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REVIEW ARTICLE

Tree injection method to manage coconut pests with special reference to blackheaded caterpillar, *Opisina arenosella* and mite, *Aceria guerreronis* - A Review

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ABSTRACT: The injection of exogenous materials into plant system for pest management is being followed since early years of twentieth century. Numerous studies on the tree injection have been done to explore the possibility of injecting chemicals into trees. Root feeding, stem or trunk injection have received significant results of nutrient and pest or disease management across the world. Owing to the practical difficulties in foliar application of pesticides in tall trees like coconut, tree injection became an alternative mode of pesticide delivery to target site. Although tree injections have some limitations, they also have some specific advantages over other methods of management such as minimized use of water and chemicals, reduction in the labour cost, effective management of target pests and environmental safety as non-target organisms can be protected from the effect of pesticides. Serious efforts are needed to standardizing of the technologies of administration for various chemicals under diverse environmental conditions to make it easy and ultimate for specify host plant / nutrient condition which cannot be properly addressed by other methods.

Keywords: Coconut palm, tree injection, pest management, black headed caterpillar, coconut mite

INTRODUCTION

The injection of various exogenous materials into plants have been implemented as early in the middle of the twentieth century (Perry *et al.,* 1991) and expanded in the 1970s. Early literatures show that supply of water to young transplanted trees through the cut end of the root was successful, thus suggested the possibility of injecting chemicals into trees (Cott, 1897). During 1910, tree injection with specific chemical, potassium ferrocyanide was reported for the control of insect pests (Sanford, 1914; Shattuck, 1915). A review on 'Methods of Tree Injection' by May (1941) created interest for injection studies on plants. Gravitational method of liquid injection was reported to control the red palm weevil of coconut (Davis *et al*., 1954). Later the method of trunk injection with systemic insecticides has become an important practice against various insect pests that are difficult to control (Ginting and Desmier, 1987). During that period numerous studies on the tree injection have been done by North American researchers (Ferry and Gomez, 2013). A´cimovi´c *et al*. (2016) examined injection port damage and wound closure in apple trees. Similarly, Dalakouras *et al*. (2018) inspected the movement of hairpin and small-interfering RNAs in apple and grape trees. Uptake and translocation of antibiotics into the tree system was explored by Killiny *et al.* (2019). Berger and Laurent (2019) focuses on modern injection technologies and factors affecting the efficacy of chemicals. Leigh *et al*., (2022) reviewed the concepts of trunk injection method, physiological principles and concerns associated with the injection method.

Considering the tree architecture of coconut, the palms have been exploited for pesticide administration through injection for management of different insect pests. Coconut palm, *Cocos nucifera* L. which belongs to family Arecaceae has been variously described as "console of the east", "the tree of heaven", the 'Kalpavriksha' because of its great versatility demonstrated for many domestic, commercial and industrial uses of its different parts like leaves, fruits, stem and roots. In India, coconut is grown under varied soil and climatic conditions in 17 States and 3 Union Territories. The decrease in yields of coconut has been attributed to a number of factors consisting of biotic and abiotic factors. Among the biotic factors, the insect pests and mites are very important. Amongst foliage pests, coconut black headed caterpillar, *Opisina arenosella* Walker (Lepidoptera: Oecophoridae) is one of the major and serious pests of coconut palm in India, Srilanka, Bangladesh and Myanmar. The pest during its larval stage causes serious damage to the leaves of the palm. In case of severe infestation, several hundreds or thousands of larvae could be observed on a single palm and affected palm often take several years to recover completely (Ramkumar, 2002).

