THE HISTORY AND APPLICATION OF THE HIGH-DENSITY ORCHARD SYSTEM

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Ann Noble
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THE HISTORY AND APPLICATION OF THE HIGH-DENSITY ORCHARD SYSTEM

A Project

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ABSTRACT

THE HISTORY AND APPLICATION OF THE HIGH-DENSITY ORCHARD SYSTEM

by

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Fruit production technology has taken an innovative turn in the last few years resulting in orchards that would be unrecognizable to farmers of previous generations. Rather than having tall trees in rows, modern orchards utilize new planting methods that more closely resemble hedges than individual trees. The new orchards utilize high densities of small stature trees to create what is known as a pedestrian orchard.

The high-density orchard concept has been effectively applied to the production of olives and apples. In both crops, costly inputs are reduced, and crop efficiency is maximized, resulting in higher profit margins for farmers. In olives in particular, the cost of production was causing very low profitability among traditional farmers. The greater efficiency of the hedgerow style orchards caused an upsurge in the production of olive oil in California, effectively creating a new industry (Lazicki, 2016).
Technological advances allow for this concept to be applied to specialty fruit and nut production as well. This project explores the opportunities in other crops, as well as outlining the advantages to this type of production over traditional orchard production including drastically reduced labor costs, and a higher crop efficiency. This concept is also applicable to a backyard setting to allow for fruit and nut production in confined space.
CHAPTER 1
INTRODUCTION

Orchards are a type of farm that are comprised of a deliberate planting of fruit or nut trees (Dolan, 2009). Most fruits and nuts are produced in orchards. Usually, the orchards consist of full-sized trees planted in rows. According to the National Park Service, a simple orchard is a horticultural system consists largely of a small plantation of trees of one or numerous species. Commercial orchards are typically larger than five acres, while smaller orchards are classified as a family farms because five acres are generally able to be managed by an individual family (Dolan, 2009).

For many orchard crops, a new type of planting is emerging that involves planting small stature trees close together. The effect is more of a narrow “wall of fruit” rather than individual tall trees. These hedges are highly productive, yet more easily managed from the ground.

There are many advantages to this new type of planting. Traditional orchards are under a variety of pressures that will be explored in this project. In fresh fruit production in particular, labor costs have increased, and profit margins narrowed, causing growers to seek new and innovative growing methods (Hansen, 2007).

As a result of these economic pressures, the tall, shaded trees of a traditional orchard are giving way to compact trees that more closely resemble hedges. These new hedges require more investment in the early years, both in higher cost of establishment and in focused management (Ruis & Lacarte, 2010). However, there are multiple advantages to the new system including reduced cost of labor, and
early productivity of fruit. Both factors are important metrics in the success of a modern orchard (Herrick, 2014). High early yields and high-quality fruit result from properly managed, high-density orchard systems (Day, 2017).

The high-density system has the longest and most documented success in the production of apples and in olives for olive oil. Using these crops as a model, opportunities in other tree crops will be explored.

Success of the High-Density System in Olive Production

High-density (HD) orchards are commonly used to grow olives in California. The concept originated in Spain in the 1980s and quickly spread to the United States (U.S.) (Ruis & Lacarte, 2010). Compared with traditional systems (see Figure 1), the high-density orchards have many advantages, including early production and good yields. The most important advantage is the easy harvestability of the long hedges of olives with a mechanical with an over the row harvester (Ruis & Lacarte, 2010). The ability to harvest the crop with a machine is advantageous when it comes to production costs. Traditionally, olives have been harvested by hand from tall trees, which is very labor intensive and thus, expensive. The new hedges (see Figure 2) significantly lower costs of production (Ruis & Lacarte, 2010).
Success of the High-Density System in Apple Production

Apples have a longer history with the high-density system. In fact, the initial impetus of the high-density form for apple production originated in the gardens of Versailles in the 17th century (Dolan, 2009).

To develop the high-density system for apples, many factors were addressed. Specialty rootstocks were developed to keep the size of the trees small in order to develop hedges rather than individually spaced, tall trees (Robinson, 2008a). Training systems and pruning techniques were developed to allow for optimal fruit production within the framework of the small sized
trees (Robinson, 2008a). Many years of research have been dedicated to the development and optimization of this system.

Today, in Europe and in the Americas, apples are commonly grown in this manner. In the U.S., a large percentage of new apple orchards are being planted in this new style with many small trees per acre (Milkovich, 2015). The high-density orchard system works for very large-scale, efficient farms. It also lends itself to smaller, specialty farms that focus on local markets. This style orchard is also suitable for U-pick orchards, as customers can more easily reach fruit on the ten-foot-tall fruiting walls rather than 20-foot traditional trees (Milkovich, 2015). In fact, studies have shown that the high-density system has the best return on investment and is the most profitable over the life of the orchard (Robinson, 2008b).

The shape of the trees in a traditional orchard differs from trees in a high-density setting. Figure 3 shows an individual apple tree trained in the traditional style. The high-density orchard shown in Figure 4 illustrates the narrow hedges producing low, easily-reached fruit. A pedestrian orchard is defined as an orchard where two-thirds of the crop can be harvested from the ground without the use of tall ladders (Long, 2005). For the purposes of this project, the terms “pedestrian orchard” and “high-density orchard” will be interchangeable. There are many advantages to this new style of orchard.
Figure 3

*Traditional Apple Tree in Oregon*

Figure 4

*High-Density Pomegranates near Firebaugh, California*
Pedestrian orchards are comprised of smaller stature trees which are more early bearing or precocious than standard sized trees. Thus, an apple orchard that ordinarily would come into full production in the eighth growing season is fully productive in the fourth year (Ames, 2019). In cherries, full production is obtained in five or six years rather than twelve years in a conventional system (Long & Kaiser, 2010).

Early bearing orchards provide farmers faster returns on their investment, and is particularly beneficial for specialty fruit producers. New, novel varieties of fruit are worth a significantly higher price, so early production is paramount (Warner, 2007). Delivering new fruit varieties to the market as quickly as possible offers the farmer the highest possible price. Due to early production and higher returns, many high-density apple orchards break even in six to seven years compared to 10-12 years for traditional systems (Parker et al., 1998).

High-density olive orchards reach full production in the third or fourth year. In a traditionally spaced planting, full production is reached in seven years. “While it is true that super high density olive grove’s establishment costs are higher compared to other productive models, it is also true that the initial investment requires a very much shorter return period” (Ruis & Lacarte, 2010, p. 9).
Planting Trees in Hedgerows Benefits Labor Efficiencies

Labor is one of the limiting factors in modern agriculture, as there are fewer people available to do fieldwork for long hours and low wages (Taylor, 2019). Hedgerows are much shorter than full sized trees, allowing much of the work to be accomplished from the ground rather than from tall ladders. Workers can complete tasks more efficiently as they reach trees from the ground rather than spending time positioning ladders. Ladders in the orchard need to be moved frequently, and time is spent climbing up and down. According to Day, “When you’re climbing up and down a ladder you’re not pruning, picking, or thinning” (Herrick, 2015, p. 23).

Elimination of ladders allows workers to accomplish tasks more quickly. For example, fruit pickers in pedestrian orchards in Oregon were able to pick 171 pounds of cherries per hour, while only picking 100 pounds an hour in a conventional orchard (Long, 2005). Additionally, when given the choice, most workers preferred to work in a pedestrian orchard (Wheat, 2019). Given the labor shortages that occur in some years, worker preference is an important factor. Avocado growers in Chile found it easier to retain their workers with the shorter stature trees in an HD orchard. With tree heights of six to eight feet, the workers were able to fill bins more easily and make more money compared to a traditional orchard (Rolshausen et al., 2016).

The costs of labor can be prohibitively expensive in fruit orchards. For example, sweet cherry harvest costs generally account for 50% to 60% of total production costs (Seavert et al., 2011). In peaches, labor is the highest production cost as well. Again, ladders add significantly
to the costs of operations in the orchards. According to Day (2010), ladders increase costs by 25% to 45%.

In crops capable of mechanical harvest, the savings are even greater due to the decrease in workers needed. An example of this can be found in Oroville, California. A local farming group planted high density canning peach orchard in the fall of 2014 (Horton & Johnson, 2005). In 2017 and 2018, this orchard was harvested with an Oxbow 6240 harvester, which is the same harvester used for high-density olives. The mechanical harvest had many advantages over hand-harvesting, including the ability to start harvest at 4 a.m. when temperatures were lower. The quality of fresh fruit, particularly peaches, decreased as ambient temperatures climbed over 90 degrees (Horton & Johnson, 2005). The main advantage, though, was the decrease in labor costs. With one driver and four support workers, the peaches were harvested at the same rate handpicking in a typical traditional orchard using 30 workers (Taylor, 2012).

For these new, compact orchards, equipment has been specially developed to help with orchard tasks. Mechanical platforms are utilized to reach the tops of the trees for harvesting. Most orchard maintenance tasks such as pruning, thinning, and spraying have been mechanized. In all cases, most hand-labor has been eliminated or made easier with technology (Milkovich, 2015).
Safer than Conventional Orchards

The use of ladders causes dangerous conditions in the orchard. Ladder usage was studied in Washington, which has the highest apple production in the nation, along with pears, peaches, nectarines, apricots, and cherries. According to the USDA, in 2011, there were 233,176 acres of orchards. Orchard injuries in Washington account for 45% to 58% of worker’s compensation claims on Washington farms (Paradis, 2001).

