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The Use of Dwarf Tropical Fruit Trees as a Management Strategy

At a Glance: Farmers have long used dwarfing to limit the height and canopy volume of tree crops. This publication highlights some crop production advantages of dwarf tree crops, defines dwarfing, describes two types of dwarfing in tree crops, and gives examples of dwarf varieties of tropical fruit trees.

How Dwarf Trees Improve Crop Management

As the name suggests, dwarf trees are shorter and occupy less volume than standard trees of the same species. The dwarfing of tropical orchard tree crops (Figure 1) has several crop management advantages that lead to reduced production costs. These advantages include that orchards can be planted at higher densities to increase fruit yield per unit area (harvest index), and tree canopy management such as pruning, spraying, fruit bagging, and harvesting is easier and more efficient (Table 1). Compared to harvesting from standard-sized trees while standing on a ladder, for example, harvesting from dwarf trees while standing on the ground saves considerable time, which can be the difference between turning a profit versus simply breaking even.

An alternative to the use of dwarf trees is canopy pruning to control the height and growth. Some tropical fruit trees are easily managed by mechanical pruning. For example, the jackfruit varieties 'Black Gold', 'Cochin', and 'J-31' can be maintained as small trees around 8 feet (2.4 m). However, mechanical pruning is labor intensive, can create soil compaction issues related to heavy machinery use, and may not be easily applied to some tropical fruit tree crops.

Dwarfing Defined

Dwarf trees can be defined by the extent to which the volume of the tree canopy is reduced. For citrus trees, in which dwarfing has been a focus of much research, Bitters et al. (1979) defined a dwarf rootstock as one that reduced tree volume by at least 75% and limited adult citrus tree height to 8 to 10 feet (2.5 to 3 m). Others have mentioned a mature citrus tree height and width of 6.5 to 10 feet (2 to 3 m) with, more importantly, an abundance of full-sized fruit.

Figure 1. Tree canopy management by pruning and the use of dwarf rootstocks can greatly improve the economics of tree fruit production, as seen here for mango (top panel) and citrus (bottom panel). Photos: Robert Paull

March 2025
Subject Category: Fruit, Nut, and Beverage Crops, F_N-70s

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This information has been reviewed by CTAHR faculty

Table 1. Comparative advantages of maintaining short tropical fruit trees through pruning and management of tree canopy and roots (traditional wide spacing) versus the use of dwarf mutants or dwarf rootstocks (high-density planting).

	Traditional Wide Spacing of Standard Trees	High-Density Planting of Dwarf Trees
Plant density	70–250 trees per hectare; 28–101 trees per acre	250–2,000 trees per hectare; 101–800 trees per acre
Establishment cost	Lower	Higher, especially if trellises are installed
Time to first fruiting	3–5 years	Sometimes from first year
Fruit yield per tree	High	Low
Fruit yield per unit area	Low	High
Tree management	More difficult to prune, spray, and thin fruit; more difficult to bag fruit	Easier
Labor requirement	More labor and/or mechanization required	Less labor required, more amendable to mechanization
Fruit harvest	More difficult and slower; often requires poles, ladders, and mechanical picker platforms	Easier and faster; cultural practices can be done from the ground, with less risk of worker injury
Fruit quality	Poorer sunlight and air penetration into the canopy; inability to thin fruit easily often leads to lower quality	Better sunlight and air penetration into the canopy; reduced diseases and higher fruit quality are possible with fruit bagging

Dwarf trees tend to have shorter juvenile periods and therefore flower sooner. However, this definition of dwarfism is not easily applied to single- stem species such as papaya. Small, so-called dwarf papaya plants have been described, especially in the 'Solo' group, according to when the first flowers appear. The first flowers can occur in papaya after 15 leaf nodes and up to 50 or 60 nodes, with approximately 2.1 nodes produced per week in Hawaiʻi. Once flowering has begun, the plant continues to flower, unlike branched perennial trees that cycle between root and vegetative growth phases and flowering and fruiting phases. This suggests that, in papaya, a shorter period of juvenility (vegetative growth phase) before subsequent continuous flowering is the cause of this dwarfing, with fruit occurring closer to the ground. Additionally, growing conditions can significantly affect papaya growth. The Hawaiʻi variety 'Kapoho' has a short internode when grown in well-drained lava-derived soil in Puna, Hawaiʻi, with long internodes occurring when grown in acidic basaltic soils.

