

Date Palm Nutrition using Trunk Injection: A Comprehensive Review

ABSTRACT

Date palm is an important agricultural crop in arid 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 injecting nutrients into the vascular system of date palms, which improves nutrient uptake and reduces environmental pollution. The review highlights the historical progression, approaches, and technological innovations of trunk injection while demonstrating its merits to traditional 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 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 and Al-Khayri, 2021). Growing date palms in large areas of vast sandy deserts 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, which makes it inefficient to uptake all the nutrients that are applied (Shareef and 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.

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

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

42

43 **Historical Development and Methodology**

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

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

55 One of the earliest recorded studies that explored the application of trunk injection for fertilization purposes
56 in date palms was by Abo-Rady *et al.* (1987), which utilized iron application, including FeEDDHA and
57 FeSO₄ · 7H₂O will promote the growth of the date palm Khlas and Ruzaiz cultivars. This study
58 demonstrated that trunk injection could effectively boost the uptake of essential nutrients and improve
59 growth. Similarly, Saleh *et al.* (2016) compared trunk injection versus conventional fertilization methods
60 and showed that trunk injection increased iron bioavailability to a larger extent than fertigation in
61 calcareous soils where iron availability is generally limited.

62 **Technological Developments in Trunk Injection**

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

72 **Trunk Injection as a Fertilization Method**

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

78 **Advantages of trunk injection**

- 79 • Enhanced Purposeful Nutrient Timing: Through direct introduction into the tree vascular system, nutrients
80 stay there for a long time and can be utilized much more efficiently.
- 81 • Environmental Benefits: As nutrients are retained within the tree's ecosystem, there is less possibility of
82 leaching or runoff leading to soil and water contamination.
- 83 • Decrement in Fertilizer Use: Fertilizer use represents a lower consumption than soil application, has less
84 environmental impact, and constitutes savings (Alayón Luaces *et al.* 2019).

85 **Methods of Injection**

86 Passive system: A nutrient solution found in a passive container (unpressurized) located above the injection
87 point, which allows for nutrients to be absorbed by the trees through its natural transpiration pull (Schreiber
88 1969).

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

93 **Mechanism of Trunk Injection in Date Palms**

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

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

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

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

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

118 **Factors Affecting Trunk Injection Efficiency**

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

- 120 • Environmental Factors: Transpiration increases with high ambient temperatures, low humidity, and sunny
 121 weather, leading to better uptake and distribution of the injected solution through the tree (Acimovic 2014).
 122 On the other hand, rain or cloudy days will slow it down, which could decrease absorption efficiency.
 123 Increased soil moisture improves tree health, which promotes faster nutrient movement within the sap of
 124 tree trunks by trunk injection (SaÂchez Zamora and FernaÂndez Escobar 2000). So, low wind speeds are
 125 more favorable for efficient nutrient uptake from injection. Transpiration is decreased under high wind
 126 speeds (Acimovic 2014).
- 127 • Size and Health of Tree: Larger, healthier trees (those with active transpiration) will take up injected
 128 solutions more freely than smaller or stressed trees. Moreover, this is also influenced by the amount of
 129 injections and diameter of injection holes (Nyland and Moller 1973).
- 130 • Nutraceuticals Preparation: The solubility of the nutrients is essential. ISL Solutions (intravenously
 131 delivered) must be maximally soluble for proper distribution in the vascular system. Fertilizers supported
 132 with nanoparticles are also becoming increasingly popular as they can be easily dissolved and provide a
 133 controlled release of nutrients *et al.* 2014).

134 **Trunk Injection Research in Date Palms**

135 Trunk injection has been studied widely in the context of date palm nutrition for promoting vegetative
 136 growth and fruit yield (Table 1). From all the applications of trunk injection in date palms, it appears that
 137 the earliest reported was by Abo-Rady *et al.* (1987), who injected iron sulfate (FeSO₄) in date palm trunks
 138 to improve growth and yield. Results revealed that iron injection could increase leaf nutrients and fruit
 139 production.

