Date Palm Nutrition via Trunk Injection: A Comprehensive Review

Abstract

Date palm is an important agricultural crop in arid ~~environments and is~~ environments, vital for food and economic security. Conventional~~/~~fertilization approaches are usually ineffective and wasteful due to nutrient leaching and soil salinity.Trunk injection is a new fertilization method based on ~~the concept of~~ injecting nutrients into the vascular system of date palms, which improves nutrient uptake and reduces environmental costs. The review highlights the historical progression, approaches, and technological innovations of trunk injection while demonstrating its merits ~~in comparison~~ to traditional ~~approaches~~ methods by providing target nutrient delivery and reduced fertilizer input. Selected research shows the effectiveness of different nutrients, such as iron, potassium, and nano-fertilizers, in increasing vegetative growth and fruit yield. It also covers challenges related to infection risk and labor requirements. Trunk injection of date palms offers great promise for sustainable crop production systems, and the prospects for its integration with precision agriculture technologies are considered, along with the need for research to ~~optimise~~ optimize this technology.

Keywords: Trunk injection, Nutrient uptake, Nano-fertilizer, Sustainable Agriculture, Date palm, precision agriculture.

Introduction

Date palms (*Phoenix dactylifera* L.) form an integral part of the economy and food systems in hot, arid, and semi-arid regions (Aseeri et al., 2021), particularly in North Africa and the Middle East. Date palms are a lifeline for millions dependent on them for their food security and economic stability due to their hardiness against draught and capability of growing in stressful conditions (Shareef & Al-Khayri, 2021). Growing date palms in large areas of vast sandy deserts ~~pose~~ poses various agricultural limitations due to the poor quality of soil, high salinity, and shortage (Shareef et al., 2021a). Due to these environmental limitations, effective fertilization techniques are urgently required for ideal plant growth and maximum seed yield.

Conventional fertilization techniques, including soil application and foliar spray, have been very common; however, they are usually ineffective in deserts (Shareef et al., 2021b). These regions are characterized by their loose sandy soils, which cause a large amount of nutrient leaching – where nutrients are washed out of the path of roots, and it is compounded by the high salinity level that makes more nutrients unavailable (Shareef, 2024). Even more so, the root system of date palms might be shallow and widely spread,

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which makes it inefficient to uptake all the nutrients that are applied (Shareef& Sweed, 2020). These limitations have led to interest in other means of fertilization that are more economical and environmentally friendly.

Trunk injection is a potential method that has received considerable research interest. Soil and foliar application feed through the environment, whereas trunk injection feeds directly through the vascular system of the palm. Trunk injection is highly advantageous in unfavorable soil environments as this strategy not only minimizes nutrient loss to the soil but also increases nutrient accessibility (Jubeir and Ahmed, 2019a). Besides enhancing nutrient absorption, trunk injection also minimizes the environmental consequences of fertilization by decreasing the potential for soil salinization and contamination of groundwater (Shareef et al., 2023). Besides, trunk injection can be optimally adjusted to supply exact fertilizer compositions and meet the nutritional requirements of the palm efficiently.

However, as the cultivation of date palms is extended to sandy desert lands, a sustainable and efficient solution using the trunk injection method may be advantageous. This technique has the potential to aid large-scale cultivation of date palms by enhancing their growth resilience and productivity while improving nutrient use efficiency and minimizing environmental impacts.

~~The purpose of this review is~~ This review aims to compile the current information regarding trunk injection in date palms (field, experimental, and commercial aspects), highlighting the advantages, disadvantages, and perspectives. The relative efficacy compared to other fertilization approaches will be the main focus of interest, both for studies that have addressed macro and micronutrients separately, as well as those ~~pertaining to~~ on new paradigms in fertilizers like their nano form.

Historical Development and Methodology

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Stem injection as a fertilization technique dates back to the early 20th century, though its application in fruit trees, including date palms, has become more prevalent in recent decades. The method leverages the anatomy of the date palm trunk, particularly its vascular bundles, to distribute nutrients efficiently throughout the plant.