Figure 2. This historical Japanese woodcut illustrates the use of grafting to create dwarf trees. (Akiyama et al. 1979)

Introduction to Dwarfing of Fruit Tree Crops

Tropical tree crops can be dwarfed in two ways: (1) by cultivating natural dwarfs or (2) by grafting using dwarf rootstocks (Figure 2 and Table 2). Both are very ancient practices (Mudge et al. 2009). Alexander the Great in 400 BCE identified dwarf apple rootstocks and sent them back to Macedonia from Persia, and in the 17th and 18th centuries the Malling M9 dwarf apple rootstock was developed, which led to a further series of dwarf apple rootstocks. In the mid-1500s, a Japanese agriculture guidebook showed the use of multiple grafts on a tree to effectively cause dwarfing.

In 1870, cuttings that would give rise to the Washington navel orange were delivered from Brazil to the U.S. Department of Agriculture in Washington, D.C. Samples were subsequently sent to California and Florida (Shamel 1915). Originally called 'Bahia'

Table 2. Examples of naturally occurring dwarf tropical fruit crops and dwarf crops induced by grafting. Natural dwarfs tend to be less tall, with shorter juvenile periods.

Natural Dwarfs	Rootstock-Scion Dwarfs
Ambarella or Wi Apple (*Spondias dulcis*)	Annona (soursop)
Avocado ('Holiday')	Breadfruit
Banana	Caimito or Star Apple (*Chrysophyllum caimito*)
Cashew	Guava
Coconut	Citrus ('Flying Dragon', 'Carrizo')
Guava	Loquat
Lychee or Lichi	Mango
Mango ('Julie', 'Ewis')	Sapodilla (*Manilkara zapota*)
	Yellow Mombin (*Spondias mombin*)

after the Brazilian city where this mutant was discovered, the new orange was renamed Washington by settlers in Riverside, California, reflecting the tree's introduction via USDA and the U.S. capital. The term navel refers to a small aborted fruit that develops opposite the stem (an extranumerary fruit), which looks like a human navel. Grafting the new orange onto a dwarf citrus root stock resulted in the dwarf Washington navel orange tree, which are 5 to 6.5 feet (1.5 to 2 meters) tall instead of 40 to 50 feet (12 to 15 m). 'Flying Dragon' and other trifoliates currently used as dwarfing citrus rootstock are discussed below.

The grafting of scions onto rootstocks was initiated to achieve trueness-to-type from seeds, as often, tree crops were outcrossed and seeds did not provide progeny with the same characteristics as the desirable parent plant. Additionally, it is difficult in many cases to root the scions or cuttings. It became apparent that the grafting of a scion, sometimes with an interstock, onto a rootstock, had other advantages. The beneficial characteristics associated with grafting onto rootstock include an increase in harvest index or yield (fruit yield per tree), earlier fruiting (shorter juvenile period), increased fruit size and quality, tolerance to climactic stresses (drought, heat, cold, salinity), resistance to pests and diseases, improved uptake of water and nutrients, and control of growth (dwarfing). In many cases, the rootstock is a different species from the same genus (Table 3). However, dwarf trees have a smaller root system, which makes the trees less drought-tolerant and less well-anchored, so that they can be blown over with strong winds and rain.

Dwarf fruit trees have been used in a multistory agroforestry cropping system (Sharma et al. 2020). In eastern India, dwarf guava is used as a second understory tree in older mango and amla (*Phyllanthus emblica*, also called aonla or Indian gooseberry) orchards or with other trees with spreading canopies. In these cropping systems, mango and amla are the main crops, guava is a filler or secondary crop, and different sets of short-cycle intercrops can be included as needed. Although this intensive cultivation presents management challenges (e.g., differences in disease and pest control, irrigation, and fertilization needs and timing), it can also generate additional income in the initial years of orchard establishment before fruiting. In these systems, the short-cycle crop grown as a cash crop would be legumes.

Another approach to cause tropical fruit tree dwarfing is genetic engineering. However, progress on genetic manipulation of tree size has been limited. The difficulties faced are large tree sizes, long juvenile periods (5 to 15 years), and the lack of genetic information on the genes that control tree size. The application of quantitative trait locus (QTL) analysis to aid in tree size breeding is limited by the absence of natural dwarfs in those species without dwarfs. The lack of knowledge about genes associated with tree size is critical for both conventional breeding and genetic engineering. The size of trees and fruit is probably controlled by many interacting genes, and the molecular

Table 3. Dwarf rootstocks and commonly used scions.

