agronomy

MDPI

Review

Training Systems and Sustainable Orchard Management for European Pear (*Pyrus communis* L.) in the Mediterranean Area: A Review

Stefano Musacchi [1,*], Ignasi Iglesias [2] and Davide Neri [3]

1 Tree Fruit Research and Extension Center, Department of Horticulture, Washington State University, Wenatchee, WA 98801, USA
2 Agromillora Group, Plaça Manuel Raventós, 3-5, 08770 Sant Sadurni d'Anoia, Spain; iiglesias@agromillora.com
3 Department of Agricultural, Food and Environmental Sciences, Università Politecnica delle Marche, 61031 Ancona, Italy; d.neri@staff.univpm.it
* Correspondence: stefano.musacchi@wsu.edu

Abstract: In 2018, 23.2 Mt of pears were produced in the world across 1.3 million hectares (ha) of cultivated land. This review analyzes different training systems and management styles that have been adopted worldwide, emphasizing the European pear's economic and environmental sustainability for the Mediterranean area of cultivation. Despite a reduced number of cultivars utilized around the world, pear presents a plethora of innovative training systems. In Europe, dwarfing rootstocks have led to reduced planting distances and a subsequent increase in planting density. Still, the economic sustainability of these systems is now questionable. Many of the quince rootstocks have made it possible to considerably reduce the size of the tree and introduce the concept of continuous row planting, with the management of orchards from the ground (i.e., pedestrian orchard). The planting distance must be chosen according to the soil fertility, the vigor of the grafting combination, and the training system. The planting distance dramatically affects the pruning and the management of soil, fertilization, and irrigation. The reduction of tree size also lowers the volume of spray necessary when applying pesticides. The variability in yield worldwide results from the interaction amongst cultivar/rootstock/training system/climate/management.

Keywords: spindle; Palmette; fruit wall; vertical axis; bi-axis; pruning; orchard management; cultivar habit

Citation: Musacchi, S.; Iglesias, I.; Neri, D. Training Systems and Sustainable Orchard Management for European Pear (*Pyrus communis* L.) in the Mediterranean Area: A Review. *Agronomy* **2021**, *11*, 1765. https://doi.org/10.3390/agronomy11091765

Academic Editor: Marco Cirilli

Received: 22 July 2021
Accepted: 30 August 2021
Published: 2 September 2021

1. Introduction

In 2018, the world production of pears was 23.2 Mt across a cultivated area of 1.3 million hectares (ha) [1]. The top ten producers in the world are reported in Table S1. China was leading the production followed by USA and Italy, with India ranking amongst the top ten as well. China's production is mainly based on Asian pear cultivars, while the other countries are producing European pear cultivars. At the European level (EU28, before Brexit), the primary cultivar is Conference, which on average across five years 2015–19, represented 42% of all production, followed by Abbé Fétel with 13%, Williams with 12%, and Rocha with 7%. These four cultivars represent 64% of pear production. In Italy, in 2019, two cultivars, Abbé Fétel (37%) and Williams (27%), accounted for 64% of pear production. In other pear-producing countries, the level of specialization is even higher, and one can even reach the varietal monoculture of Portugal, which produces only the Rocha pear. In Belgium and the Netherlands, Conference is grown almost exclusively and represents 91% and 75.9% of the production, respectively. Spain's main cultivars are Conference (50%), Blanquilla (11.8%) (the most produced until 2002), and Coscia (11.5%), which together represent 73.3% of the country's total production [2].

In the USA, Williams (Bartlett) (51%) and Beurré Anjou (34%) alone account for about 85% of the total production. Among the producers of the southern hemisphere who are also the leading exporters of pears, it is worth mentioning Argentina, where Williams (40%), Packham's Triumph (30%), and Beurré Anjou (15%) represent 85% of production. In Chile, the variety assortment is based on four cultivars Packham's Triumph (34%), Abbé Fétel (18%), Forelle (12%), and Coscia (10%). In South Africa, the main varieties are Packham's Triumph (34%), Forelle (26%), Williams (19%), and Abbé Fétel (6%) (Prognosfruit, 2019). It should be noted that the production of Packham's Triumph is mainly concentrated in the southern hemisphere [2].