Coconut eriophyid mite, *Aceria guerreronis* (Keifer) is another important and introduced pest of coconut palm. At the end of the 1990s it was reported for the first time from Sri Lanka and southern India (Fernando *et al*., 2002) causing considerable damage to coconut. The coconut eriophyid mites feed and breed beneath the perianths (floral bracts) of coconut fruits causing damage to the epidermal meristematic tissues. The severity of its damage on nuts may result in deep fissures on pericarp, distortion of the fruit, reduction in fruit size and weight, and a decline in copra yield (Julia and Mariau, 1979; Hall *et al.,* 1980). Higher damage caused by these mites leads to premature nut drop or extreme reduction nuts size which are difficult to dehusk and yield losses ranges from 10 to 70 per cent (Moore *et al*., 1989) while reduction in nut size led to 25 per cent yield loss of copra (Gopal and Gupta, 2001). Several studies have been undertaken for the management of these pests through use of conventional pesticides, biopesticides, natural enemies and palm injection. Injection as a delivery method has received significant results in managing these pests on coconut palm. However, the complete knowledge of injection methods on different aspects have been lacking. Therefore, we reviewed the tree injection methods and pesticides used on different trees and coconut palm.

TREE INJECTION METHOD

Injection hole

Injection of chemical materials requires the drilling hole ranging from of 2 mm to 9.5 mm. The injection devices are high pressure devices whose pressure ranges up to 100 psi or more (Leigh *et al*., 2022) or 207 kPa to 450 kPa (Berger and Laurent, 2019). High pressure injection uses 7.15 mm or larger diameter plastic plugs as injection ports which inserted into the tree after drilling of a hole. Low pressure injection allows the plug-free injection of materials and occurs at relatively low pressures (<60 psi) by manual squeezing or with spring-loaded syringe system. The rate of liquid uptake associated with higher pressure is faster than lower pressure devices. However, the different tree injection methods explored the different types of the injection tools with a range of injection hole.

Pesticide transportation in tree system

Understanding of the transportation of pesticides to be administered in the tree system has important significance for the injection method. The movement of chemical in the tree system varies mainly on environmental conditions and physiological attributes of the tree. Generally, metabolically activeness and high vapor pressure deficit have a positive effect on the movement of chemical materials into the tree (Hunt *et al.,* 1974). Anatomical features of the plants *viz.,* size and arrangement of xylem vessels, tracheids and vessel parenchyma cells determine the path, patterns of compound uptake and distribution and efficiency of the chemical substances in the trees as well as wound response and compartmentalization (Martínez-Vilalta *et a*l., 2012; Cartenì *et al*., 2018). The radial movement of chemicals may occur via active transport of parenchyma cells and diffusion through cell walls (Kuroda *et al*., 2021).

Various studies have been taken into consideration to understand the transportation of the chemicals in the tree systems. Shivashankar (1999) studied the procedure for chemical translocating in the tree system after treatment through injection. In the study the movement of the insecticide soluneem (neem-based bio-pesticide) in the internal tissues of coconut trunk was understood. A mixture of methylene blue (3 g) and soluneem (1500 ppm) was dissolved in 20 ml of mineral water and was administered by syringe method in coconut palms on trunk and after 24 hours of placing syringes, the palms were cut to record the movement of the dye. They found that methylene blue dye mixed with soluneem was traced in the xylem vessel up to a height of 6.3 m within 24 hours and revealed that chemical translocate into the tree via xylem vessels. Similarly, the translocation speed and distribution of thiamethoxam solution in date palms was studied by Samarrie and Abula (2011) and showed that thiamethoxam when injected, moved at a rate of 2.8 meters per hours in date palm trunk. In another study, Harrell (2006) studied that green ash trees (*Fraxinus pennsylvanica*) when injected with imidacloprid to control emerald ash borer (*Agrilus planipennis*) was found in sap, leaves, xylem and cambial zone tissues up to 90 days after treatment. He also found the higher concentrations of imidacloprid in xylem and cambial zone tissue of trees. Similarly, Mota-Sánchez *et al*. (2009) injected green ash (*Fraxinus pennsylvanica*) and white ash (*Fraxinus americana*) trees with 25 µCi of ^{14}C-imidacloprid plus non-labelled imidacloprid against emerald ash borer, *Agrilus planipennis.* The results of their studies showed that imidacloprid translocation occurs primarily in xylem. They also observed that extremely high concentrations of imidacloprid were observed in the stained regions of the trunk cross-sections and in leaf tissues and lower amount in roots. In their experiment emerald ash borer, *A. planipennis* was controlled in both green and white ash trees.