140 Recent research has focused on potassium and nano-fertilizers, too. For example, soil application and foliar
 141 spraying of potassium sulfate (K₂SO₄) were found to be inferior in terms of fruit weight and total yield as
 142 compared to the trunk injection method. Likewise, trunk injection of nano-fertilizers enhanced both
 143 chlorophyll content and fruit ripening rates (Jubeir and Ahmed, 2019a,b). One research indicated that zinc
 144 and nitrogen injections promote date palms' fruit set, yield, and quality. These nutrients were absorbed by
 145 the tree much better when applied through injection instead of the conventional method (Hesami *et al.*,
 146 2017). The effects of trunk injection in various date palm cultivars and for various nutrients/compounds on
 147 growth, fruit weight, and yield are summarised using data from some of the studies discussed in the review
 148 (Table 1).

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

151 Nutrient management in date palms is of such importance that each farmer can cultivate the best crop with
 152 ample yield and desired quality. Foliar fertilization, soil fertilization, and trunk injection are the various
 153 methods of fertilization involved. All three methods differ in mechanisms, advantages, and disadvantages
 154 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.

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157 **Table 1. Effect of trunk injection on date palm Growth and Yield**

Nutrient	Concentrations	Time of Application	Cultivars	Effect on Growth and Yield	References
	25, 50 and 100 g palm ⁻¹ (pH 3.5)	1 st March	Khlas and Ruzaiz	Increased all growth characteristics, nutrients, fruit weight, yield	Abo-Rady <i>et al.</i> (1987)
				Increased all the characteristics of	Saleh (2008)

FeSO ₄			Piarom	growth, nutrients, weight of fruits, yield	
				Strengthened all the characteristics of growth, nutrients, weight of fruits, yield	Saleh <i>et al.</i> (2016)
			Sayer	Increased all the characteristics of growth, nutrients, weight of fruits, yield	Mohibi <i>et al.</i> (2010)
	25 ml	1 st March	Khadrawi	Increase N-P-K-Fe-Zn as well as the chlorophyll content of the leaves and increase the yield	Abdul Wahid <i>et al.</i> (2012)
Potassium sulfate	2 %	1 st March	Jabjab	Increased all the characteristics of growth, nutrients, weight of fruits, yield	Abdi and Hedayat (2010)
	1, 2 and 3%	1 st 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 <i>et al.</i> (2018)
Amino Iron	20 ml	1 st March	Khadrawi	Increase N-P-K-Fe-Zn as well as the chlorophyll content of the leaves and increase the yield	Abdul Wahid <i>et al.</i> (2012)
Aqueous zinc sulfate (ZnSO ₄ .7H ₂ O)	1.15 and 2.30 g l ⁻¹	15 th March and 15 th May	Jabjab	Increase the percentage of nodes, yield, fruit quality, and zinc concentration in the leaves	Hesami <i>et al.</i> (2017)
Marine algae extract	10 ml l ⁻¹	28 th March, 12 th May, and 12 th July		Increased fruit weight, taste, and total yield	Hashim and Al-salihi (2019)
Licorice extract	20 ml l ⁻¹		Zahdi	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			Increased fruit weight, taste, and total yield	Jubeir and Ahmed (2019a)
solution Optimus-Plus	0.5 and 1 ml l ⁻¹	1 st March	Khastawy	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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164 **Methodologies for Conducting Trunk Injection**

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

167 **1. Injection Site Preparation:**

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

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

170 **2. Injection Setup:**

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

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

173 **3. Injection Process:**

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

176 **4. Post-Injection Monitoring:**

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

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

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

188 **Challenges and Considerations in Trunk Injection**

- 189 Trunk injection has many benefits but not without challenges:
- 190 • Injection infection risk: If pathogens enter the tree during injection due to poor technique, infections can
191 occur at the injection site.
 - 192 • Labor and Equipment: Timely implementation of trunk injection does entail the use of equipment, which
193 requires a significant workforce to support large-scale operations.
 - 194 • Novice Users: The lack of training and experience for novice users could put tree health at risk.
 - 195 • Harvest Effects: Long-term growth effects on trees that had multiple harvests showing the effectiveness of
196 active control methods at the trunk level (Archer *et al.* 2021).

197 **Future Prospects and Research Directions**

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

204 **CONCLUSION**

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

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

216 **DISCLAIMER (ARTIFICIAL INTELLIGENCE)**

217 Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT,
218 COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this
219 manuscript.

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UNDER PEER REVIEW