Many authors mention several events about the trunk injection history (Robbins 1981; Sánchez-Zamora and Fernández-Escobar 2004; and Doccola and Wild 2012); according to them, Leonardo da Vinci first investigated this method, but some of the earliest tree injection experiments were not recorded until early in the 20th century (Roach 1939). A deep description of the advances in this technique throughout history is presented by Robbins (1982). Many researchers investigated the use of trunk injections for different purposes associated with trunk conservation, protection, tree pathology, entomological threats, and nutritional and physiological aspects, even killing trees.

One of the earliest recorded studies that explored the application of trunk injection for fertilization purposes in date palms was by Abo- Rady et al. (1987), which utilized iron application, including FeEDDHA and $FeSO_4$. $7H_2O$ will promote the growth of the date palm Khlas and Ruzaiz cultivars. This study demonstrated that trunk injection could effectively boost the uptake of essential nutrients and improve growth. Similarly, Saleh et al. (2016) compared trunk injection versus conventional fertilization methods and showed that trunk injection increased iron bioavailability to a larger extent than fertigation in calcareous soils where iron availability is generally limited.

Technological Developments in Trunk Injection

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Trunk injection approaches have progressed through the years, and several related systems have been developed to improve nutrient delivery over an individual tree. The two principal modes are passive and active injection systems. There are passive systems that depend on gravity to import the nutrient solution into the tree, and there are active systems in which pressure is applied to propel the solution into the vascular tissue. Schreiber (1969) pointed out that the passive method was also efficient for trees since it did not rely on high pressures that could damage tree interiors. While Active systems have a higher operating cost, they provide the fastest delivery of nutrients. Other innovations in injection devices have specifically targeted damage prevention in the tissues and increased the absorption mechanisms of injected solutions (Alayón Luaces et al. 2019).

Trunk Injection as a Fertilization Method

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Over the years, trunk injection has emerged as a supplemental technique to traditional fertilization methods. This is a direct approach to introducing nutrients, pesticides, or other compounds into the vascular bundles of the tree (instead of relying upon soil and foliar uptake). This practice was applied as far back as the time of Leonardo da Vinci, but it was not formalized until the 20th century when equipment and methodology had advanced (Roach, 1939).

Advantages of trunk injection

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• Enhanced Purposeful Nutrient Timing: Through direct introduction into the tree vascular system, nutrients stay there for a long time and can be utilized much more efficiently.

• Environmental Benefits: As nutrients are retained within the tree's ecosystem, there is less possibility of leaching or runoff leading to soil and water contamination.

• Decrement in Fertilizer Use: Fertilizer use represents a lower consumption than soil application, has less environmental impact, and constitutes savings (Alayón Luaces et al. 2019).

Methods of Injection

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Passive system: A nutrient solution found in a passive container (unpressurized) located above the injection point, which allows for nutrients to be absorbed by the trees through its natural transpiration pull (Schreiber 1969).

Active System: It uses a pressure method; it pushes the nutrients with either low-pressure systems using syringes or high-pressure systems for quick nutrient infusion into the tree vascular system. The selection of these systems will be determined by the size, age, and kind of nutrients that will be applied to the trees (Filer 1973).

Mechanism of Trunk Injection in Date Palms

In date palms (*Phoenix dactylifera* L.), the absence of a vascular cambium, which in most trees facilitates radial growth and the formation of growth rings, creates unique challenges for nutrient distribution. This absence means that date palms don't undergo the typical thickening seen in dicotyledonous trees, resulting in a simpler, more columnar trunk structure (Alla et al. 2023). Because of this structure, any nutrients injected directly into the trunk are dispersed through a more constrained pathway, primarily relying on two main vascular tissues, the xylem and the phloem.

Xylem Transport: The xylem is responsible for upward movement, transporting water and dissolved minerals from the roots to the leaves. Injected nutrients entering the xylem are generally pulled upward by transpiration—the movement of water from roots to leaves driven by evaporation at the leaf surfaces. This pathway allows mineral nutrients to reach the photosynthetic tissues, yet it does not allow for significant lateral spread within the trunk due to the absence of radial growth and secondary xylem formation (Shareef & Sweed, 2020).