This lack of varietal innovation is common to all countries where this species is grown. In many cases, the pear is perceived by the consumer as an "ancient" product. To this, varietal stagnation is added to the challenging environmental conditions present in some production areas. For example, in Italy, pears reduced fruit set with heavy frost conditions at bloom in 2021. Additionally, they experienced prolonged, very hot summer periods with temperatures higher than 35 °C for several days in northern Italy. These conditions can be associated with climate change and are becoming more and more frequent. Thus, severe problems are arising (a sort of sudden pear decay), mainly in high-density orchards of Abbé Fétel grafted on dwarfing quince (*Cydonia oblonga*) clones [3]. Phytosanitary problems/pests have also increased, such as the Asian stink bug (*Halyomorpha halys*), blackspot (*Alternaria alternata* or *Stemphylium vesicarium*), fire blight (*Erwinia amylovora*), psylla (*Cacopsylla pyri* in Europe and *Cacopsylla pyricola* in North America), pear scab (*Venturia pyrina* for European pear and *Venturia nashicola* for Asian pears), and valsa (*Valsa ceratosperma*) [4–7]. All of these issues jeopardize the sustainability of this crop. Therefore, mitigating pests and increasing the level of production and fruit quality are fundamental goals to maintain the vitality of the pear industry. The few breeding programs around the globe that are still active have obtained cultivars that are resistant or tolerant to some of these biotic adversities. Still, despite this competitive advantage over traditional varieties, they struggle to establish themselves on the market. These new cultivars are more sustainable than the old ones, given their tolerance/resistance capabilities, thus limiting the need for chemical pest control applications [4,5].

As previously mentioned, varietal compositions show specialization in the different producing countries, and the lack of innovation is a worldwide characteristic of pear production, compared with other species, such as apple or stone fruit species [8]. The effort of different active breeding programs during the past decades resulted in selecting a large number of new varieties [9]. Pear consumers are used to buying traditional and specific varieties in terms of appearance and taste. For this reason, innovation is difficult and requires extra effort when compared to apple, where new variety development is common [9]. Consequently, any new variety has significantly impacted pear production compared with the important number of varieties released. Only specific examples of development are in progress, such as Q-Tee, Fred, Sweet Sensation, Migo, Angelis, Pika series, Carmen and Falstaff in Europe, Cheeky, New Celina and Gräfin Gepa in South Africa, or Summercrisp in the USA [4,10].

Despite the lower level of innovation in variety development, a wide range of orchard design systems, from low density to ultra-high density, are already established worldwide [11]. In general, we are observing an increase in planting density in pear orchards, enhanced by the use of dwarfing rootstocks (Table 1). In recent years, especially in Europe, there has been a gradual intensification due to the use of quince accessions characterized by limited vigor [12,13]. The possibility of using rootstocks characterized by different vigor and the plasticity of the pear allows the tree to be modeled in various shapes, which has favored the high diversity of the training systems adopted worldwide [12,14–17].

Table 1. Historical profile of pear orchard development in Italy's main district (Po Valley).

Density	Trees/ha	Rootstock	Training System
1930s–1940s			
Low	300–500	Seedling	Open Vase and Pyramid
Medium	500–1500	Seedling	Pyramid
High	1000–3000	Local quince	Spindles and horizontal Palmette
Very High	3000–6000	Local quince	Vertical axis
1960s–1970s			
Low	1000–1500	Local quince	Palmette oblique
Medium	1500–3000	Angers and Provence quinces	Irregular Palmette and spindle bush
High	3000–4000	Angers and Provence quinces	Spindle
Very High	>4000	Provence quinces	Spindle
2000s–2020s			
Low	1000–1500	Seedlings, BA29	Free Palmette
Medium	1500–3000	BA29, Sydo, MH	Free Palmette and spindle
High	3000–4000	MH, Adams MC	Spindle, V system
Very High	>4000	MC, Adams	V-system, Vertical axis
Ultra High	>8000	MC	Vertical axis

The high-density planting (HDP) orchards are generally not designed to last very long. Nowadays, the orchard layout tends to reduce the economic life within 20 years [11]. For this reason, trees must crop early, by year 2–3, and pre-formed trees from the nursery can minimize the unproductive time [12]. Other potential problems are related to the necessary intensive management and outbreaks of diseases, or weather events like hail or frost, that can reduce the orchard's economic viability. In some production areas, where the conditions are more favorable, orchards can last 30–40 years or more, like in the Pacific Northwest of the USA and Argentina [11]. Planting density is a relative concept and can vary in the different districts of production. High-density plantings were initially developed to increase yield and optimize fruit quality [11]. Large canopy trees have a population of fruit characterized by varying maturity levels depending on the canopy position where they are born [18]. Therefore, the planting distance dramatically affects the type of pruning that must be chosen and applied to optimize the balance of the tree. Additionally, the management of the training system must also follow the habit of the cultivar to avoid drastic interventions and delays in fruiting [19].