Over a 6-year period from 1996 to 2001, ladders were the top cause of orchard injuries, costing the state $21.5 million dollars (Hoffman et al., 2006). Injuries occurred from unstable placement of the ladder, overextension of the third leg, slipping while descending, and being struck by a falling ladder (Murphy, 2007). The most common accidents are falls from the ladder, usually from the upper part. The orchard related injuries were fairly serious, resulting in an average of 150 days of missed work per incident (Pacific Northwest Agricultural Safety and Health Center, n.d.).

Related to safety is the cost of insurance for the farmers. For worker’s compensation insurance in Washington, a pedestrian orchard is placed in the same category as a vineyard, rather than an orchard, because of the difference in harvest techniques (WSLI, 2021). Farmers can save around 40% on their insurance costs when eliminating ladders in their operations (Eddy, 2014).
Higher Quality Fruit than from Conventional Orchards

Fruit from pedestrian orchards tends to have more uniformity than in conventional orchards (Sansavini et al., 1981). This is due to the more even light differential from the top to the bottom of the smaller trees. In a tall tree, light is plentiful at the top, but shading occurs in the lower branches that can cause smaller or less colorful fruit. Because the canopy is narrow for the “wall of fruit”, light is fairly even from top to bottom. As shown in Figure 5, quality fruit is produced throughout the tree canopy when grown in the high-density system. Fruit of greater size, with better color and higher sugar, result from the more optimal light conditions in the shorter trees (Sansavini et al., 1981).

Figure 5

Specialty Plums in Visalia, California
Description of the Project

Given the success of the high-density system in apples and olives, this project explores the application of the high-density system to other fruit and nut crops. It also outlines a step-by-step guide to creating a high-density orchard, whether at the commercial scale or as a backyard project. The desired effect is to introduce this new technology, both in history and theory, and to present a practical handbook in the hopes of it being applied to benefit commercial growers considering this system, or for backyard gardening enthusiasts.

The target audience for this handbook is commercial growers interested in trying a new system, either for higher quality fresh fruit, or reduction in labor costs. Homeowners interested in achieving an edible landscape, or simply wanting to enjoy producing fresh fruit in their backyard, may also be interested in the techniques outlined in this handbook. This project is meant as an overview of the pedestrian orchard system, and more crop specific information and site-specific information will likely be necessary to take full advantage of the system.
CHAPTER II

LITERATURE REVIEW

The key to the high-density system is the development of compact, easy-to-manage trees. To make compact trees, either a small-sized variety must be found or developed, or a variety can be grafted onto a dwarfing rootstock (O’Brien 2014). The rootstock imparts the small stature of the tree, while the variety allows for normal size fruit (Martin, 2008). The use of dwarfing rootstocks and dwarfing varieties makes the small-sized trees possible (Robinson 2008a).

Additionally, the trees are trained into a configuration that allows for optimal production while also facilitating efficient harvest of the crop. Training involves encouraging certain branches to form, while removing other branches (Parker, 2014). The goal is to achieve a certain shape to the trees and to the hedge (Vas den Ende, 2016). It is important to allow for adequate space for the fruit or nut to form, and to allow for sunlight to be evenly distributed for optimal development of the fruit or nut (Lampien et al, 2011). Adequate airflow within the hedges is necessary for sprays to penetrate within the canopy to prevent pests or pathogens (Parker, 2014).

This section explores the development of compact trees and of the various training systems that make high-density orchards possible.
Dwarfing apple trees have been around for hundreds of years. Alexander the Great brought a dwarfing apple variety named “Spring Apple” from Asia to Greece around 370 BC (Fallahi et al., 2002). This apple variety spread throughout Europe and was used as a dwarfing rootstock in the famous Gardens of Versailles in France during the reign of King Louis the 14th. Other dwarfing varieties were discovered as well. One of the dwarfing rootstocks was named “Paradise,” but before long, many dwarfing rootstocks were also called Paradise, and the growers were not certain what they would get when purchasing a “Paradise” rootstock (Fallahi et al., 2002).

**Dwarfing Rootstock Breeding**

In England, around the turn of the century, a breeding program in East Malling produced dwarfing rootstocks (Preston, 1955). This program focused on evaluating existing rootstocks and labeling them. “Paradise” rootstocks were gathered from across Europe, then propagated and evaluated in the field (Preston, 1955). Nine selections were subsequently released as Malling rootstocks. It was a very successful program and some of these selections, such as M9, are still used today. The Malling rootstocks slowly gained acceptance by the farmers, and by the 1940s, were in widespread use. The other positive characteristics of the Malling series were precocity, heavy yields, and ease of propagation (Preston, 1955). More rootstocks were released, for a total of 27.
At this time in England, wooly apple aphid was not a serious pest, so the tolerance to this pest was not considered (Preston, 1955). However, as soon as the rootstocks were exported to Australia and New Zealand, tolerance became a concern. The subsequent Malling Merton Breeding Program began in 1928. It featured the Northern Spy apple variety as a parent because of its known tolerance to the wooly aphid (Preston, 1955). The Malling Merton program used planned crosses. Fifteen rootstocks were released from this program, MM 101 through MM 115 (Preston, 1955).

Cold tolerant rootstocks were developed in Poland and the former Soviet Union. These are known as the Polish Series and the Budagovsky Series. Bud 9, Bud 10, and Bud 118 from the Budagovsky series are very cold tolerant varieties that are still in use today (Wesley et al., 2017). Poland 18 is also currently available.

In 1968, the Geneva apple rootstock program was initiated in New York (Norelli et al., 2003). Its original focus was disease resistance for fire-blight and Phytophthora, which is a soil-borne pathogen causing crown and root rot. The program is famous worldwide for productive, disease resistant varieties. It is a very rigorous program, and seedlings are initially subjected to many pathogens to find only resistant varieties (Norelli et al., 2003).

The Geneva program begins with planned crosses (O’Brien, 2014). Flowers on a promising female parent are hand-pollinated. Resulting seeds are planted in the greenhouse and inoculated with Phytophthora, a harmful pathogen that often causes death. Any survivors of the Phytophthora are subjected to fire blight (Erwinia amylovora). The very small percentage of seedlings that survive these treatments are analyzed for genetic markers for positive traits. Only then are they propagated and tested in the field at multiple locations.
It generally takes 20 to 30 years of evaluation before the elite selections are released as a variety (O’Brien, 2014). This is a very rigorous program resulting in high quality, disease-resistant material (Robinson et al., 2003).

The use of compact trees made possible by the dwarfing rootstocks changed the apple industry. This technology was also adopted in other parts of the world. In Europe, it was utilized in Holland, which then influenced other countries (De Meyer, 2014). An example of this is the South Tyrol region of Italy. The Italians of Tyrol observed the technology in Holland in the 1970s. It took nearly 20 years for adoption, but by 1990, 80% of the production area was planted to intensive orchards (De Meyer, 2014). Trees on dwarfing apple rootstocks account for roughly 98% of new plantings in the U.S., while the remaining are standard seedling rootstocks (Agricultural Sciences Education and Communication, 2004). Dwarfing can also improve fruit quality, diminish insecticide use, and reduce harvest-related injuries (O’Brien, 2014).

Tree Training Systems

Training trees in a certain configuration as they grow is another important consideration in the creation of an efficient high-density orchard. Training the trees involves selecting strong branches and encouraging them to grow in a certain way (Parker, 2014). Training systems for trees evolved through trial and error. Initially, researchers observed that the globular shape of traditional trees shaded too much of the fruit, so they proposed a pyramid-shaped tree to allow for increased light interception. In North America, Heinicke developed the central leader
system in 1975 utilizing this new tree shape (Ferree & Warrington, 2003). The lower branches are widest, with successive tiers being increasingly smaller, like a Christmas-tree shape. Wide gaps are left between the tiers of branches to allow light to penetrate through all the layers of the tree canopy. Heinicke increased the number of trees per acre but did not install supports or trellises for the trees (Ferree & Warrington, 2003). The Palmette-leader system was adapted by Lakso in 1989. In this system, the trees are trained in a flat fan-shape from in a north-south orientation (Ferree & Warrington, 2003). This system can be used to convert fully-grown semi-dwarf trees from a traditional planting (Lakso, 1989). Removing limbs over a 3-year period allows the new tree shape to be formed. Increased light throughout the canopy leads to increased fruit quality.