Phloem Transport: Unlike the xylem, the phloem moves sugars and other organic compounds bidirectionally—from the leaves, where photosynthesis occurs, to other parts of the tree that require energy and carbon compounds. In the case of injected nutrients, the phloem can distribute these compounds across a wider area, though the palm's unique vascular layout still limits it.

Due to these anatomical factors, trunk injection in date palms requires careful placement and possibly higher doses to ensure that nutrients or treatments reach the targeted areas. Precision in injection placement is critical, as injected solutions do not disperse as freely as they would in trees with radial vascular growth. This structural limitation is also why injected treatments might need to be applied more frequently or with modified techniques to optimize distribution efficiency across the tree's height and canopy.

Hence, proper information on the date palm trunk is necessary for nutrient delivery. Vascular bundles of the trunk are dispersed within the stem (Boumediri et al. 2019) and intermixed with parenchyma cells, allowing for injected solutions to move up and down.

Factors Affecting Trunk Injection Efficiency

From weather conditions to solution properties, various aspects have an impact on trunk injection success:

• Environmental Factors: Transpiration increases with high ambient temperatures, low humidity, and sunny weather, leading to better uptake and distribution of the injected

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solution through the tree (Acimovic 2014). On the other hand, rain or cloudy days will slow it down, which could decrease absorption efficiency. Increased soil moisture improves tree health, which promotes faster nutrient movement within the sap of tree trunks by trunk injection (SaÂnchez Zamora and FernaÂndez Escobar 2000). So, low wind speeds are more favorable for efficient nutrient uptake from injection. Transpiration is decreased under high wind speeds (Acimovic 2014).

• Size and Health of Tree: Larger, healthier trees (those with active transpiration) will take up injected solutions more freely than smaller or stressed trees. Moreover, this is also influenced by the amount of injections and diameter of injection holes (Nyland and Moller 1973).

• Nutraceuticals Preparation: The solubility of the nutrients is essential. ISL Solutions (intravenously delivered) must be maximally soluble for proper distribution in the vascular system. Fertilizers supported with nanoparticles are also becoming increasingly popular as they can be easily dissolved and provide a controlled release of nutrients (Van Woerkom et al. 2014).

Trunk Injection Research in Date Palms

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Trunk injection has been studied widely in the context of date palm nutrition for promoting vegetative growth and fruit yield (Table 1). From all the applications of trunk injection in date palms, it appears that the earliest reported was by Abo-Rady et al. (1987), who injected iron sulfate ($FeSO_4$) in date palm trunks to improve growth and yield. Results revealed that iron injection could increase leaf nutrients and fruit production.

Recent research has focused on potassium and nano-fertilizers, too. For example, soil application and foliar spraying of potassium sulfate (K_2SO_4) were found to be inferior in terms of fruit weight and total yield as compared to the trunk injection method. Likewise, trunk injection of nano-fertilizers enhanced both chlorophyll content and fruit ripening rates (Jubeir and Ahmed, 2019a,b). One research indicated that zinc and nitrogen injections promote date palms' fruit set, yield, and quality. These nutrients were absorbed by the tree much better when applied through injection instead of the conventional method (Hesami et al., 2017). The effects of trunk injection in various date palm cultivars and for various nutrients/compounds on growth, fruit weight, and yield are summarised using data from some of the studies discussed in the review (Table 1).

Comparison of Foliar Fertilization, Soil Fertilizer and Tree Trunk Injection in Date Palms

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Nutrient management in date palms is of such importance that each farmer can cultivate the best crop with ample yield and desired quality. Foliar fertilization, soil fertilization, and trunk injection are the various methods of fertilization involved. All three methods differ in mechanisms, advantages, and disadvantages of providing nutrition to date palms, which are intrinsic to arid nature and deep rooting systems (Saleh et al., 2016; Shareef et al., 2021b) see Table 2.