This review will analyze the different training systems adopted and management styles around the world, emphasizing the economic and environmental sustainability of this crop.

2. Rootstocks

For the European pear, it is possible to distinguish two main groups of rootstocks: the quince (*Cydonia oblonga* Miller), used mainly in Europe, and the pear rootstocks (*Pyrus communis* L.), mostly obtained from seed or clones, which are mainly widespread in USA, South Africa, and South America, while their use in Europe is primarily limited to Williams [12,15,20–22] (Figure 1, Table S2, Appendix A).

The most viable rootstock option for all types of high-density production in fertile soils and suitable climates is dwarfing quince. Indeed, the best response from quince emerges in cool continental climates, without excessive winter temperature swings in non-lime, non-clay, or otherwise non-heavy soils. Quince often responds unsatisfactorily in hot, dry Mediterranean or sub-tropical areas, even when irrigated, due to high spring and summer temperatures curtailing root development and shoot growth, leading to phenomena like graft incompatibility with most of the pear varieties. The more dwarfing a stock is, the greater the risk of these phenomena, and with the impacts of climate change, this risk continues to increase [23,24].

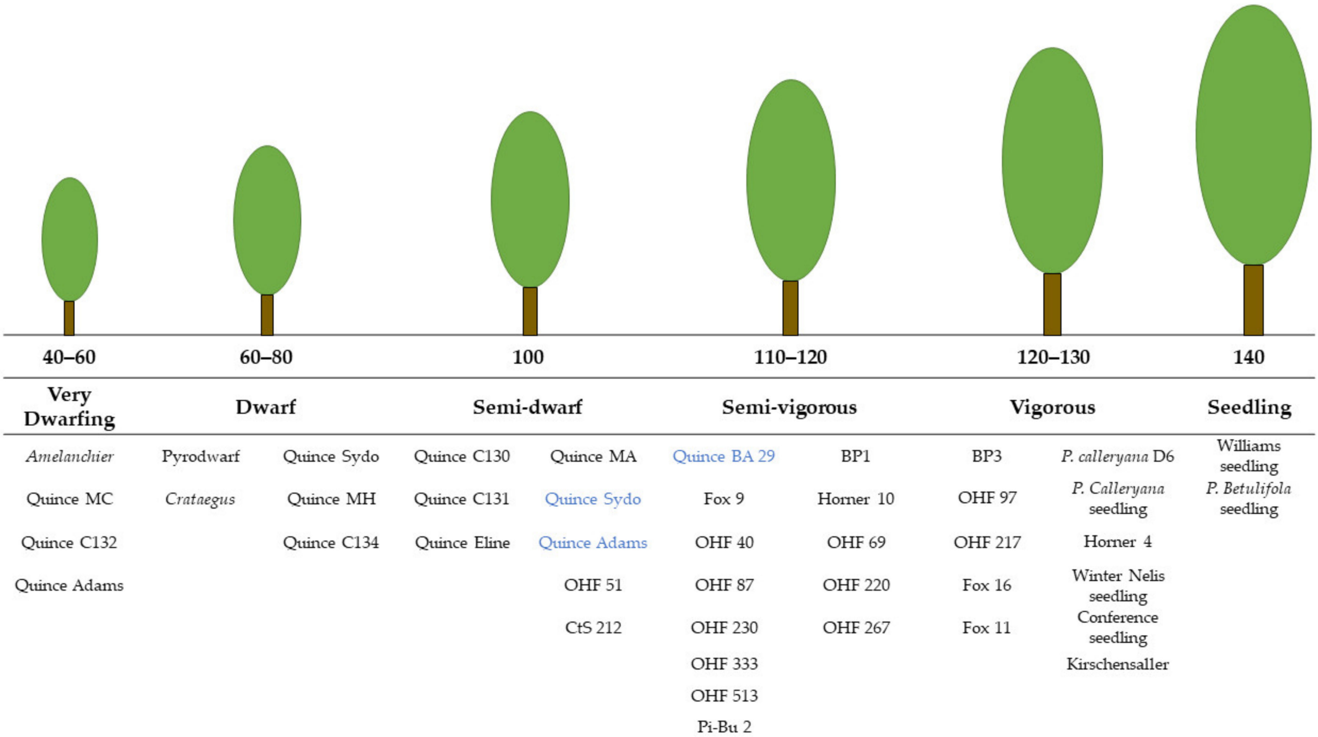

Figure 1. Main rootstocks utilized and their vigor compared to quince MA in Italy. The accessions in blue express the vigor in a different district of production (Ebro Valley-Spain).

In Italy, the largest pear producer in Europe, the most common rootstocks are the quinces. The presence of self-rooted varieties should also be noted, such as Williams, Abbé Fétel and Conference, which account for only 1% of the total orchards. Among the quince rootstocks used in Italy, BA29 (44%), Sydo (24%), and Adams (13%) together represent 81% of all trees produced [25]. It should be noted that the quince MC, which represented 15% of the production of new trees in 2012, has now practically disappeared due to some of its negative characteristics. These include sensitivity to iron chlorosis, small fruit size, and a high level of graft-incompatibility. However, there are varietal differences in the use of quince rootstocks. For example, 97.4% of the nursery-produced Abbé Fétel material is grafted on quince, while for Williams, this percentage is only 61% [25]. In general, quinces allow the control of tree vigor, rapid entry into production of the orchard (i.e., precocity) [21,26], and are particularly suitable for HDPs up to 3000–4000 trees/ha. Additionally, the ease of propagation linked to high rhizogenic capacity is also among the advantages of using quinces. On the contrary, a significant disadvantage in the use of quince is the high susceptibility to iron chlorosis [27,28], compromising the production results in some cultivation