In Australia, the “tatura trellis” method was developed. This involved training the trees to a V-shaped trellis with the edges of the V extending over the orchard aisles (Feree & Warrington, 2003). Figure 6 shows a specialty apricot tree trained in a V-shape. The advantage to this system is that light shines on most parts of the tree through the V in the top, so production and fruit color is good. The main disadvantage is that most fruit occurs on the inside of the V, so pickers must reach through the canopy to pick the apples, which is inconvenient for workers, but also can injure the fruit as it is pulled through the branches. Also, in the V-shape, the tree sometimes grows more on one side than the other, which can cause a weakened trunk.
The slender-spindle system is the training form most used today. It was developed in Holland in the 1960s by Bob Wertheim (Ferree & Warrington, 2003). He planted high numbers of trees and maintained the height to eight feet to allow tasks to be completed from the ground. Dwarfing rootstocks were used to create compact trees, and trees were supported either with an individual stake or a trellis. This technology spread throughout Europe and is widely used today. Dr. Terence Robinson, fruit physiologist with Cornell University, is a strong proponent of the Single Spindle training system (Lordan et al., 2018). He works extensively with apple orchards in the Northeastern U.S., optimizing training systems and analyzing the economics of different systems. His 20-year analysis identified the Single Spindle as the highest-yielding over time, and that the more trees per acre, the higher the profit margin over the life of the orchard up to 1,200 trees per acre (Lordan et al., 2019). According to Robinson
(2007), “a low-density orchard will never catch up to a high-density orchard system, even though density production eventually levels out to some extent” (p. 482).

**History of HD Olive Production**

Olives have a more recent history in the high-density system, but HD has been as successfully applied to olives as for apples.

Olives have contributed to the human diet for at least 6000 years. According to Vossen (2007), olives originated in the Mediterranean where Turkey, Syria, and Lebanon are located today. Olive trees were most likely distributed by trade to western regions along with wine grapes, date palms, and figs. Olive oil was produced in the Mediterranean countries of Spain, Portugal, Italy, Greece, Morocco, and Tunisia (Ruis and Lecarte, 2010). The rise of the Roman Empire further aided the distribution of olive trees around the Mediterranean and North Africa (Ruis & Lacarte, 2010).

Olive trees can live for hundreds of years, and many very old orchards are still in production. Olives were often planted on poor soils in areas with limited water (Vossen, 2007). Trees are able to tolerate such conditions, but they do not produce much in comparison to irrigated olives. Olives traditionally are grown as a rainfed crop resulting in larger crops in some years, and low yields in years without adequate water. Vossen (2007) discussed the extensive olive acreage in Tunisia, Morocco, Turkey, Portugal, and Syria, but how it produces very little oil. Typical yields are about 0.5 tons per acre in this dryland system, while irrigated olives
produce around five tons per acre (10 times as much). Traditional trees can grow to heights of 20 to 50 feet tall, so ladders are needed to hand pick the olives. Alternatively, long sticks or rakes are used to knock the fruit onto tarps on the ground. Both harvest methods are slow and labor intensive.

Olives were introduced to California in the 1700s when Spanish priests brought olive trees to plant at their missions all along the coast (Lazicki, 2016). The Mission olive is thought to have originated from these plantings, initially at the San Diego Mission in 1767 (Lazicki, 2016). By 1870, many small orchards of various European olive varieties were established for oil production. The first commercially produced olive oil was produced in Ventura in 1871 (Vossen, 2007). The industry continued to grow in acreage for 15 years or so, but growers found it difficult to compete with imported oil from Europe. When the oil market took a downturn, Freda Ehmann, a German widow, invented the canned black olive in barrels on her back porch in the late 1880s. Her company, the Ehmann Olive Co. (known today as the California Ripe Olive Company), processes around 100,000 tons of olives annually (Weston, 2010). By the early 1900s, the emphasis shifted to olives for eating rather than for oil (Vossen, 2007). Table olives continued to dominate the olive acreage until the high-density concept was introduced from Spain.

In the 1980s, a Spanish company, Agromillora, began to evaluate the use of technology in agriculture and in olives specifically (Gro-Intelligence, 2016). In the 1960s, the grape industry had remarkable success using a mechanical harvester. Observing the mechanical grape harvest led the founders of Agromillora to evaluate growing olives in a method similar to wine grapes. In 1986, an olive nursery was established in Catalonia, Spain. Agromillora collaborated with
Catalonia’s Institute of Agriculture and Technology (IRTA) to gather and evaluate olive cultivars from various regions of Spain (Tous et al., 2011).

Olives are grown on their own roots, so there was no need to develop dwarfing rootstocks. Instead, three dwarfing olive varieties (Koroneiki, Arbosana, and Arbequina) were identified, and in 1994, the first “Superintensive” olive orchard was planted in Spain (Vossen, 2007). While traditional orchards consisted of 80 to 200 trees per acre, the new orchards had tree densities of 600 to 1000 trees per acre (Tous et al., 2011). By 1997, the technology was being utilized in France, and in 1998, HD olives were planted in California (Ruis & Lacarte, 2010).

Agromillora partnered with California Olive Ranch to plant 400 acres of high-density olives near Oroville, California. Compact olive trees were planted at 3-foot intervals and encouraged to grow into long hedges (Vossen, 2007). After establishment, all orchard tasks from spraying to pruning were mechanized. As shown in Figure 7, harvest of the fruit was also mechanized using an over-the-row harvester. This machinery uses direct canopy contact in the same style as blueberries and grapes.
The initial planting was a success, and more acreage was planted. Sturzenberger (2009) found that by the end of 2008, there were 12,137 acres of SHD olive, with most planted between 2005 and 2008. California Olive Ranch estimated that acreage in 2016 was around 22,000 acres (Gro Intelligence, 2016). In 2016, California’s olive oil production was 13,300 tons (Lazicki, 2016).

In 2015, about 60% of California’s olive production was for oil. Prior to 2000, only 4% of the acreage was for oil (Lazicki, 2016). This shift in acreage is partially due to table olive acreage being converted to higher-value crops, but it is still an indicator of the success of the high-density system to produce olive oil.

Status of Other Crops

Given the success of apples and olive production in the high-density system, what other crops can be produced in this manner? The crops with potential for this system in the Northern
California region were chosen to be featured in this project. Other industries such as avocado, hazelnut, pomegranate, and even litchi fruit are trying high-density plantings (Rohlshausen et al., 2016). The crops in this project were all directly observed and evaluated.

Cherries

Two species of cherries, sweet cherry (*Prunus avian*) and sour cherry (*Prunus cerases*), are grown in the U.S. Sweet cherries are grown in California and Oregon, while sour cherries are generally grown in the cooler climates of Washington and Michigan (Perry, 2015). In California, there is great interest in developing varieties with lower chilling requirements in order to grow cherries as far south as possible, potentially even into Mexico. The first cherries to reach the market receive the highest prices, so the ability to grow varieties requiring fewer chilling results in early profitability for California growers (Warner, 2006). As the crop further north in Oregon matures, fruit prices drop (Courtney, 2016).

Cherries receive a high price in the markets, particularly the export market to Japan. Growers can invest in new innovations and new technologies. Many combinations of rootstocks and training methods have been attempted. In the northern part of the country, high density growing systems are used in combination with high tunnels to protect the valuable fruit (Mertz, 2019).

The industry explored mechanical harvest as well. Researchers at Michigan State University planted six varieties of tart cherries in a spacing of 5x13 feet (Perry, 2015). In 2015, the first harvest was undertaken using an over-the-row berry harvester. Researchers were
pleased both with the removal rate of the machine and the quality of the fruit (Perry, 2015). This system also allows for harvesting in the third growing season. A traditional orchard uses a trunk shaking system for harvest, and trees are not strong enough to withstand the force until the sixth growing season. Perry (2015) compared this new system to high-density apples which were developed 20 years ago. He expects the cherry industry to convert quickly, as long as the trees can be kept at a reasonable size.

Unfortunately for the cherry industry, rootstock breeding has not been as successful as in other crops. Cherries on their own roots are very large trees, much larger than apples (Long, 2005). Because cherries adapted to competing for sunlight with nearby trees, they grow rapidly upwards and have strong apical dominance (Long, 2005). This tree form is the exact opposite of the desired form for a pedestrian orchard, small trees with many branches. Dwarfing rootstocks are available, but most growers have not been satisfied with them (Cline & Norton, 2004). Trees still require a substantial amount of specialized pruning. Some rootstocks result in trees that produce smaller cherries, and some tend to put energy toward vegetative growth rather than fruit when they are pruned (Cline & Norton, 2004).

The most common rootstock choices for cherry are the Gisela 5, Gisela 6, and Krymsk 5 (Herrick, 2012). There is also the “Zee Stem” from Zaiger Genetics (Hansen, 2005). The Zee Stem is an intermediate piece of rootstock that is compatible both with the rootstock and the scion. The Zee Stem takes longer and is a bit more expensive due to the need for two graft sites and a little slower growth at first. It enables a wider variety of rootstock/scion combinations though, which allows cherries to be grown in an expanded production area. Usually, cherries
are planted only on the best ground, but with more rootstock options, cherries can now tolerate sandy or alkaline soils (Hansen, 2005).

**Citrus**

High-density citrus has been slower to catch on, primarily due to the suitability of the harvesting equipment. Growers in the 1950s initially used equipment that would harvest traditional sized trees, but these harvesters were very heavy, expensive, and difficult to move from one orchard to the next (Ehsani & Khot, 2012). Additionally, citrus trees are more flexible than other fruit and nut trees, so the machine must apply excessive vibrational force which may cause structural damage to the tree. Freestanding apple trees have similar results with an over-the-row-harvester. Due in part to the flexible nature of apple trees, they are currently harvested by hand with the use of a mechanized platform rather than with a harvester (Feree & Warrington, 2003). Similar to apples, oranges cling to the tree, and workers use a twisting motion or a knife to remove them, and oranges are not easily shaken from the tree for a shake-and-catch mechanized system.