Adnan *et al*. (2006) reported translocation and movement of some systemic and non-systemic insecticides *viz.,* dimethoate + phenthoate, primiphos-methyl, chlorpyrifos-ethyl + dimethoate, chlorpyrifosmethyl and lambda-cyhalothrin in date palm trees. Their results revealed that these pesticides distributed through the date palm trunk and detected in pith at above the injection pore on 10, 20, 30 and 100 days post injection in the same and the opposite sides of injection pore. They concluded that distribution of the pesticides in trunk sap facilitated by existence of large vascular bundles tubes over whole trunk of date palm. Moreover, the pesticides can also be reached the plant sap either by root up take, penetration through leaves and stem or directly by injection into trunk. However, interestingly in one study, Sharma (2018), reported that pesticides translocation and distributions in plant tissues were influenced by the pesticide's physical properties such as solubility partitioning and polarity as well as the appropriate application position which affect trunk injection methods efficiency. He assumed that abiotic factors *viz., w*ater soluble potential of active ingredients, water soluble potential of non-active ingredients components and other environmental variables like humidity, temperature, rainfall etc. as well as biotic factors *viz.,* the anatomic point of injection site on the coconut palm and age of the coconut palm may influence the transport of the chemical into the tree. He observed the solubility potential of formulation of monocrotophos and cartap hydrochloride have the highest absorption in coconut palm. As monocrotophos has the highest solubility (100% soluble in water, Tomlin, 1994) followed by cartap hydrochloride (20 mg/ml; Hartley and Kidd, 1997). The non-active-ingredients components of these insecticides had the lowest impact on the solubility of formulation and therefore monocrotophos and cartap hydrochloride had highest absorption even at highest concentrations whereas, other insecticides studied had lower absorption potential in the decreasing order as follows; acetamiprid > emamectin benzoate > clothianidin > spinosad > imidacloprid > thiacloprid. Though the insecticides formulation such as acetamiprid and emamectin benzoate had a relatively better solubility of active ingredient, the presence of the non-active-ingredients components may find to interfere with the absorptions. He also made comparison that, when the polarity of non-active ingredients of the insecticide formulation is hydrophobic a complex and stable emulsion is formed upon diluting with water. Though these emulsions are stable at lower concentration, at higher concentration the non-active ingredients of the emulsion form fine aggregates and a suspension is often formed. A suspension naturally will have fine insoluble particulate matter and such matters are tend to sediment on long duration static storage and form a thin film on the bottom of the cavity. The coconut palm/frond has a very unique stem anatomy with xylem and phloem confined to vascular bundles scattered throughout the central cylinder of the stem/ frond.

In most species, these bundles are concentrated near the periphery of the stem and interspersed within a matrix of thin-walled undifferentiated parenchyma cells. Palm stem xylem, phloem and even parenchyma cells remain alive for the life of the palm, which can be hundreds of years in some species (Tomlinson and Huggett, 2012). In the centre of the stem, the number of vascular bundles per unit cross sectional area is quite low but in the cortex region this increases rapidly. In cortex region (about 75 to 100 mm), the vascular bundles are very congested and separated by only very narrow bands of ground parenchyma tissue (Richolson and Swarup, 1977). Below the cortex region the vascular bundles are embedded in ground tissue. Upon making an incision of size (0.3 × 2 cm) on the basal region of coconut palm stem and (0.3 × 1.5 cm) on the frond and base of the of coconut palm (Sharma, 2018); the vascular bundles include xylem, phloem, parenchyma tissues and thick-walled sclerenchyma fibres are directly exposed in the incision. When the syringe loaded with the appropriately diluted insecticide formulation is plugged into the incision, a very unique micro environment is created in which the diluted insecticide formulation is directly fed into the vascular bundles. In coconut palm, though the vascular bundles are unified with different types of tissues, it is believed that a major portion of the insecticide solution is taken by the xylem vessels. In addition, differences in the site of injection can affect the rate of uptake and distribution (Tanis *et al*., 2012). The dye in a root injection moved to the xylem vessels of the current year's growth (Holmes, 1982) whereas dyes injected into the lower trunk of the trees moved radially throughout the entire root tissue, while in the stem the dye was confined to the most recent growth (Tattar and Tattar, 1999). However, further studies on the possibility of the entry of the insecticide formulation on other types of vascular tissue, uptake and distribution of chemicals as a function of the injection location on the tree are required for individual crop species.