areas, such as those characterized by sub-limestone and heavy soils. Another limiting factor in the use of quince is graft-incompatibility, which in some combinations becomes particularly serious [29]. The graft-incompatibility between pear and quince is localized so that it can be overcome with an interstem technique, consisting of the interposition of a compatible cultivar between the incompatible scion and the quince rootstock. The most used variety as an interstem is Beurré Hardy. Especially important are these two limiting factors: susceptibility to iron chlorosis and lack of compatibility with important varieties such as Williams or Guyot, in the Mediterranean basin of south European countries like Spain, France, or Italy [9]. In Spain, MC has never been used due to the negative characteristics described previously in Italy. In recent years, the use of BA29 or MA shows a lack of vigor and decay of vegetation and yield in adult trees. Furthermore, in the choice of rootstocks clones, it must be considered that the high summer temperature limits the root growth in the upper most layers of the soil, which creates problems, like pear decay, for low vigor rootstocks in high-density orchards. Hence, the fruit industry needs to have new size/vigor controlling rootstocks in the *Pyrus* genus [30,31] to limit the use of quince as a rootstock.

3. Orchard Design and Planting Density

The use of dwarfing rootstocks has led to an increase in planting density. Many of the quince rootstocks have made it possible to considerably reduce the size of the tree and introduce the concept of continuous row planting, with the management of orchards from the ground (i.e., pedestrian orchard). The planting distance must be chosen according to the fertility of the soil, the vigor of the grafting combination, and the training system to be adopted (Tables 2 and 3). The reduction of tree size also lowers the volume of spray and the amount of active compounds necessary to apply pesticides [32–35].

Table 2. Training systems, spacing, and rootstocks of pear orchards in Italy's main district (2010–2020).

System	Density	Spacing (m)	Trees/ha	Rootstocks
(1) Low, Medium and High density				
Spindle bush/pyramid	LDP LDP	4.5 × 2.5 5.0 × 3.5	890 570	Seedlings
Free Palmette	LDP LDP LDP	3.6 × 1.5 4.0 × 2.0 4.0 × 1.5	1850 1250 1660	Seedlings, OHF 40, BA29 BA29
Slender Spindle	MDP HDP LDP	3.5 × 1.0 3.5 × 0.7 4.5 × 1.2	2850 4080 1850	BA29, Sydo, MH MH, Adams, MC BA29
Y systems	MDP	4.0 × 0.8	3125	Sydo, MH, Adams, MC
V shape, cordons, vertical and oblique axis	HDP	3.5 × 0.7	4081	Adams, MC
(2) Very high and ultra-high density				
Super spindle and V shape	VHDP	3.5 × 0.7	6000	Adams. MC
Vertical axis, cordon	VHDP	3.0 × 0.4	8000	MC
Cordon and super spindle (testing)	UHDP UHDP	3.0 × 0.3 2.5 × 0.3	11,000 13,000	MC MC

Table 3. Training Systems and spacing of pear orchards in Spain's main district Ebro Valley (2010–2020).