One option that is being explored is keeping trees very small and using a smaller stature harvester. The smaller trees bear fruit near primary scaffold branches that transmit the shaking motion more efficiently to the fruit (Ehsani & Khot, 2012). In South Florida in 2011, a blueberry harvester and an olive harvester were used to harvest small young citrus trees with good results. “The small-sized trees have a fruit-bearing zone near primary and secondary scaffold branches that increases vibration transmissibility to the fruit-stem junction” (Ehansi & Khot,
2012, p. 11). Although the fruit conveyance portion of the machinery will need to be adjusted, researchers were pleased with the results of this trial. In 2011, only 8% of Florida citrus orchards were harvested mechanically (Ehsani & Khot, 2012). Since this trial, there is renewed interest in the citrus industry for mechanical harvest and for developing compact trees on dwarfing rootstocks.

Another challenge worth mentioning is that in some citrus crops, flowers and fruit happen simultaneously and the tree is harvested several times a season. In this case, it would be difficult to mechanically harvest without disturbing unripe fruit and flowers. So, innovators in high-density citrus need to be mindful when choosing varieties to grow.

Dwarfing rootstocks are being developed for citrus. A new rootstock from the University of Florida, UFR-6, is size controlling and is compatible with oranges, mandarins, lemons, and limes (University of Florida, 2021).

**Peaches, Plums, Nectarines, and Apricots**

These crops are in the early stages of adoption of the high-density system in the U.S. Peaches and nectarines are commonly grown in high-density orchards in Europe and high-density almonds are common in Spain.

Peaches, plums, nectarines, and apricots are all in the *Prunus* family, so they are compatible with many of the same rootstocks (Cline & Carter, 2013). Rootpac-20 rootstock (from the Spanish company Agromillora) enables the development of compact almond, peach, nectarine, plum and apricot trees (Eddy, 2016). For plum, the Citation dwarfing rootstock is
widely used as well. For apricots, it tends to be more variety specific. Some varieties perform well on the dwarfing rootstocks, but in some cases, incapability occurs. This is often seen as a syndrome called “brown line” where there is incomplete healing of the graft, thereby creating a brown line of dead cells (Reiger, 2007).

Due to increasing labor costs and shortage of workers, there is increasing interest among American fruit growers for high density production (Lewis, 2015). Labor costs are a large portion of the total production costs for a fruit operation and the growers are eager to shift to a mechanized system. When surveyed about mechanization, North American fruit growers ranked mechanical harvest as the number one need for mechanization (Lewis, 2015). Figure 8 and Figure 9 illustrate the structure of a pedestrian peach orchard, and the mechanized harvest possible for canning peaches.

Figure 8

High-Density Canning Peaches
Wages for farm labor are increasing. In California, for instance, minimum wage has steadily increased. Overtime pay for agricultural workers begins after ten hours per day, but legislation has been introduced to begin overtime pay after eight hours (State of California Department of Industrial Relations, 2021). Also, it is sometimes difficult to find enough workers at harvest time, which can cause losses due to overripening of the fruit (Taylor, 2019).

Almonds

Although almonds are in the same family as peaches and nectarines, the situation is quite different for growers (Eddy, 2016). The almond industry is not under the same labor pressures because traditional nut production is already highly mechanized (Micke, 1996). In the U.S., conventional sized trees are shaken with a mechanical shaker, causing the nuts to fall to the ground. Nuts remain on the ground for a week or so while drying, then a mechanized
sweeper is used to pick up the dried nuts (Micke, 1996). There is no need for workers to pick the nuts by hand, so almond growers are less motivated by high labor costs (as compared with fresh fruit growers) to switch to a high-density system.

High-density is commonly used in Spain and other parts of Europe to grow almonds (Eddy, 2016). Figure 10 shows a typical high-density almond orchard with the trees forming long hedges. There is tremendous interest in Australia as well due to rains during harvest that creates higher pressure from soil-borne disease. If nuts are allowed to get wet, particularly when in contact with the soil, unpleasant and hazardous biological pathogens thrive. The California Almond Board (2020) lists aflatoxin as the pathogen of most concern.

![Almond Orchard in Spain](image)

Figure 10

Almond Orchard in Spain

Even in dry soils, pathogens can be conveyed to the nuts. A 1970s study in applied microbiology found Coliforms, Escherichia coli, and Streptococcus were isolated from the nuts,
and their presence was correlated with soil contamination (King et al., 1970). With the mechanical harvest, there is no need for the almonds to contact the ground.

Prunes

Prunes are also members of the *Prunus* family, and trees are naturally small in stature. Trees are currently spaced at 18-foot intervals with 20-foot rows to accommodate the large “shake and catch” harvesting equipment. As a result, the trees do not intercept as much light as they would if they were planted closer together, so yield is not as high as it would be if the maximum amount of light were captured.

The following illustrates an early-stage example of the high-density system for prunes. In Chile in 2014, a high-density prune orchard was planted at 758 trees/acre (Zuniga, 2018). Figure 12 and Figure 13 show the new style orchard, in contrast to the traditional orchard shown in Figure 11. The spacing was 5-feet with 11.5-foot row spacing. Prune trees at this age (4th leaf) are approximately 7-feet. This orchard’s first harvest was in February 2018 using an over-the-row harvester that harvested 2.5 acres per hour. A traditional four-year-old orchard is expected to yield less than one dry ton. This orchard produced 2.5 dry tons and the fruit grade was size large, also known as U.S. Choice (Zuniga, 2018). The unknown factors include life span of the orchard and production over the life of the orchard. Although early indications look promising, it will be important to track the progress of this orchard to assess whether high-density is suitable for prunes in the long term (Zuniga, 2019).
Figure 11

*Traditional Prune Orchard in California*

Figure 12

High Density Prune Orchard in Chile
Figure 13

*Individual HD Prune Tree*
CHAPTER III

METHODOLOGY

This project was inspired by a visit to the pedestrian peach orchard mentioned in chapter one. The form of the orchard and of the individual trees were new and interesting. This orchard is an experimental orchard with the same peach variety on three different rootstocks and two training styles, central leader and V-shaped. It seemed an interesting an innovative path forward for fresh fruit growers.

Next, the high-density system was researched. The system has proven successful in the production of olives for olive oil and in fresh fruit apple production. Many scientific papers and research studies are available to utilize, ranging from agronomic information to cost analysis studies. California Olive Ranch, the first U.S. company to grow HD olives, is in Northern California, and their olive orchards can be readily observed in this area. Most of the HD apples are in the states of Washington and Michigan, but many articles and studies are available regarding their long-term history and popularity among growers.

For the background information of the handbook, tree crops were evaluated for their suitability to the high-density system. Many crops are easily adapted, but some have traits that are challenging for mechanization. As previously mentioned, many citrus varieties cling to the tree and workers use a twisting motion or a knife to remove them. Oranges are not easily shaken from the tree for a shake-and-catch mechanized system (Ehsani & Khot, 2012). Still, oranges are a good candidate for high-density, especially for juice production, and varieties are being developed that release from the tree more easily. Oranges and other citrus crops are
suitable for high-density combined with hand-picking rather than mechanized harvest. This would be most suitable with high value, fresh fruit varieties (Elkins et al, 2011).

One of the main factors for suitability to HD is the ability of the fruit or nut to be mechanically harvested. Mechanized harvest is a huge benefit when it comes to labor and the reduction of costs. For instance, in olive harvesting, one person can hand-pick about 5 to 6kg of olives in an hour; with a mechanical harvester on a SHD orchard, one person can harvest up to 555,500 kg per hour (Gro Intelligence, 2016). Some fruit crops are unsuitable for mechanical harvest, as the bruising of the fruit is too severe. These crops can still be grown in the high-density system but require picking by hand from the ground or moveable platform. Apples seem like a crop that would easily adapt to mechanization, but they bruise easily, so the many acres of high-density apples are picked by hand (Nikos-Ros, 2020). The use of mechanized platforms makes harvest easier, and the efficiency is increased due to the elimination of ladders, but it would be easier still if the apples could be harvested by machine.

Another important factor for suitability for the HD system is whether a dwarfing variety is available, such as in olives, or whether a rootstock is available for that crop that causes the trees to grow in a compact shape. Pears are a prime example of a crop that would greatly benefit from the high-density system, but unfortunately, dwarfing rootstocks for pears are not currently available (Elkins et al, 2011).

Many crops are being explored for high-density, and the suitability and challenges of each crop were researched. For some crops, including specialty plums, cherries, and pomegranates, experimental orchards are available for first-hand observation. High-density farms were observed for crops that are further along, such as canning peaches, almonds, and
prunes. Several ranches are in the early stages of high-density production, ranging from newly planted to 10-year-old orchards. Farm managers shared information about the successes and drawbacks in their sites and microclimates.