Tree injection for disease management

Early studies on trunk injection were reviewed by Roach (1939). Applications of liquids through roots and stems in combination with syringes, tubing systems and specially designed devices were explored in many countries during the 19th and beginning of the 20th century (Roach, 1939). However, more research aspects on tree injection took place with the devastating spread of Dutch elm disease in the 1960s (Perry *et al*., 1991). The onset of Dutch elm disease in the United States led to a renewed interest in tree injection. Richard and Susan

(1997) conducted studies to determine the curative and efficacy of avermectins in controlling plant parasitic nematodes, *Meleidogyne javanica* and *Radopholus similis* when injected into the pseudo stem of banana (*Musa acuminate*). The results of the study indicated that avermectins injection of 250 and 500 µg a.i./plant were effective in reducing nematode infection up to 28 to 56 days after imposing treatments. Similarly, nematicidal solutions *viz.,* carbofuran, oxamyl, phenamiphos, sulfocarb and di-bromo-chloro-propane (DBCP) were used against the nematode, *Pratylenchus vulnus* through pressurized injection technique by Viglierchio *et al*., (1977). They observed significant reduction in *P. penetrans* incidence on apples and walnuts. The fungicides *viz.,* dimethomorph, fosetyl-al, iprovalicarb and metalaxyl were applied as stem injection in field-grown grapevines and obtained the desired protective effect against downy mildew (*Plasmopora viticola*) (Duker and Kubiak, 2009). Similarly, fungicides namely, triazoles (myclobutanil, penconazol and tebuconazole) were used for the control of powdery mildew by means of stem injection and found effective in managing the disease (Duker and Kubiak, 2011). In a field study, the fungicides namely; propiconazole, phosphites and penthiopyrad were injected against apple scab, *Venturia inaequalis* on apple trees (Vanwoerkom *et al.,* 2014). But they observed limited effectiveness of these fungicides in the management of apple scab. However, similar trunk injection of fungicide phosphorous acid was performed on mature apple trees to manage apple scab, *V. inaequalis* and resulted in lower incidence of apple scab compared with untreated trees (Coslor, 2017).

Tree injection for insect pest management

In 1970s, several systemic insecticides were used via trunk injection for the management of insect pests. These insecticides studied were *viz.,* monocrotophos, dichrotophos, acephate, phorate and methamidophos (Wood *et al*., 1974). Similarly, application of 6 ml of 60 per cent monocrotophos per palm via stem injection was given highest mortality of the coconut caterpillar, *Brassolis sophorae* (Rai, 1973). Similarly, the insecticides *viz.,* monocrotophos, methamidophos and acephate were effective in controlling the leaf miners on angsana plant, psyllid and buprestid on pongamia plant at doses of 6 ml (3.30 g a.i.), 6 ml (2.90 g a.i.) and 6 g (4.50 g a.i.) per tree respectively, when administered through trunk injection at three points at midway, between the first crown and on the ground using 20 ml Chem-Jet syringes (Jusoh, 1998). In a sequence, the green ash (*Fraxinus pennsylvanica*) street trees were injected on the trunk with emamectin benzoate at rates of 0.10 to 0.60 g a.i. per 2.54 cm diameter at different locations in Michigan, United states and the result showed that a single trunk injection of emamect in benzoate at the rate of 0.1, 0.2 and 0.4 g a.i. gave 100 per cent control of emerald ash borer larvae in 98 of 99 treated trees for a long time up to 2-3 years (Smitley *et al*., 2010). Hasber (2012) conducted field trial to evaluate trunk injection technique using systemic insecticides *viz.,* methamidophos and monocrotophos to control bagworm, *Metisa plana* in oil palm. He used a plastic syringe containing 10 ml solution per palm each methamidophos (5 g a.i.) and monocrotophos (6 g a.i.) formulations to inject chemicals into the hole. The results of study showed that both methamidophos and monocrotophos were highly effective in reducing the population of bagworms up to 94 to 97 per cent after 3 days of treatment in all injected plants. Similarly, in a study by Huang *et al*., (2016) the Sweet olive trees (*Osmanthus fragrans)* were injected using a no-pressure injection system to control the nettle caterpillar, *Latoia lepida* and found that 4% imidacloprid + carbosulfan and 21 % abamectin + imidacloprid + omethoate were completely absorbed in 14 days with lower mortality of *L. lepida* while 10 % emamectin benzoate + clothianidin and 2.5 % emamectin benzoate were reported to absorbed in 30 days but achieved the higher larval mortality of the nettle caterpillar in the canopy.