Table (1). Effect of trunk injection on date palm Growth and Yield

Nutrient	Concentrations	Time of Application	Cultivars	Effect on Growth and Yield	References
$FeSO_4$	25, 50 and 100 g palm^{-1} (pH 3.5)	1st March	Khlas and Ruzaiz	Increased all growth characteristics, nutrients, fruit weight, yield	Abo- Rady et al. (1987)
			Piarom	Increased all the characteristics of growth, nutrients, weight of fruits, yield	Saleh (2008)
				Strengthened all the characteristics of growth, nutrients, weight of fruits, yield	Saleh et al. (2016)
			Sayer	Increased all the characteristics of growth, nutrients, weight of fruits, yield	Mohibi et al. (2010)
	25 ml	1st March	Khadrawi	Increase N-P-K-Fe-Zn as well as the chlorophyll content of the leaves and increase the yield	Abdul Wahid et al. (2012)
Potassium sulfate	2 %	1st March	Jabjab	Increased all the characteristics of growth, nutrients, weight of fruits, yield	Abdi and Hedayat (2010)
	1, 2 and 3%	1st March, April and May	Barhee	Increase the weight of fruits, the percentage of fruits, the percentage of fruit ripening, and the total yield of fruits.	Elsayd et al. (2018)
Amino Iron	20 ml	1st March	Khadrawi	Increase N-P-K-Fe-Zn as well as the chlorophyll content of the leaves and increase the yield	Abdul Wahid et al. (2012)
Aqueous zinc sulfate ($ZnSO_4.7H_2O$)	1.15 and 2.30 g l^{-1}	15th March and 15th May	Jabjab	Increase the percentage of nodes, yield, fruit quality, and zinc concentration in the leaves	Hesami et al. (2017)
Marine algae extract	10 ml l^{-1}	28th March, 12th May, and 12th July	Zahdi	Increased fruit weight, taste, and total yield	Hashim and Al-salihi (2019)
Licorice extract	20 ml l^{-1}			Increased fruit weight, taste, and total yield	Hashim and Al-salihi (2019)
Clove extract	10ml l^{-1}			Increased fruit weight, taste, and total yield	Hashim and Al-salihi (2019))
Saad tuber extract	10ml l^{-1}			Increased fruit weight, taste, and total yield	Hashim and Al-salihi (2019)
Sea algae nanoscale extract (Super Fifty)	0.5 and 1 ml l^{-1}	1st March	Khastawy	Increased fruit weight, taste, and total yield	Jubeir and Ahmed (2019a)
solution Optimus-Plus	0.5 and 1 ml l^{-1}			Increased fruit weight, taste, and total yield	Jubeir and Ahmed (2019)
NPK Nanofertilizer	1, 2, and 4 g l^{-1}			Increased fruit weight, taste, and total yield	Jubeir and Ahmed (2019)

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Table 2. Comparison of Foliar Fertilization, Soil Fertilizer, and Tree Trunk Injection in Date Palms

Fertilization Method	Mechanism	Benefits	Limitations	Best Use
Foliar Fertilization	Direct leaf absorption	Fast response, ideal for micronutrient deficiency correction, reduced nutrient loss	Limited to small nutrient quantities, risk of phytotoxicity	Quick correction of micronutrient deficiencies
Soil Fertilization	Root absorption via soil	Suitable for macronutrient supply, improves soil structure, and is cost-effective	Limited effectiveness in high-pH or saline soils, leaching risk	Primary nutrient supply, especially for macronutrients
Trunk Injection	Direct vascular system delivery	Targeted, rapid response, reduced environmental impact	Invasive, labor-intensive, not suitable for macronutrients	Specific nutrient deficiencies, especially in challenging soil conditions

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Methodologies for Conducting Trunk Injection

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For practical application, current research practices can be relied upon on how to perform trunk injections step by step and effectively based on best practices, see Figures 1 and 2:

1. Injection Site Preparation:

•Select a site on the trunk approximately 1.5 meters above the ground.

•Drill a hole at a 45-degree angle with a 10–15 cm depth.

2. Injection Setup:

•Use a syringe connected to a plastic or rubber tube leading to a container with the nutrient solution.