In many cases, there were missteps that were very informative and should help others in the adoption of the system. For example, almond orchards attempted to use standard California varieties on dwarfing rootstocks. The almond variety Nonpareil is widely grown in California. It has high yields and the highest price of the almond varieties due to its size and the thin “paper-shell” that is associated with almonds in the U.S. (Almond Board of California, 2020). Nonpareil requires two pollinator varieties, often Butte and Padre, or Aldrich and Wood Colony, to set the crop. Unfortunately, the California varieties are quite vigorous, even on a dwarfing rootstock. This is partly due to the vigor of the tree, and partly due to the manner in which they are grown. Farmers are accustomed to pushing the trees to grow with nitrogen and other nutrients (Micke, 1996). In the high-density system, it is imperative for the trees to remain small and to produce in the interior of the tree, thereby creating the “fruiting wall” which is then mechanically harvested (Eddy, 2016. In the case of the California varieties, the nut production occurs on the outer edges of the tree and the inside becomes woody and non-productive with many areas of blank wood. Almonds are successfully grown in Spain with the high-density method. There are many key differences, however.

First, the soil in Spain tends to be rocky and arid (Andrade-Limas et al., 1999). The trees in these soils naturally stay compact without excessive vigorous growth. Another significant difference is the self-fertile almond varieties grown in Spain allowing for single variety orchards, making management considerably easier. The timing for pest control sprays and harvest are all
based on the one variety rather than the three varieties in American orchards (Andrade-Limas et al., 1999). As self-fertile varieties such as “Independence” were developed domestically, the high-density orchards were more easily managed, requiring less pruning and harvester passes. Additionally, the production yields increased. An example of a successful almond orchard using the Independence almond variety is on the Lyon Ranch near Modesto California (Eddy, 2016).

Tree nurseries growing various rootstock/scion combinations for this system were observed, and informative field days or tours attended. New techniques have evolved in the nursery system to supply the trees necessary for high density (Robinson and Hoying, 2005). For instance, tissue culture is a fairly new technology that allows for very rapid multiplication of clonal plants. Nurseries commonly use tissue culture to produce plants rather than seeds and cuttings. New micrograft techniques allow plants to be grafted when they are quite small, rather than grafting older trees in the field. The number of trees needed for high density plantings is spurring greater efficiency in tree production.

Crop specific grower meetings were attended. These meetings give a wealth of information. UC scientists give presentations on the latest research regarding the specific crop. Economists and marketers present the latest market news. Many growers attend and are open to discussion about their farms, concerns, and interests. These meeting were invaluable in determining useful information for the handbook.

The handbook is the compilation of information from many sources. The most important information was gathered first-hand from visiting various high-density plantings and speaking with the growers and managers. Direct observation of the trees along with information regarding the planting and management techniques were crucial in determining
methods that work, along with methods that resulted in missteps. When introducing a new technology, trial and error occurs along the way. Varieties and techniques that work in one region or country may not translate well to another region. This has been the case with the high-density system. Many adjustments were made in California to adapt the Spanish system of growing olives. As previously mentioned, soils in California tend to be more fertile and of a heavier composition than soils in Spain (Storie & Weir, 1951). Adjustments needed to be made to the fertility program and the hedging timing was different. And, when adapting the high-density almonds, the variety differences were an unexpected challenge. Although much trial and error are still underway as growers seek optimal crop efficiency, the continued efforts indicate the strong need for a change from the traditional systems.
CHAPTER IV

RESULTS

The manual provides a step-by-step approach to assist farmers and homeowners interested in this revolutionary technology. Although more crop specific information and site-specific information will be necessary to fully make use of the high-density system in a particular situation, this manual gives an overview for the high-density planting system.

The target audience for this handbook is commercial growers interested in trying a new system, either for higher quality fresh fruit, or reduction in labor costs. Homeowners interested in achieving an edible landscape, or simply wanting to enjoy producing fresh fruit in their back yard may also be interested in the techniques outlined in this handbook. This project is meant as an overview of the pedestrian orchard system, and more crop specific information and site-specific information will likely be necessary to take full advantage of the system.
CHAPTER 5

CONCLUSION

The high-density system inspired a new form of agriculture. Rather than tall trees requiring substantial hand labor, the new system optimizes fruiting area and takes advantage of labor-saving technology. High density orchards require more investment in the early years, both in higher cost of establishment and in focused management. The advantage to the new system is reduced cost of labor, and early productivity of fruit, both important metrics in the success of a modern orchard. High early yields, and high-quality fruit result from properly managed, high density orchard systems.

The olive oil industry and the apple industry have benefitted from the use of high-density plantings. The HD system has led to higher profitability for four main reasons: labor savings, precocity of the crop, elimination of ladders, and high fruit quality.

**Labor Savings**

High-density plantings result in greater efficiency in harvest, as most of the work can be done from the ground. Mechanization for common orchard tasks also save hand labor costs, particularly the mechanized harvest possible of olive crop.
Precocity of the Crop

High-density plantings have earlier production of fruit than traditional plantings. This early production is of great benefit to the growers, as they can begin making profit faster.

Elimination of Ladders

The elimination of ladders saves time for the workers, and is also safer, so insurance costs are lower.

Fruit Quality

The narrow canopy of high-density orchards allows for even light distribution. Fruit size and color are both improved in this system. In a traditional size tree, the fruit at the top gets the most light, so color and size are optimal. In the rest of the tree, some of the fruit is shaded, causing uneven fruit color and size.

The potential for other tree crops to be grown in a pedestrian orchard is difficult to determine at this point, as most HD orchards are in the early stages. Time will tell if cherries, canning peaches, prunes, and other crops can be efficiently produced in this manner. The outlook seems bright for the success of this system, but more data is needed regarding yields over time, longevity of trees, and disease pressure when compared with traditional orchards.
Appendix A: Handbook for Creating a Pedestrian Orchard
Planning a pedestrian orchard optimally begins two to three years ahead of planting. It will take time to properly analyze and prepare the soil and to plan for the optimal spacing and placement of trees. Suitable trees will need to be ordered from the nursery two to three years ahead of time (Robinson et al, 2006). Site selection is important for fruit and nut orchards of all types. Fertile soil and favorable temperatures are important for the success of fruit and nut orchards. Olives are a little more forgiving with soil type as they do not need as much water and nutrients compared with other tree crops (Ruis & Lacarte, 2010). Depending on the desired crop, low temperatures for the area need to be researched. Some crops are more tolerant low temperatures. Length of warm hours, or growing season, need to be assessed as well (Acquaah, 2005).

Temperatures of a region also need to be assessed for chilling hours. All fruit and nut trees require a period of dormancy or rest during the winter to produce optimal crops in the summer. The number of chilling hours vary from crop to crop, and different varieties of each fruit require different amounts of chilling. Tulare cherries require around 400 hours of chilling hours, while Bing need 900 chill hours (Hansen, 2014). In California, all weather and temperature related questions can be investigated using the online California Irrigation Management Information System (CIMIS). CIMIS is a network of weather stations maintained by the University of California, and temperature information for all regions is readily available.
and information regarding the agriculture of that state. Cooperative extension agents are sometimes available as a resource as well. The cooperative extension can be accessed online, and usually has a local office as well.

**Initial Groundwork**

Before groundwork begins, it is important to analyze the soil. Orchard trees prefer well-drained aerated loam at least three feet deep (Micke, 1996). Drainage is extremely important as many trees cannot tolerate extended time in conditions that are too wet (known as “wet feet” or asphyxia). The tree roots require times of dryness in between watering to obtain oxygen (Van den Ende, 2015). To test for adequate drainage, dig a test hole at least four feet deep to examine the soil profile (Acquaah, 2005). Make note if there are any layers of clay or hardpan as this may inhibit root growth. Check the hole periodically during the wet season to be sure that there is adequate drainage. If necessary, soil drainage can be corrected with drainage systems or with surface modification.

For the soil analysis, take samples from several places in the field. On a 20-acre lot, a sample of 15 to 20 locations should be collected. Have soil tested for pH, nutrients, nematode presence, and organic matter content (Ruis and Lacarte, 2010). Planting a cover crop is recommended to reduce weeds and to increase organic matter in the soil. Some good cover crop options are purple vetch or fava beans, as they have nitrogen-fixing nodules in their roots and will enhance the nutrient content of the soil. Cover crops are typically grown over the
winter, then plowed into the soil in the spring to increase organic matter and nitrogen (Van den Ende, 2015). If necessary, amend the soil with phosphorous and potassium as well.

Soil pH is another important factor. For optimal nutrient uptake, soil pH should be 6 to 6.5. If pH is too high, it can be adjusted with lime (Ferree & Warrington, 2003). The lime application is especially important to do before planting trees, as it is more difficult to adjust soil pH after trees are planted (Van den Ende, 2015).

Nematode presence in the soil can injure or kill young trees. If nematodes are detected in the soil analysis, fumigation may be necessary. Also, if the site was previously planted with orchard trees, it may have a history of oak root rot or crown gall. Fumigation will help with these conditions as well. As Ferree and Warrington (2003) stated, “in many cases, tree growth of new orchards that are planted on old orchard land can be improved significantly with soil fumigation” (p. 395).

Irrigation

Access to water is an important consideration. Determine whether there is access to public irrigation water or if a well is needed. For conventional orchards, surface irrigation or sprinklers are used for irrigation (Acquaah, 2005). Surface irrigation (also known as flood irrigation) is a popular choice in many conventional orchards. It requires a level field. It has the advantage of not needing installation or equipment but has less precision than the other methods (Acquaah, 2005). Sprinklers may be used in areas where the ground is not level. The
advantage to using sprinklers is that the amount and timing of the water application is controlled by the farmer (Micke, 1996).