A field trial was determined using two systemic insecticides imidacloprid 200 SL and thiamethoxam 240 SC to manage Arabian Rhinoceros Beetle (*Oryctes agamemnon arabicus)* in date palms by three methods *viz.,* direct spray, trunk injection and drenching and the results showed that trunk injection method was more effective as compared to other methods tested (Khalaf and Alrubeai, 2016). Coslor (2017) tested the insecticides *viz.,* emamectin benzoate, imidacloprid, dinotefuran, spinosad, chlorantraniliprole and abamectin via trunk injection against pests of apple trees. He indicated that tested neonicotinoids reduced *Empoasca fabae* while emamectin benzoate, chlorantraniliprole and abamectin resulted in moderate to high mortality along with reduced feeding by *Choristoneura rosaceana* and spinosad was found with lower absorption and least effective. In field trials, Sharma (2018) and Sharma *et al.* (2020) reported that the different insecticide solutions when injected to fronds and base of the coconut palms managed *O. arenosella* effectively (figs. 1 and 2) Furthermore, the insecticides also reduced the pupation, pupal weight, adult and parasitoid emergence of *O. arenosella*.

Tree injection for the management of *O. arenosella* and *A. guerreronis*

Root feeding

The difficulties in spraying taller palms and harmful

Fig.1 Syringe method of insecticide application at base of coconut palm (Image; 1- Excavating soil around the coconut base, 2- Removing the bark at cortex region to drill a hole, 3- Drilling, 4- A fresh hole made by hand drill, 5- Sealing wax on end (tip) of syringe, 6- Measuring injection volume, 7- Placement of syringe into drilled hole and 8- Syringe covered with polyethene cover (Sharma, 2018).

effects of spray application on natural enemies lead to administering chemicals through root feeding and stem injection. The first report on root feeding method was attempted by Ganeswara *et al*., (1980) using systemic insecticide monocrotophos against *O. arenosella* in coconut palms. Subsequently, the root feeding method was followed by Pushpalatha (1986). A smooth slant cut was made to the root, with a sharp knife, and then the cut end was inserted into the glass tube contained the monocrotophos solution in such a way that the tip of the root contacted with the bottom of the tube and monocrotophos at the rate of 9 ml and 18 ml through the root feeding for the coconut palms below 10 years and above 10 years, respectively was found effective against *O. arenosella*. Similarly, neem-based biopesticide was also tried for the management of coconut black headed caterpillar using root feeding method palms (Srinivasa *et al*., 1994).