Rootstock	Scion
Quince (*Cydonia oblonga*)	Loquat
Ambarella or Wi Apple (*Spondias dulcis*)	Red and Yellow Mombin
Mango ('Julie')	Mango
Maprang (*Bouea macrophylla*)	Mango (in test)
Cashew	Mango

mechanisms are not fully understood. In some trees, such as banana, lychee, mango, and breadfruit, the modification of genes associated with the gibberellin plant growth regulator is involved in tree growth, but this finding may not apply to other tree species.

In addition to grafting, another approach to achieve canopy management and tree shape is physical manipulation of the root-to-shoot ratio, normally by restricting root growth or pruning roots. Root restriction and severe pruning are used to manage the growth of the lychee canopy. The 'Irwin' mango is grafted onto the 'Formosa', and canopy growth is limited by restricting root development in the planting hole and with early pruning of the terminals immediately after harvest, to allow the production of only two vegetative flushes before flower differentiation. The relatively weak self-incompatibility of 'Irwin' allows good yields. The carambola is easily adapted to different pruning and training methods.

Chemical control of shoot and root growth is possible, but it is difficult to obtain registration in the United States for minor tropical fruit tree crops. Plant growth regulators used in other countries include daminozide (Alar®), paclobutrazol (Cultar®) and chlormequat (Cyclocel® or CCC).

Natural Dwarfism

Ambarella or Wi Apple: A dwarf ambarella (*Spondias dulcis*) has been reported (Yalia 2012; Candido et al. 2024). The normal tree height varies from 19 to 80 feet (9 to 25 m), and the dwarf from 5 to 10 feet (1.5 to 3 m).

Banana: Several dwarf banana (*Musa* spp.) types have been recognized (Cheeseman 1933), including within the Cavendish and Prata groups. Natural dwarf mutants and somaclonal variations from *in vitro* culture are observed (Smith et al. 1990; Creste et al. 2003).

Cashew: The dwarf cashew (*Anacardium occidentale* L. var. *nanum*) has been widely reported. The main early cashews are the clones of CCP06 (yellow peduncle), CC09 (yellow), CCP76 (red), CCP1001 (red), Embrapa 50 (yellow), Embrapa 51 (red), BRS 189 (red), BRS 226 (orange), BRS 253 (red) and BRS 265 (red) (Donadio et al. 2019).

Citrus: Numerous citrus dwarfs (*Citrus* spp.) are available. Examples include lemons 'Improved Meyer' and 'Dwarf Lisbon'; lime 'Dwarf Bearss Seedless'; oranges 'Dwarf Campbell Valencia' and 'Dwarf Washington Navel'; mandarin oranges 'Clementine', 'Satsuma', and 'Dwarf Tango'; blood oranges 'Moro' (semi-dwarf) and 'Smith Red'; grapefruit 'Dwarf Redblush', and kumquat 'Nagami' (Hayat et al. 2022).

Coconut: Giant and dwarf coconuts were recognized early. The giant normally produces coconuts for copra (that is, the dried, white flesh), and production begins after about 6.5 years from planting. The yield of the giant is about 70 fruit per tree per year. There are some lines that are mutants that do not form copra but remain jellylike inside. *Cocos nucifera* L. var. *nana* Griff. (versus *typica*) is known as dwarf, is self-pollinating, and reaches a height of 35 feet (10.7 m) with smaller fruit and about 120 fruit per tree per year. However, dwarfs are susceptible to pests and diseases and do not tolerate drought. Dwarf coconuts also vary widely in color. Some hybrids have been developed.

Guava: A dwarf guava (*Psidium guajava* 'Nana') is commercially available, along with a seedless version.

Lychee or Litchi: The lychee (*Litchi chinensis*) varieties 'Ziniangxi' and 'Ya1' are reported to be dwarf (Zhang et al. 2011). Dwarfing has been associated with gibberellin effects on vegetative growth (Hu et al. 2018).

Rootstock-Scion Dwarfism in Fruit Trees

Breadfruit: Breadfruit (*Artocarpus altilis*) scions grafted onto marang (*A. odoratissimus*) rootstocks are identified as dwarfs (Zhou et al. 2014; Zhou and Underhill 2019; Zhou and Underhill 2020).

Caimito or Star Apple: Caimito (*Chrysophyllum caimito*) when grafted onto a satin leaf (C. oliviforme) is reported to be a slow-growing dwarf tree (Crane and Balerdi 2009).