For the high-density pedestrian orchards, drip irrigation is best (Pollock, 2017). It provides volumes of water at set intervals. The system can be used on even or hilly ground. It is more expensive to install than the sprinkler system but requires less maintenance. As shown in Figure 14, double line drip irrigation is recommended, one line on either side of the row of trees. A single line is cheaper but causes the tree roots to grow in an uneven pattern as they seek water on one side of the tree (Ruis & Lecarte, 2010).

![Double Line Drip Irrigation](image)

**Figure 14**

*Double Line Drip Irrigation*
For most crops, a trellis structure is necessary to support the trees and to ensure the rows are straight (Ampatsidis et al., 2013). In general, strong 12-foot end poles are placed at a 30-degree angle for strength. Metal poles or thick wooden poles are often used in this capacity. Treated lodgepole pine is a good option, or pressure treated wooden line poles (Waliser, 2010). In an organic orchard, treated wood is not allowed, so steel poles (see Figure 15) are a better choice. End poles are placed 2 ½ feet in the ground, leaving 9 ½ feet above ground. The trellis in this example was in a canning peach orchard. The trees were kept to a 9-foot height. For some crops, such as olives or almonds, the trellis structure can be less extensive (Eddy, 2016).

Figure 15
Trellis End Pole
The anchor is one of the most essential elements in a trellis. A screw anchor is the best choice (Waliser, 2010). It should be placed in the ground as far away from the end pole as the height of the pole. A 4-foot screw anchor is standard, and a 5-foot anchor is recommended for long rows or in cases where there is a lot of stress on the trellis. The wire running from the anchor to the end pole needs to be very strong, as strong as the trellis wires combined (Waliser, 2010). The supporting line wires are then placed wires horizontally every 2 ½ feet. Or, alternatively, the bottom wire can be set three feet from the ground, then 2 ½ foot intervals. Placing the starting wire at three feet makes it easier to train the lower limbs of the tree (Robinson & Hoying, 2005). Line wires are usually galvanized steel with a tensile strength of at least 180,000 pounds per square inch (Waliser, 2010). A spinning wheel tightener, shown in Figure 16, is used to tighten the wires initially and to tighten them later in case they become loose with wind or changes in weather.

Figure 16

Spinning Wheel Tightener for Tightening the Trellis Wire
Metal poles are placed every 40 feet or so down the line of the trellis to further support the wires (Waliser, 2010). Figure 17 shows 12-foot metal fence posts that are a good choice for these supporting poles as they are sturdy and have notches to attach the wire.

![Figure 17](image)

*Figure 17*

_T-post for Support in the Center of the Trellis_

Light Interception

The most important goal when designing a pedestrian orchard is to maximize light interception. According to Day (2010), the structure of the tree exists to carry leaves to intercept light and to carry fruit. Multiple studies indicate that light interception is the single most important determinant of fruit yield in an orchard.
To design an orchard for light interception, orient the rows from north to south when possible. This optimizes sunlight as the sun moves across the sky and minimizes shading (Tukey, 1978). For optimal light, follow the “Rule of 70.” Orchards have optimal yield when the trees are intercepting 70% of the available sunlight; some light is lost due to spacing in between the rows and at edges of the field. If an orchard is intercepting 70% of the light, the trees do not need to be taller. “Vigor is a function of genetics and environment. Overall tree height has little effect” (Day, 2005. p.76).

To maximize light interception, space the rows no more than 14 feet apart (Long, 2010). The goal is to create a wall of fruit. For maximum production efficiency, the tree canopy should be three to four feet wide and 10 to 14 feet tall (Lewis, 2015).

Manage light interception with proper pruning. Canopies for fruit should be kept around three feet deep so that all the branches have sun for flower bud production. This is important to keep fruit-growing spurs active, and fruit needs adequate sunlight to achieve optimum size and coloration (Lampien et al, 2011).

Unrelated to light, another important design consideration is to leave room at the end for the field equipment to turn around. Make the rows as long as possible to minimize the time the equipment takes to turn around.
Tree Selection and Root/Scion Combinations

The scion is the flowering and fruiting part of the tree. This is the portion of the tree most people think of when they order trees, but the rootstock is equally important (Martin, 2008).

For all commercial orchard production, fruit and nut trees are grafted onto rootstocks (Cline & Norton, 2004). In Northern California, this can be observed when driving by walnut orchards. The tree will have white, smooth bark except toward the bottom, where the trunk appears dark and rough. Figure 18 is an example of an English walnut variety that is grafted onto black walnut rootstock. In this case, the English walnut scion produces high quality, light colored nuts. English walnut roots, however, are very susceptible to disease. So, the desirable English walnuts are grafted onto black walnut rootstock that is resistant to soil borne disease (Ramos, 1997). In this way, a crop tree is formed that will be long lasting in the environment with the more desirable nut type.

Figure 18

*English Walnut Scion on Black Walnut Rootstock*
For pedestrian orchards, special dwarfing rootstocks are used to limit the size of the tree. In fruit and nut trees, the rootstock determines the structure of the tree and the scion determines the type and size of the fruit (Ames, 2019). Grafting a desirable fruit scion onto a dwarfing rootstock results in a small stature tree with “normal” sized and commercially acceptable fruit. This is what makes the pedestrian orchard concept possible. Short stature trees produce high quality fruit that can be maintained and harvested from the ground or from a moveable platform (Hansen, 2007). Hundreds of rootstock/scion combinations are available. Trees must be ordered two to three years ahead of time from a commercial nursery. The nursery will make the trees to order, then grow them until they are tall enough to plant in the field (Robinson & Hoying, 2005).

Roots determine many tree characteristics. In the case of the pedestrian orchard, the most important characteristic that the rootstock contributes is the size-controlling characteristic (Long & Kaiser, 2010). The roots determine the size of the overall tree, while having little effect on the size of the fruit. Roots determine precocity or the age when the tree begins to bear fruit (Robinson, 2005). They contribute to disease resistance, particularly diseases caused by nematodes (small, soil-borne round worms). Roots determine if a tree will survive when subjected to waterlogged conditions, and the roots produce hormones called cytokinin which determine when the trees break dormancy in the spring.

The scion is the top part of the tree that is grafted on to the rootstock. It determines the type and quality of the fruit (Martin, 2008). It also determines flowering and fruit patterns, such as annual bearing or alternate bearing. The scion determines whether the growth pattern
of the tree is compact or spreading, the strength of the wood, and the branching angles (Martin, 2008).

The scion determines the size of the fruit while the rootstock determines the size of the tree. So, by pairing a high-quality fruit scion with a dwarfing rootstock, a small stature tree that produces high quality fruit is created (Cline & Carter, 2013).

**Dwarfing Rootstocks by Crop**

**Apples**

The well-known Geneva series of rootstock was developed by a renowned breeding program in Geneva, New York. Geneva rootstocks are suitable for growing very dwarfing trees to full-sized trees. (Robinson et al., 2003)

**Cherries**

Dwarfing rootstock options are limited for cherries. The Gisela series is available, as is Kymsk 5 and 6. (Cline & Norton, 2004). The “Zee Stem” interstem is another option (Hansen, 2005).

**Peaches, Plums, Nectarines, Apricots, and Almonds**

These crops are all in the Prunus family and are compatible with the same rootstocks for the most part. Rootpac-20 is good for all these crops (Eddy, 2016). The Controller series of
rootstocks developed by the University of California is also a good option. Citation rootstock is also commonly used for plums (Hansen, 2008).

Olives

Olives are grown on their own roots, so just select a compact variety such as Arbequina, Arbosana, or Koroneiki.

Number of Trees

The number of trees per acre is determined by the crop and by type of training system. Other considerations are the return on investment and long-term profitability. For apples, a single-spindle system is recommended, with a tree density of up to 1,200 trees per acre (Robinson et al., 2007). For olives, “about 1,300 trees to the acre is optimal in many areas” (Ruis & Lacarte, 2010, p. 47).

When factoring in the number of trees, keep in mind that many crops also need pollinator trees. Apples that are not self-fertile, for example, need a pollinator every 10th tree. In olives, it is common to plant one row of pollinator trees for every six rows of crop trees (Ruis & Lacarte, 2010).

Also, the orchard may benefit from windbreak trees in very windy areas. The windbreak trees can be planted along the edges of the orchard.
The training system is an important decision when designing a pedestrian orchard. The options for training systems vary according to the crop. The training system impacts initial costs such as the type of trellis system and the number of trees needed (Waliser, 2010). Many training systems have been tried throughout the last 30 years, and it has been narrowed down to a few optimal systems per crop.

**Apple and Pear Training Systems**

Robinson is a fruit crop physiologist who works extensively with apple orchards in the Northeastern U.S. His work involves optimizing training systems and analyzing the economics of different systems. According to Robinson et al. (2013):

> The change in planting systems over the last 50 years has been dramatic. As we look to the future the current best system, the Single Spindle, is likely to continue to be the best system...we expect such orchards to have very high yields (1,500 bu/acre) with uniformly high fruit quality.