Similarly, root feeding with triazophos 20 ml per palm was found effective in reducing *A. guerreronis* population (Mohansundaram *et al*., 1999). Subsequently, use of eco-friendly formulation such as TNAU Agrobiocide 30 ml per palm also recorded the reduction in *A. guerreronis* population of 65-100 per cent over untreated control using root feeding (Kannaiyan *et al*., 2000). The comparison between the two methods was made by Dey *et al*., (2001) who reported that application of fenazaquin 10 EC administered through roots at 10 ml per palm and spraying the same chemical at 200 to 250 ml/litre of water reduced *A. guerreronis* population by 83 and 92 per cent respectively. Similarly, root feeding of fenpyroximate 5 EC at 10 ml per palm reduced *A. guerreronis* population by 90.24 per cent whereas spraying palm with same chemical at 1.0 ml/litre of water found reduce mite population by 80 per cent (Dey and Somchoudhary, 2001). Sujatha *et al*., (2004a) evaluated different chemicals *viz.,* monocrotophos, fenobucarb, fipronil at 20 ml + 20 ml water respectively, fenazaquin at 1 ml + 10 ml water and acetamiprid at 0.5 + 10 ml water through root feeding against *A. guerreronis* in coconut palms. The results revealed that monocrotophos was most effective with 89 per cent decrease in mite population followed by fenazaquin with 78 per cent reduction. Subsequently Sujatha *et al*., (2004b) found that fenpyroximate (10 ml + 10 ml 1 % urea solution) via root feeding was most effective compared to monocrotophos (10 ml + 10 ml 1 % urea solution), triazophos (20 ml + 20 ml water) and dicofol (15 ml + 15 ml 1 % urea solution). The study using different chemicals namely, abamectin 1.8 EC (2.5, 5.0 and 7.5 ml), profenofos 50 EC (10, 15 and 20 ml) and monocrotophos 36 SL (15 ml) applied through roots as aqueous solutions against *A. guerreronis* indicated abamectin 7.5 ml + 7.5 ml water and abamectin 5 ml + 5 ml water resulted in moderate reductions (58.84 and 51.44 %) of mite population (Shanmugam and Kunchithapatham, 2012).

Stem injection

Nadarajan and Channabasavanna (1981) used stem injection method against *O. arenosella* using monocrotophos at 3.5 ml and 7.0 ml, below 5 years old and more than 5 years old, respectively. They found that both the dosages were effective in reducing larval population. Moreover, they reported that monocrotophos persisted up to 90 days after administration. Similarly, Kanagaratnam and Pinto (1985) worked on stem injection method in coconut palm. The drill hole (15 cm deep) was made using an auger at an angle of 45 degree on the trunk at a height of one metre from the ground level and monocrotophos injected at 5 ml and 10 ml per palm of undiluted 60 per cent water soluble concentrate. After the treatment of 36 to 85 days, no live *O. arenosella* larvae and pupae were recorded from the infested palm. Similar, finding was observed with undiluted monocrotophos 60 WSC when administered through stem injection (Rao *et al*., 1981) and 5-10 ml quantity of chemical was sufficient to kill the larvae of *O. arenosella.* An eco-friendly bio-pesticide, soluneem (water-soluble neem formulation) containing 3000 ppm of azadiractin was injected using syringes to manage *O. arenosella.* The significant reduction in the larval population, adult emergence and malformation in the emerged adults were recorded in soluneem treated trees. Soluneem was effective up to 120 days with no phytotoxic symptoms to the treated palms (Shivashankar *et al*., 2000). Sharma *et al*., (2020) conducted a field study at farmer's field in Halebudanuru village in Mandya district in Karnataka, India during 2017-2018 using the frond injection method. This novel approach of insecticide administration into the coconut palm was applied using the imidacloprid 17.8% SL, acetamiprid 20% SP, clothianidin 50% WG, thiacloprid 21.7% SC, emamectin benzoate 5% SG, spinosad 45% SC, cartap hydrochloride 50% SP and with check monocrotophos 36% SL against *Opisina arenosella*. Cartap hydrochloride 50% SP and monocrotophos 36% SL caused 100 per cent larval mortality and all other treatments also gave significant mortality over control. Frond injection in coconut was done first time in India and it was found easy, quicker and accurate method for observing the absorption and efficacy of insecticides and also not caused any secondary infection and damage to the frond tissues. Periodic application of monocrotophos using stem injection was found effective to manage the coconut eriophyid mite (Julia and Mariau,1979). In the Caribbean region, vamidothion, an organophosphate was used as stem injection but was not effective in reducing coconut

Fig. 2. Frond injection of pesticides on coconut (1-4 Making holes; 5-9 administering pesticides)

eriophyid mite (Moore and Alexander, 1987; Moore *et al*., 1989). In Sri Lanka, trunk injection of monocrotophos was recommended to control *A. guerreronis* population. Although control was effective initially for about 2 months (Fernando *et al*., 2002). However, in a study, on absorption of pesticides formulation into coconut palm using syringe method of pesticides application, Sharma *et al*., (2019) showed that the acaro-insecticides *viz.,* spiromesifen 22.9 % SC, abamectin 1.9 % EC, fipronil 5 % SG and buprofezin 25 % SC found to have very low solubility threshold and were not effective in complete absorption by coconut fronds. They concluded that though the acaro-insecticides having acaricidal activity but may not be used against coconut eriophyid mite. This study, therefore, suggest that desire solubility level of different chemical formulations and their absorption should be considered for effectiveness.