System	Density	Spacing (m)	Trees/ha	Rootstocks
(1) Low, Medium and High density				
Free Palmette/Pal-Spindle	LDP LDP LDP	4.0 × 2.5 4.0 × 2.0 4.0 × 1.5	1000 1250 1667	KIRSCHENSALLERBA29 MA
Slender Spindle or central axis	MDP HDP LDP	4.0 × 1.2 3.5 × 1.0 3.0 × 0.8	2083 2857 4166	BA29, MA BA29, MA MAMH
Y systems	MDP MDP MDP	4.0 × 1.2 3.5 × 1.0 3.0 × 0.8	2083 2857 4166	MA, Sydo, MH
(2) Very high density				
Vertical axis	VHDP	3.0 × 0.4	8333	BA29, MA, MH
Y system	VHDP	2.8 × 0.6	5952	BA29, MA, MH

In pear, it is possible to find orchards characterized by less than 1000 trees/ha, up to very high-density plantings with 13,000 trees/ha. These latter planting densities find an economic value only in the conditions in where production is maximized without taking into account the negative effect of reducing the size of the fruit [11,32,33].

For the low-density plantings (LDP) (1000–1500 trees/ha), the most used form is still the Palmette (hedgerow-fruiting wall), which maintains its validity, but also shows some limits, such as large planting distance, slow entry into production, difficulties in the mechanization of many cultivation operations, higher pruning requirements (in particular during the formation period), and harvesting costs depending on canopy height [36]. These planting densities are mainly utilized for seedling rootstocks like the Farold® series and the most vigorous quinces (e.g., BA29). With LDPs (600–700 trees/ha), the trees can be trained as small open vases without any support structures [37].

The spindle training system is the most widespread for medium- and high-density plantings (MDP, HDP) (2000–4000 trees/ha). It allows the intensification of orchards without excessive costs of structures and labor, especially in harvesting operations that are carried out almost exclusively from the ground [32,33]. The use of the spindle requires pre-formed trees with feathers from the nursery that allows, in combination with the use of dwarfing quince rootstocks, such as Adams, MH, Sydo and BA29, to obtain significant early production in the second/third year of planting [38–40].

In regard to MDPs (3000 trees/ha), the most recent Y-shaped system has also been developed, with a pre-formed bi-axis tree in the nursery. This system is also known as Bibaum®. This type of tree avoids the need to head back the main axis in the field and suffer the consequence of losing one year for canopy formation. In any case, an excessive crop load level must be avoided in the first two years to help achieve the final size of the tree. It is a "fruiting wall" system (flattened and high), similar to the Palmette, that helps control the tree's vigor by dividing it into two pre-formed axes in the nursery (i.e., vigor distribution). An advantage of this system is the reduction of pruning times in the first years after planting in the field [12,13]. This training system utilizes semi-dwarfing rootstocks like Sydo or BA29.

For VHDPs (5000–8000 trees/ha), the alternative to the spindle is the V-system, obtained by alternately tilting the trees at an angle of 15° from the vertical. This system is particularly suitable for the vegetative-productive habit of pear and has the great advantage of doubling the productive walls to maximize light interception and early yields. On the other hand, the disadvantages are represented by the higher costs of trees and support materials (e.g., trellises) and the increased labor required to prune the internal parts of the tree [11]. The rootstocks utilized in combination with this training system are MC, Adams, and, for low fertility soil, MH [32,33]. The common distance used in commercial orchards with this VHDP is 2.8 m × 0.6 m (5952 trees/ha). Conference and Rocha, mid-vigor cultivars, on MA and BA29 rootstocks are the main selections utilized with this system. Full yields are achieved in the 4th year of planting, and the mean average annual production is between 40 to 50 t/ha.