After many years of working with different train systems, the system he favors by far is the Single Spindle System (Robinson, 2007). The Slender Axis System is also a very profitable system (Lourdan et al, 2019).

**Single Spindle**

Trees are planted three feet apart with 11 feet between rows with 1,320 trees per acre. Basically, the result is a 10-foot-tall trunk with small fruiting branches from top to bottom. To achieve this in three years, start with three-foot-tall trees with 10 to 15 small branches, or
“feathers,” of not more than a foot in length (Robinson, 2008a). Trees must be at least 5/8 inches in diameter so that they will be strong enough to bear the weight of early crops. After planting, the central leader is not cut. The leader will reach its mature height in four to five years. It is then headed to prevent it from growing any taller (Robinson, 2008a). This system requires a four-wire trellis system to support the tree. All the feathers along the trunk need to be tied or weighted down to below the horizontal. The keeps the limbs small and prevents them from trying to compete with the central leader (Robinson, 2008a). It also means that minimal pruning will be required. After the initial set of feathers are tied down, new feathers that arise will naturally be weighed down by fruit, so it is not necessary to perform another round of tying (Robinson, 2008a).

To maintain the conical shape of the tree, remove whole limbs near the top. The removal of one or two limbs per tree per year is recommended. When cutting the limbs, leave a small stub. This will encourage a small, weak branch to grow. As this is repeated over the years, the top of the tree will be comprised of small, fruitful branches. The conical shape ensures good light penetration which is crucial for production of flowers and to achieve optimal color for fruit (Parker, 2014).

**Slender Axis**

Trees are planted four feet apart with 12 feet between rows at 908 trees per acre. This system is like the Tall Spindle in that there are no permanent branches. Start with a highly feathered tree and tie the feathers (small branches) below horizontal. The feathers should start out high enough that no feathers need to be tied up, so higher than 24 inches. Any
feathers that occur lower than 24 inches can be removed (Robinson, 2007). Rubber ties are often used, or specialty ties that resemble small bungee cords, so the ties do not injure the tender bark of the branches (Robinson, 2007). These ties are commonly available at orchard supply stores.

Cherry Training Systems

Cherry trees are more challenging to keep in a compact size as their natural growth pattern is to just grow vigorously straight up. Cherries have strong apical dominance and require training when the trees are young to encourage lateral growth and fruiting spurs. Without intervention, a cherry tree can grow to 60 feet and take several years to produce fruit (Long, 2005). For cherry trees, there are several options for training systems.

Kym Green Bush (KGB)

This results in a fully pedestrian orchard. The system works for most cherry varieties, but it is not recommended for non-spur varieties, such as Regina. These varieties produce their fruit at the base of one-year-old shoots, and this wood is pruned off in the KGB system. The lower framework of the tree is permanent, but all the vertical leaders are pruned (Long, 2010).

Spanish Bush

This starts with the same structure as with KGB, but vertical leaders are maintained. Fruit is produces on the small laterals from the vertical leaders, so the laterals are pruned to keep the spurs young. Due to the heading cuts, this system is not precocious, and the trees can
take more than 6 years to produce a crop (Long, 2005). Another concern with this system is that the trees can be more susceptible to bacterial canker due to the amount of pruning. Spanish Bush and KGB are freestanding trees that do not need a support structure. Trees are kept to a maximum height of 2.5 meters. The trees are spaced at six to eight feet and 14 to 18 feet between rows (Long, 2005).

Super Slender Axe

This system is a modification of the spindle. In this system, dwarfing rootstocks are used to control the tree size. Trees are planted at a very high density, up to 2,000 trees per acre (Long, 2005). The trees are planted 20 to 40 inches apart and have a small trunk diameter. A trellis system is necessary to support the trees. This system works well with varieties that have good vigor, upright growth, and produce fruit on the basal buds of one-year-old shoots.

Tall Spindle Axe

Similar to the Super Slender Axe, in this system, the tree is allowed to develop a central leader. The branching is renewed every year, creating greater numbers of lateral branches. Fruit is borne on these lateral branches rather than at the basal buds (Long, 2005). The only permanent structure is the central leader. This system also requires size controlling rootstocks. Trees are planted five to eight feet apart and 11 to 14 feet between rows.
Upright Fruiting Offshoots (UFO)

This training system is closest to Espalier. The tree trunk is trained horizontally along a wire. All off-shooting branches grow vertically and bear fruit. A trellis system is required. Little pruning is required at planting and the structure is easy to maintain (Long, 2005).

Vogel Central Leader

This system also allows the tree to develop a central leader. Size controlling rootstocks are used and an intermediate planting density. Minimal pruning in the first year results in a Christmas-tree like shape that promotes good light penetration. This is a very precocious system due to the minimal pruning (Long, 2005). Clothespins are attached to new young laterals to weigh them down, causing horizontal growth. They can also be tied down or spread to maintain an angle of at least 60 degrees. Fruiting wood needs to be renewed on a regular basis to maintain productivity, so several laterals should be cut back every year. Branches of more than ½ inch in diameter are also pruned, reducing any shading. This system has excellent light penetration because of the yearly pruning and the Christmas tree shape of the trees (Long, 2005). It may not be suitable for heat-sensitive varieties.

Other systems include the Zahn system and the Solaxe. These are not widely used in the U.S. A side note about cherries — cherries are a high value crop and are being produced in high tunnels in the cold areas of the country (Mertz, 2019). The tunnels are constructed of plastic stretched over a metal framework that protects the fruit from cold and rain, thus preventing cracking and yield loss.
Almond Training Systems

Almond trees are usually planted with an individual stake rather than a trellis. The almond trees have strong wood and become quite sturdy in the first few years (Eddy, 2016). The trees are usually planted five feet apart with twelve feet between the rows. Figure 19 shows an almond orchard with high density.

Figure 19

High-Density Almond

Olive Training Systems

Olives are usually planted at a spacing of three to four feet between trees and 10 feet between rows. Olive growers have a two to three wire trellis to train the trees (Ruis & Lacarte, 2010). With the use of low vigor varieties, the olive trees easily form a hedgerow capable of mechanical harvested (see Figure 20). This system is currently used to grow olives for olive oil, but with the development of new varieties, it may be possible to grow table olives as well. New advances in harvest machinery also bode well for table olive production.
For high-density peach orchards, there are two primary systems— the Single Spindle (see Figure 21), which has been previously discussed, or a V-training system. For the V-training system (see Figure 22), the tree is trained to have two main scaffolds. The advantage to this system is that it allows fewer trees to be planted and eventually the canopy space will fill in fully (Day, 2005). In some cases, though, one side of the tree becomes stronger and more dominant. When that happens, the canopy space is not filled in optimally.
Figure 21

Spindle Training System

Figure 22

V-Training System
Mechanization

Although the trees are shorter in stature, as the orchard matures, not all the work can be accomplished from the ground. The use of mechanized platforms addresses this issue (see Figure 23). Instead of climbing up and down ladders, workers stand on a platform that moves slowly through the orchard as they conduct tasks such as spraying, pruning, and picking fruit (Elkins et al, 2011). Many models are currently available, and more are in the design phase. The most useful models are self-driving platforms that can be operated by the workers rather than being pulled by a tractor (Robinson et al, 2013). This eliminates the need for an additional worker to drive the tractor and allows the rows between trees to be narrower, which optimizes light interception and fruit production.

Figure 23

*Mechanical Platform Demonstration*
Using a mechanized platform, workers can easily prune the trees, train the trees to the tallest wire, thin the fruit, and harvest the fruit, all without the use of ladders. Growers are pleased with the efficiency and safety of the platforms. McDougall and Sons, a large apple producer in Washington, had no worker injuries with platforms. Using ladders, they previously had 28 injuries in one year (Wheat 2016). Machines are also available to do overall hedging.

String-thinners machines that mechanically thin the flowers from the trees to optimize fruit size. Thin pieces of string whip around a rotating head to knock flowers off the tree (Lewis, 2015). Thinning the flowers eliminates some of the potential fruit, allowing the remaining fruit to grow larger. The increased efficiency of the automatic string thinners versus sending workers picking flowers off by hand saves labor costs (Lewis, 2015). And of course, harvest is efficient with the over-the-row harvesters if that is suitable for the crop (Ehsani & Knot, 2012).

When planning a pedestrian orchard, look into the equipment that is suitable for the orchard. Some equipment will be necessary right away, and some purchases can be delayed until later (Lewis, 2015). Much of the land preparation work can either be hired out, or equipment can be rented. A small tractor and a sprayer that fits down a narrow aisle will be necessary in the first year or two. Consider buying multipurpose equipment. Often, tractors have attachments for hedging or mowing. By year three or four, a mechanized platform may be required. It is important to plan ahead for optimal management decisions (Ferree & Warrington, 2013).
Planting the Trees

Trees should be planted on a berm or raised bank. This allows the trees to be slightly elevated and prevents wet feet (another name for asphyxia). Berms also provide the trees a little elevation in the case of severe winter storms. Trees grow best in well-drained soil.

Be careful to plant trees with the graft union higher than the soil line. Even after it is fully healed, the graft union is a weaker part of the tree and bacterial will enter if given the chance. It is important to make sure that the roots are fully in contact with the soil. Any air pockets will cause that area of the root zone to die.

