desirable for trunk-injected formulations. The table below shows the wide range of Koc and water solubility values for ais already used for trunk injection.

4.3 Antibiotics: Oxytetracycline Calcium

Oxytetracycline Calcium was recently launched as an injectable product for suppression of a range of important tree diseases including Bacterial Leaf Scorch, Fire Blight and palm diseases. Mauget was the first company to introduce such a product in 2010 with other US companies following suit in 2013.

Table 18: Oxytetracycline products

Brand name	% ai	Company	Year	Notes
Terrier	4.3	ArborSystems	2013	For suppression of lethal yellow disease in palms
Springer	4.3	ArborSystems	2013	For ornamental trees
Arbor-OTC	36.7	Arborjet	2013	-
Mycoject	4.3	Mauget	2010	-

4.4 Biopesticides

Verticillium alboatrum is the most important biological pesticide available, marketed under the brand name “Dutch Trig”. It is an industry standard method for treatment of Dutch elm disease, and played a key role in bringing the disease under control in North America. In the USA, the registration is held by the company Tree Care Innovations, whilst the Dutch company BTL Bomendienst holds registrations in Europe and Canada.

Other available biopesticide active components are azadirachtin (by Bioforest Technologies), metarhizium anisopliae (by Marrone Bio Innovations) and bacillus amyloliquefaciens.

4.5 Plant growth regulators

The following injectable plant growth regulator formulations are available from ArborSystems and Arborjet.

Table 19: Injectable PGR products

Ai	Brand name	% ai	Company	Year introduced
Flurprimidol	Mastiff	48.1	ArborSystems	2008
Dikegulac	Pinscher	18.5	ArborSystems	2003
Paclobutrazol	Shortstop	22.3	Arborjet (from SePRO)	-

4.6 Novel trunk injection formulations

There are dozens of patents filed for product formulations designed for treatment of trees which state that trunk injection is one possible method for administering the chemical to the tree. Such patents have been omitted here due to the fact that formulations intended for trunk injection should be designed with that sole purpose in mind. Such patents are likely to overlook the formulation characteristics necessary to ensure that the product is genuinely injectable.

5.1 North America

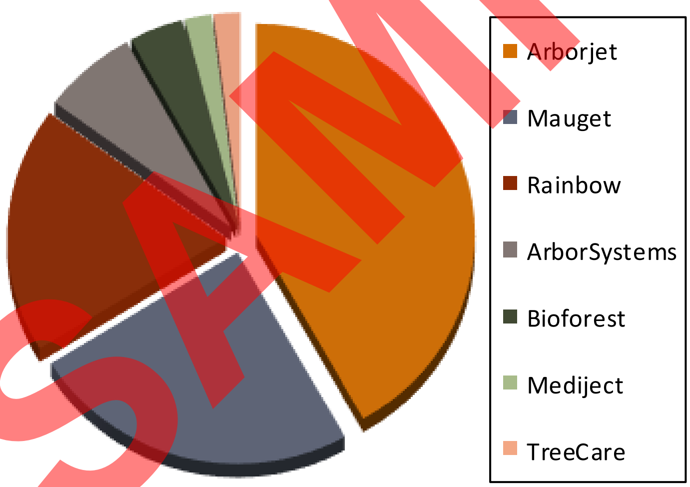
The market for trunk injection in North America is estimated at $9.9 million and is almost exclusively in ornamental trees and forestry, and some small usage in agricultural fruit trees. Trunk injection is used to control a range of tree disorders, diseases and pests though just a handful of tree issues create most of the demand. These issues are Dutch elm disease, Emerald Ash Borer and iron chlorosis.

5.1.1 USA

The USA is by far the largest market for trunk injection systems and chemicals at $7.0 million comprising nearly 50% of the total global market. The use of trunk injection products in the USA is concentrated in the more populated regions of the North Eastern states and coastal West.

The market is supplied almost exclusively by the domestic tree injection specialists Arborjet, J. J. Mauget, ArborSystems and Rainbow TreeCare (85% of the market). All of these companies have chemical registrations across the USA except Arizona. The international tree care specialists Chemjet and Fertinyect also have a small presence in the USA, both through exclusive distribution deals with US companies (J. J. Mauget and Brandt respectively).