Finally, the vertical axis has been adopted for the ultra high-density plantings (UHDP) (9000–13,000 trees/ha) due to the reduced planting spacing. No more than 30–35 cm spacing is given within the row and 2.5–2.8 m between the rows. A vertical axis is formed with short branches with periodically renewed spurs [32,33]. This system has a very high initial cost and can only be performed using dwarfing rootstocks like quinces MC and Adams because the other rootstocks are too vigorous. In these UHDP orchards, where the trees are 30–35 cm from each other, the self-production of the trees directly in the field is used very often to reduce the establishment costs [11,12,39,40]. Towards the end of the 1990s, the use of the quince MC made it possible to reduce the size of the trees and allow this increase in planting density.

When choosing the appropriate planting density, the driving reason is the cost of labor increasing more than the fruit price for growers. However, three key concepts must be respected: (a) integrated pest management or organic production (which almost all orchards adhere to in Europe), while limiting the use of fertilizers and pesticides; (b) sourcing virus-indexed and genetically certified plant material for both cultivars and rootstocks; and (c) achieving high fruit quality to remain competitive in the market [23,24]. High density is a relative concept, varying and adaptable to a range of circumstances: containing tree growth, inducing early cropping, increasing yield efficiency without the risk of rapid tree decay, enhancing fruit quality, cutting management outlays, and promoting faster orchard turnover [23,24].

4. Productive, Economic, and Social Sustainability

Early cropping is important to reach the break-even point since overhead costs cannot be cut beyond a certain threshold, and prices cannot be raised by command. This is viable only with trees carrying pre-formed branches in the nursery to attain two-year-old limbs with buds during the first year of orchard life [23,24]. The economic success of spindle systems, with scions having numerous pre-formed branches of the right length for orchard spacing, demonstrates this. When density is very high (>5000 trees/ha), desirable cropping with super spindle, cordon, or single-axis trees calls for an extra reproductive effort that is not always possible. There must be many early, short branches with the potential to originate fertile spurs in one season while giving rise to fertile stem spurs. Since this occurrence may not always be possible, year-2 cropping is not at a peak, and any chance of breaking even vanishes with low pear prices, given the high investment outlay. Hail nets are a must in districts at risk, especially when it comes to VHDP, in that any damage will readily impair not only the immediate crop but extend to affecting orchard life as well. Trees should have the capacity to renew and form short fruit-bearing organs, like brindles (shoots that carry only one fruit bud at the apex), directly on short limbs and the trunk. Almost without branches, the single-axis tree should have a high natural spur potential. As a result, in Italy, the costs of HDP orchards establishment achieve and exceed 50,000 €/ha (including hail nets and irrigation equipment). Yet, this means that investment outlays are a real constraint. According to the training system, the additional costs for an intensive planting mean that the break-even point is reached, with fruit prices of at least €0.45/kg, between the 6th and the 11th year, according to the training system [23,24]. In a 20-year run, the most profitable shape is the slender spindle, and the least is the super spindle. If pear prices achieve only 0.30 €/kg, neither the former nor the latter training system cover the cost until 20 years old. More recently, an additional problem for the Italian pear industry is the declining yield per hectare due to climate adversity and pest and disease pressure. In 2018, the average yield per hectare in Italy was 24.2 t/ha [1]. Other producing countries such as Switzerland (53 t/ha), New Zealand (51 t/ha), Holland (40 t/ha), United States (38 t/ha), Belgium (36 t/ha), and Chile (34 t/ha) recorded much higher yields per hectare [1]. In particular, Abbé Fétel is now presenting a problem of profitability and the inability to compete on international markets due to the high production costs and the low level of yields. In fact, Abbé Fétel, the main variety produced in Italy, has an average production cost per year of €18,000, one of the highest ever in the fruit sector. This translated into a unit production cost oscillating between €0.6 and €0.75/kg of product [41].

Production cost has always been an important factor of competitiveness for fruit growers. This is even more important in the scenario of the last two decades, since the prices perceived in the main producing countries of Europe, in general, cannot compensate for the production costs. To give an example of a cost partitioning, the data corresponding to Conference and Abbé Fétel cultivars in a traditional bi-axis orchard in the Ebro Valley Spain are exposed in Figure 2. The labor represents 38% as the main cost (harvest and winter pruning), followed by crop protection, plant phytoregulators, and soil cover crop management (25%) (Figure 2). These data show that by increasing the efficiency in the use of labor and crop protection, the cost could be significantly reduced. The remaining costs (direction, amortization, insurance, etc.) are more difficult to reduce and are not related to the use of inputs. In this case, the total cost of planting is 20,500 €/ha and 35,000 €/ha with hail net protection.