Trees can be planted by hand, or with the use of a semi-automated planter. The planters are pulled by a tractor and dig a groove in the soil in the front. Trees are fed into the planter by one or two workers, and trees are tucked into the ground and soil pulled around them. Planters can be adjusted for depth, and plant the trees at set intervals, so the trees are spaced evenly in the orchard. Usually, a worker follows behind and checks the trees. Use of the planter is more efficient than planting by hand, usually a 10 times faster rate.
Section A.2 Managing a Pedestrian Orchard

Pruning and Training

Training is conducted in combination with pruning to create the initial shape and structure of the tree. Training is done when the trees are young, and involves encouraging the tree to grow in a certain manner by tying it to the trellis or stake (Parker, 2014). For the high-density system to work, adequate attention must be given to the training of the trees in the first years (Robinson, 2008b). The training forms the structure of the tree throughout its life, so it must be pre-planned and executed properly. Training creates the “wall of fruit” structure mentioned previously which also allows an even distribution of light to the fruit, resulting in even coloring and sugars whether the fruit grows at the top of the tree or the bottom.

For fruit bearing trees, the main goal of the training is to create an optimal framework for the fruit to hang. The angle of the branching determines the amount of fruit that the tree can comfortably hold. To create strong branches, the angle between the branch and the trunk of the tree must approach 90 degrees. Trees that form branches with angles of 30 or 45 degrees are much more likely to break under the weight of the fruit. Wide angle branching (greater than 60 degrees) is a desirable trait in a tree for a pedestrian orchard (Parker, 2014). Wider angles result in strong branches that will bear fruit. If branches are too upright, they will compete with the central leader for dominance and result in vegetative growth rather than fruit production (Robinson, 2008a). The other advantage of wide angled branches is that it allows more optimal air and light into the center of the tree. The light penetration keeps fruit bearing...
spurs active (Lampinen et al., 2011). The better airflow of an open center prevents some diseases from forming and allows for more efficient spray coverage. In the case of high-density apples, the lateral branches must be tied down below horizontal for the branch to produce fruit.

Pruning is the process of removing branches or portions of branches. In conjunction with training, pruning is an important part of maintaining a pedestrian orchard. Pruning maintains the size and architecture of the tree. It helps maximize sunlight interception which is important for flower bud production. It increases air circulation which allows for spraying. Pruning removes dead wood which helps prevent the spread of disease and keeps trees healthy. Removing branches with narrow angles helps to strengthen the tree and increase production. Branches are stronger when their angles approach 90 degrees (Parker, 2014).

Time of year is important when planning pruning. Dormant pruning during the winter stimulates vegetative growth. Pruning during the winter allows for removal of dead branches, and branches that are not optimally placed (Parker, 2014).

Pruning during the summer de-invigorates the tree and helps control the size. The other main advantage to summer pruning is that the cuts are less likely to become infected. Summer pruning should be done before the summer solstice in mid-June (Long, 2005). Pruning after this point can result in the new growth being too tender for winter temperatures which can cause die-back and leave the tree vulnerable to infection. Pruning methods will vary with the type of training system.
Thinning the Fruit

Maintaining optimal crop load is important in all years, but particularly in the first few years of tree growth. There is a linear relationship between number of fruits per tree and final tree size. For long term production, it is important not to over crop the trees in the first few years. Bearing too much fruit in the second or third year can cause stunting of the tree and reduce its overall growth and vigor.

The cropping targets (Robinson, 2008b) are as follows:

- Year 1: 1-5 fruits
- Year 2: 20 fruits
- Year 3: 40 fruits
- Year 4: 70 fruits
- Year 5: 90 fruits

Nutrition

During the soil preparation, the soil was tested for nutrient content and pH levels. This establishes a good baseline for an orchard nutrient program (Acquaah, 2005). Any differences in the composition of the soil throughout the orchard are also important to keep in mind. Often, there will be one area that has more of a hardpan or a different soil type than the rest of the orchard. This area will need to be managed differently than the rest (Vas den Ende, 2015).
Every year, have a leaf analysis done by a reputable lab. Sometimes a visual inspection of the trees is not enough, and an analysis will detect any nutritional imbalances. The nutrition program can then be adjusted if necessary, to ensure that the crop is getting the nutrients for optimal production (Acquaah, 2005). For pedestrian orchards, fertilizer can be applied in small doses through the drip irrigation system. In this way, the nutrients stay in the root zone of the plants rather than being leached away. This is known as “spoon feeding” and is an efficient method of delivering nutrients. “Frequent low doses of nitrogen fertilizer, either through the trickle system or on the ground with irrigation, will generally improve tree growth during the first few years to speed development of the canopy” (Ferree & Warrington, 2003, p. 395).

When planning for orchard nutrition in a high-density orchard, it is important to factor in tree size. While it is important to provide nutrition for the health and productivity of the orchard, it is not recommended to “push” the trees with excessive nutrients. “Excessive fertilization, especially nitrogen, can cause too much growth, which results in greater pruning costs, delayed flowering, reduces yields, and poor fruit quality” (Ferree & Warrington, 2003, p. 395).

**Pest Management**

Weed control is important for the health of the trees, especially young trees. After trees are planted, place milk cartons or tree protectors around the bottoms. This will protect the tree from herbicide sprays. The tree protectors shield the young trees sunburn and excessive
wind as well. The center of the aisles can be disked to disrupt the weeds. After the first two growing seasons, this practice should be discontinued as the tree roots will have grown into this area (Ruis & Lacarte, 2010). The middle of the aisles can still be mowed to help with weed control.

Gophers are a concern as well. Gophers feed on young roots and can cause tree death. Monitor the orchard for gopher activity, especially in the springtime (Acquaah, 2005).

A dormant oil spray in the early spring is recommended for most orchard crops to control aphids, mites, and scale (Wonderlich et al., 2007). Dormant copper sprays help with disease control and are especially important after pruning to prevent infection.

Crop specific guidelines for insect and disease management can be found at the UC IPM website www.ipm.ucdavis.edu. This is a valuable resource for growers. Another option is to hire a professional crop consultant or pest control advisor (PCA). A PCA will usually have one charge for the entire growing season. Their service includes monitoring the orchard and making application recommendations.

For other advice about irrigation, nutrition, training, or pruning of specific crops, contact the local university extension advisor for the production area. Most states have a Division of Agriculture and Natural Resource program that provides extension agents for farmers. The UCANR in California is a robust program with a great informational website with industry information and grower specific guidelines, including research on high density orchards and mechanization. The USDA also has some educational resources, including a program specifically for beginning farmers. Information can be found on the USDA website.
Section A3. Adapting the Pedestrian Orchard to the Backyard

High density plantings are suitable for a backyard. The compact tree size allows for multiple varieties in a small space, so it is possible to plant multiple crops. Another option is to plant one crop with different ripening times, for instance multiple peach varieties, resulting in fresh peaches from early July through August (Creasy, 2010). Design options are plentiful. Depending on the shape and size of the backyard, a hedgerow may be an option. It is also effective to plant multiple trees in one hole, up to four trees (see Figure 24). This “close-planting” helps to keep trees small and manageable. Also, with multiple varieties in such close quarters, pollination is optimized.

Figure 24
3-in-a-Hole

Note: Picture used with permission from UCCE Master Gardeners of Sacramento County.
Get to know the conditions in the backyard. Track where the sunlight hits and the number of hours of sunlight in the proposed planting area. Note the soil condition. If drainage tends to be slow, it will help the trees to plant them on a raised berm.

If planning a hedgerow, trees can be planted three feet apart. Use the same or similar rootstocks for the trees, this will simplify management. If planning multiple trees in a hole, the trees can be planted 18 inches apart, then three feet from the next grouping (Creasy, 2010).

When planting, whether in the ground or on a raised berm, keep the crown of the tree above the soil line. This part of the tree is susceptible to soil-borne bacteria and moisture.

Summer pruning is a good way to keep the trees small. Cutting off the photosynthetic leaves de-invigorates the plant and encourages fruiting rather than vegetative growth. When pruning, cut off enough growth to keep the trees at a manageable height (Parker, 2014). If one variety is outgrowing the others, cut that tree back more severely so it does not shade out the other trees. Also, consider air circulation. If air can flow through the tree, it helps minimize disease and fungal pressure. It also allows for adequate spray coverage for pest control (Parker, 2014). The other thing to watch for is branches rubbing together. In this case, one or both should be cut back to avoid infection.

Another option is to hire a company that specializes in the installation of backyard orchards. Many people are quite passionate about edible landscapes and have creative ideas for any yard. When properly installed, backyard orchards only require a few days of work per season and can yield many pounds of fresh fruit and nuts (Copeland, 2011). This system incorporates the concept of edible landscapes (Creasy, 2010). According to Sutton of Orchard
Keepers in Santa Cruz, “if you’re going to water it, you should be able to eat it” (Copeland, 2011, p. 15).

For further information on backyard projects, the local Master Gardener program is a good resource. The Master Gardener program was started in the 1970s in Washington State to help the agricultural extension agents. Master Gardener participants receive several weeks of extensive training and have experience with plants in the local area, so they are a great resource for homeowners. In most states, the Master Gardeners can be found through the university farm extension office.
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