Tree injection for nutrient management

In an earlier study, injection method was employed in delivering nutrients in trees of lemon to cure chlorosis through directly injection of ferrous sulphate solution into the plant system by Lipman and Gordon (1925). Similarly, the injection of iron salts into holes bored on the stem proved effective in overcoming chlorosis of grape vines, peach and apple trees (Wann, 1929). In ‘Red Delicious’ apple trees (*Malus domestica*) iron deficiency was cured either by ferrous sulphate ($FeSO_4 \cdot 7H_2O$) or ferric citrate ($FeC_6H_5O_7 \cdot H_2O$) at rates of 100 ml of 1 % solution per year of tree age through pressure injection (Danny *et al*., 2008). Mahmoud (2009) also showed that mango and grapevine plants can be fertilized by trunk injection through xylem. He also suggested that growth of mango trees was 20-25 % higher in injected trees than soil fertilized trees. Similarly, in grapevine fruits the yield was increased by 32-49 % higher as compared to fruit harvested from the plants given soil fertilization. Felipe *et al*., (2013) also showed that application of fertilizers at 0.9 m insertion height through stem injection in banana plants was found better than soil application.

LIMITATIONS AND ADVANTAGES OF TREE INJECTION

Pesticides administration through injection methods have some of the limitations such as chemical toxicity, mechanical injury and secondary infections to the tree. Earlier studies showed that administration of chemicals *viz.,* copper sulphate, boric acid, ferrous sulphate, manganese sulphate and zinc sulphate using trunk injection were resulted in oozing out of liquids from the trunk and induced deleterious effects in coconut palms (Davis *et al*., 1954). The major drawback to the trunk injection method on coconut palm include drilling of a 3-6 mm diameter hole approximately 75 mm deep on the trunk above the ground level (injection site) led to results in bleeding of sap from the injected site. Since coconut palms produce no secondary trunk growth, these holes remain indefinitely resulting in dark stains and these sites serve for secondary infections by pathogens (Mccoy, 1977). A few limitations were studied regarding trunk injection by Richard (1977) in control of Dutch elm disease management. He found that chemical moves upward from points of incision on stems and losses its strength as dosage decreases and often ineffective at higher canopy of the tree. Sometimes under the most advantageous circumstances, the chemical is not uniformly distributed in whole tree and some branches receive little or no chemical at all. In addition, chemical may lead to phytotoxicity to foliage or internal tissue of trunk. The wound reacting at the chemical tissue may interfere with normal translocation of food and water. The wounds of the injection site enhance the probability of secondary infections by parasitic fungi and bacteria. The wounded cell tissues are not replaced and the cells peripheral to the injured zone react to create barriers, isolating the healthy area from the outside and this process is called “compartmentalization” in trees (Shigo, 1972) and “sealing” in palms (Shigo, 1994). Tree injections have some limitation but also have many of the significant advantages over other delivery method such as minimized use of water and chemicals, reduction in the labour cost and environmental safety as non-target organisms can be protected from the effect of pesticides etc.

CONCLUSION AND PERSPECTIVES

Tree injection methods are useful for taller plants and also manage persistent and notorious pests where the other methods of pest management have less importance. Injection method has also received significant results in nutrient and disease management. However, the transportation of pesticides to be administered in the tree system via injection method need to be focused under the further research studies. The complete knowledge about the chemicals and their transportation into the different trees should also be assessed. The recommendation should be assessed for the pests, nutrient and disease management sing the trunk injection method for effective and suitable pesticides. Furthermore, strategies should be planned to minimize chemical toxicity, mechanical injury and secondary infections to the tree using injection methods. More focused efforts are required to standardization of methods of injection of different chemicals under various environmental conditions.

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