Figure 28: USA company market shares



5.1.2 Canada

The market for trunk injection in Canada is estimated at $1.9 million and is concentrated around the Great Lakes. The market is supplied almost exclusively by the Canadian tree care and forestry company Bioforest Technologies (77%). The remaining 23% is supplied by the US companies Arborjet, Mauget and TreeCare Products.

Training and resources

Mauget is an important resource for the industry, disseminating information on current tree pest and disease trends in North America via its bi-annual "Feeder Tube" newsletter. It is also the only tree injection specialist offering arborists certification for application of their products. Certification ensures that products are used correctly, and gives customers looking to use Mauget technology confidence in choosing someone local to carry out the work. Training is carried out by Mauget staff or by arborists already holding the certification, and can also be completed through on-line self-study.

Mauget view on growing the industry

J. J. Mauget believes that largely untapped markets outside of the USA such as Russia and Eastern Europe offer considerable opportunity for growing the industry. Mauget is the only US tree injection specialist to have a dedicated distributor in Russia which was established in February 2009. Key Mauget USA personnel have visited their Russian counterpart on numerous occasions to provide advice and training on Mauget products and to learn about the sorts of tree disease and pest issues experienced in the country. Mauget is also the sole provider of trunk injection to the US territory of Puerto Rico.

6.1.2 Arborjet

Arborjet was setup in 1999 and has since developed the widest range of injection systems. The company specialises in solving Emerald Ash Borer (EAB) problems using its highly effective TREE-age injectable emamectin insecticide. The efficacy of TREE-age against EAB has been published in scientific articles showing control for up to three years, possibly the longest residual of any injected product. TREE-age can also be used on over 25 other important pests.

Table 29: Arborjet in numbers	
Turnover (USD million)	3.3
Year of formation	1999
No. of patents	6
USP	Range of injection methods

Research and development

Arborjet has a research team performing field trials and developing new formulations. In 2017, the company conducted field trials on Coneworm, Gypsy Moth, Gall Wasps and the Polyphagus Shot Hole Borer.

Training and resources

Arborjet offers hands-on training of its products across the USA as well as a ten-week webinar series to give users a basic understanding of their technology and the tree care industry. There is also an on-line video archive on the Arborjet website containing over 60 videos covering a range of tree-related topics such as product training and troubleshooting.

The research to date is independent – published both as scientific journal papers and theses - and looks at the efficacy of trunk injected chemicals on common apple tree issues and the distribution of chemicals following injection including residue analysis of chemicals in the apple fruits.

7.1.1 Apple tree issues

Potato leafhopper

Potato leafhoppers (PLH, Empoasca fabae) are of the Hemiptera order of insects (that of aphids) and are a serious agricultural pest in North America. Apples are one of the crops to be impacted the most as well as potatoes, clover beans and alfalfa. They are a sucking insect with the nymphs preferentially feeding on young shoots. Their feeding involves the release of saliva into tree parts causing leaf curl and yellowing referred to as “Hopperburn” and if severely infested will lead to leaf necrosis. The current economic cost of PLH to apples in North America is not reported, however to give an idea of this pest’s impact, historically losses to alfalfa from PLH have been as much as $177 per hectare (46% of expected revenue – 2018 prices).

Figure 31: Potato leafhopper images: a. PLH nymph and b. “Hopperburn” damage on a sugar maple

Photo credits: Frank Peairs, Colorado State University; Eric R. Day, Virginia Polytechnic Institute

7.1.2 Efficacy of trunk injection

In both scientific studies recently published, imidacloprid was highly effective against potato leafhoppers (PLH). Using an injection rate of 0.4 g ai per 25.4 mm of trunk diameter, the first study (VanWoerkom, 2014) saw the number of PLH nymphs per 20 tree shoots reduce from 1.9 to 0.2 twenty-one days’ post-injection – a mortality rate of 83.3%. Within forty days, the second study caused a mortality rate of 89.5% reducing the number of nymphs per 20 shoots from 1.9 to 0.2. Emamectin showed a greater effect on leaf miners.