Citrus: Dwarf citrus trees have been sought by citrus growers in different parts of the world for many years (Hayat et al. 2022). 'Flying Dragon' (FD) trifoliate orange (*Poncirus trifoliata* Raft var. *monstrosa*) rootstock induces small trees that do not grow taller than 8 feet (2.5 m) and have early production (Mademba-Sy et al. 2012). FD reduces tree growth by 75% compared to standard trifoliate orange rootstocks (Bitters et al. 1979), of which 'Carrizo' rootstock is the most commonly used. FD is also tolerant to citrus tristeza virus and has resistance to *Phytophthora* spp. and citrus nematodes. This rootstock tolerates cultivation in heavy soils. Selection of scions is critical when FD is used as a rootstock. The 'Xiangcheng Orange', 'Citrange' and 'Red Tangerine' rootstocks are commonly used in China and are considered semi-dwarf and dwarf rootstocks (Hayat et al. 2022). The rootstocks of rough lemon and Volkamer lemon (sometimes called kalpi in Hawai'i) give trees high vigor; these rootstocks are not dwarfing, but the resulting trees can be easily managed with proactive pruning.

Guava: Costa Rican guava (*Psidium friedrichsthalianum*), when used as a rootstock, has a significant dwarfing effect on guava (*P. guajava*). Other dwarfing rootstocks include *P. pumilum*, *P. chinesis*, 'Pusa Srijan', and Aneuploid-82.

Loquat: The size of 'Magdal' loquat (*Eriobotrya japonica*) when grafted on the 'Quince C' quince (*Cydonia oblonga*) in Spain, is significantly reduced, reaching a maximum height of 6 feet (1.87 m). The grafted tree has early production and higher yields under protected cultivation (Hueso et al. 2007).

Mango: The dwarf rootstocks of mango (*Mangifera indica*) include the Indian mangoes 'Mallika' and 'Amrapali'. The latter, a monoembryonic type, reduces the size of the mango tree independent of the canopy cultivar (Pinto et al. 2011). Other rootstocks that impart dwarfing include 'Arauca', 'Latra', 'Mylepelian', 'Vellaicolomban, and 'Brodie' (Dhurve et al. 2023).

Sapodilla: Sapodilla (*Manilkara zapota*) is often used as a rootstock to propagate selected trees with better fruit quality and tree characteristics. Other species, such as *M. emarginata* and *M. hexandra*, have been recommended as possible dwarf rootstocks for the sapodilla, and *Bassia latifolia*, *B. longfolia*, *Sideroxylon dulcificum*, and *Mimusops hexandra* have also been used successfully. *M. kauki* and *M. latifolia* in India and *B. longfolia* in Sri Lanka are used as rootstocks (Lederman et al. 2001).

Soursop (Annona): When soursop (*Annona muricata*) is grafted onto biribá (*Rollinia mucosa*), the vigor of the scion is reduced. Pond apple (*A. glabra*) is another dwarf rootstock that results in small trees and is resistant to wet soil conditions and root rot. *Rollina emarginata* (arachichu) also induces canopy dwarfism of the soursop with some tolerance to root rot and good tolerance to stem borer. This rootstock has good compatibility with scions of atemoya (*A. cherimola* Mill × *A. squamosa* L.) and cherimoya (*A. cherimola* Mill) (Scalopi Junior 2013). The *Rollinia* genus has been merged back into the *Annona* genus, retaining the specific species name (Leal and Paull 2023).

Table 4. Commonly researched mechanisms by which rootstock could control scion growth to cause dwarfism in tree crops.

Possible Causes of Rootstock-Induced Dwarfism
Semi-incompatibility or partial incompatibility between the scion and rootstock
Water stress in the scion due to restricted water flow from the rootstock
Nutritional deficiencies due to rootstock
Hormonal/signaling changes due to altered coordination of root and shoot growth
Changes in carbohydrate reserves or mobilization capacity from the rootstock
Competition between root and shoot for available growth resources

Causes of Dwarfism in Fruit Trees

There is a large body of research on the causes of dwarfing associated with the use of different rootstocks. This contrasts with the knowledge of natural mutants, which frequently involves changes in genes that impact the activities and interactions of plant growth regulators such as gibberellin, auxin, and cytokinin.

Some of the possible causes of rootstock-induced dwarfism (Table 4) involve anatomical, physiological, and biochemical changes related to the the reestablishment of the water and sugar transport systems at the rootstock graft site (Basile and DeJong 2018). It is possible that different dwarfing mechanisms or combinations of mechanisms are involved for different crops and different rootstock-scion combinations.

Acknowledgements

The authors thank Amjad A. Amhad and Andrea Kawabata for their helpful feedback.

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