•Ensure that the solution is prepared and diluted as needed (for example, $FeSO_4$ at 25 g l^{-1}).

3. Injection Process:

• Slowly release the solution into the tree, ensuring it absorbs fully before sealing the injection site with cotton or wax to prevent infection (Archer et al. 2024).

4. Post-Injection Monitoring:

• Observe the response of the tree (i.e., leaf ~~colour~~color, fruit size, and general growth) to adjust nutrients and repeat injections as required depending on the stage in the tree or seasonal development.

~~**Figure (1)**~~ **Fig. 1.** Method of injecting palm trunk using feeder and injection tube (Abdul Wahid et al. (2012))

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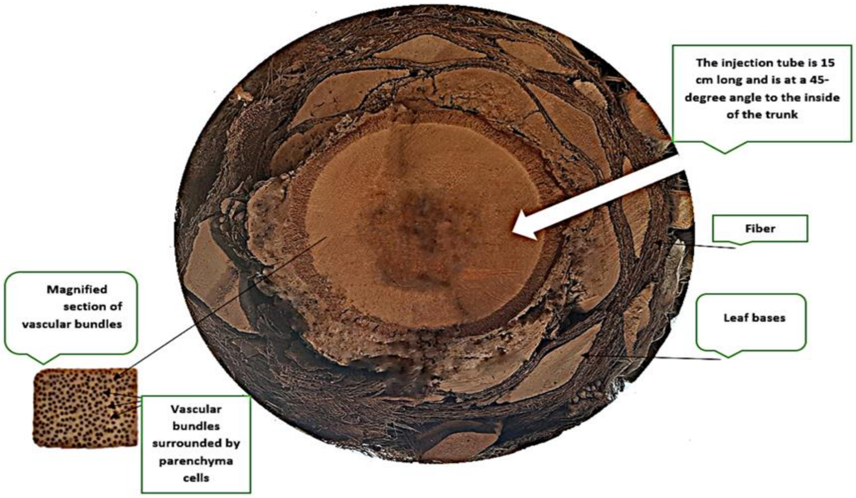

~~Figure (2)~~ Fig. 2. cross-section of the trunk of the palm showing the bases of the leaves, the fiber wrapped around the trunk, and the spread of vascular bundles in the parenchyma cells along the trunk

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Challenges and Considerations in Trunk Injection

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Trunk injection has many benefits but not without challenges:

• Injection infection risk: If pathogens enter the tree during injection due to poor technique, infections can occur at the injection site.

• Labor and Equipment: Timely implementation of trunk injection does entail the use of equipment, which requires a significant workforce to support large-scale operations.

• Novice Users: The lack of training and experience for novice users could put tree health at risk.

• Harvest Effects: Long-term growth effects on trees that had multiple harvests showing the effectiveness of active control methods at the trunk level (Archer et al. 2021).

Future Prospects and Research Directions

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Trunk injection is in the best possible position – while the future lies with new, viable technologies such as automated micronutrient delivery systems. This progress is due in large part to these developments, as advances in nanotechnology now offer many exciting avenues toward delivering more efficient and environmentally friendly nutrient formulations. Further research could improve nutrient solubility, investigate the long-term physiological response to injection, even at high rates over the years, and extend the method to sustainable cultivation of the globally important date palm crop.

Conclusion

Trunk injection represents a significant leap forward in the field of palm fertilization. It provides a more precise method that improves nutrient availability and reduces negative environmental impacts. Here, we summarize the advantages of trunk injection over conventional methods and show that direct delivery of macro-and micronutrients has the potential to enhance vegetative growth and fruit production.

Despite its advantages, challenges remain in the form of infection risks, labor intensity, and specialized equipment. Future work should focus on improving injection methods, developing new nutrient formulations—including nanoparticle-based fertilizers—and assessing long-term effects on tree health. Unfortunately, conventional trunk injection can be ineffective in certain applications and often requires additional investment by farmers. The future of integrating trunk injection and precision agriculture techniques is, therefore, very promising for both soil health and science. Trunk injection could be the key to sustainable palm cultivation, and future on-site research will play a key role in improving it.

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