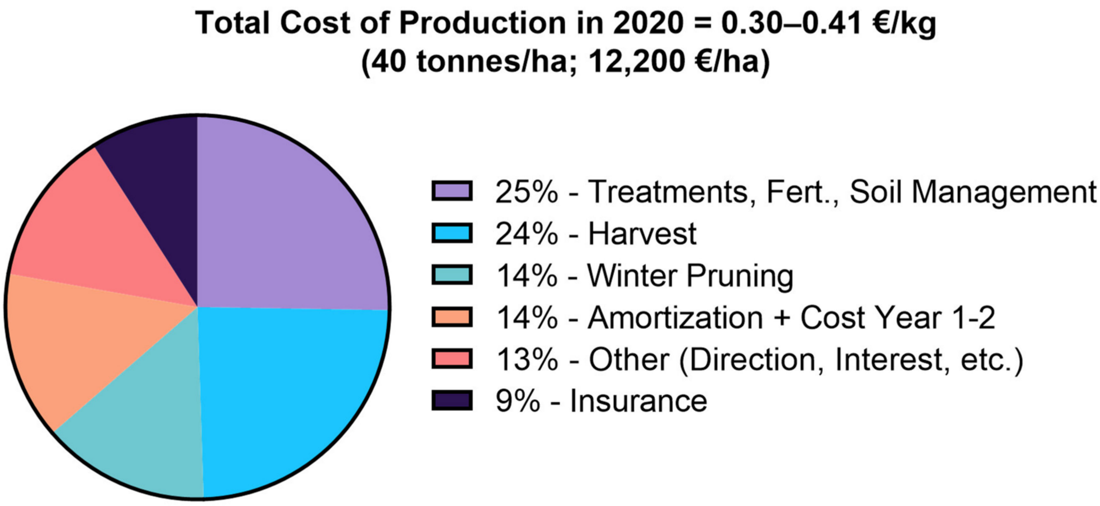

Figure 2. Cost of production corresponding to Conference (0.30 €/kg) and Abbé Fétel (0.41 €/kg) pear cultivars in a traditional orchard trained in bi-axis in the Ebro Valley, Spain.

The development of intensive orchards with planar canopies improves the efficiency of labor, machines, and inputs such as pesticides, fertilizers, or water irrigation when compared to a traditional goblet used in different producing countries. Several authors reported a reduction of cost of production from 15 to 25% in peach, plum, or almonds [42–44]. Pear has been, together with apple, one of the species on which the availability of size controlling rootstocks, as quince selections, resulted in developing more intensive orchards and more two-dimensional canopies. In any case, the production cost reduction should not be the only strategy for successful pear production, since the fruit quality and the environment should always be preserved for any certified premium-price label.

Sustainable farming systems need to have a social dimension. Organic farming is presently in transition from a niche to a mature sector. There is scope for the development of organic certification systems. The main driving forces conditioning the future development of the organic farming system in Europe include disposable income; consumer attitudes towards environmentally friendly products and organic, 'low-input' substitutes; and policy targets. Organic farming in Italy represents a promising business opportunity nowadays, particularly for young farmers. Besides the progress of organic farming management, new holistic approaches capable of reconnecting agriculture and food chains with societal needs represent new promising frontiers for pear production [45].

5. Training System

In pear, as in other deciduous fruit species, selecting a specific training system is important as it will determine the rootstock to be used and the inter-row/inter-tree spacing. Considering the training system evolution in pear over the last 50 years, it is clear that it is undergoing a process of intensification resulting in smaller trees, much like what has happened in apple (Figure 3). This results in early yields and a reduction of labor in the first years when training the trees. This is because the space assigned to each tree is smaller, so there is no need for the manual bending or inclination of branches to the right position compared to higher volume vase or Palmette training systems. It is also important to point out that this change of canopy architecture from volume (3D) to planar (2D) canopies (Figure 3) has also been associated with the availability of vigor controlling rootstocks, mainly quince selections (MC, MH, MA, BA29), as exposed previously.

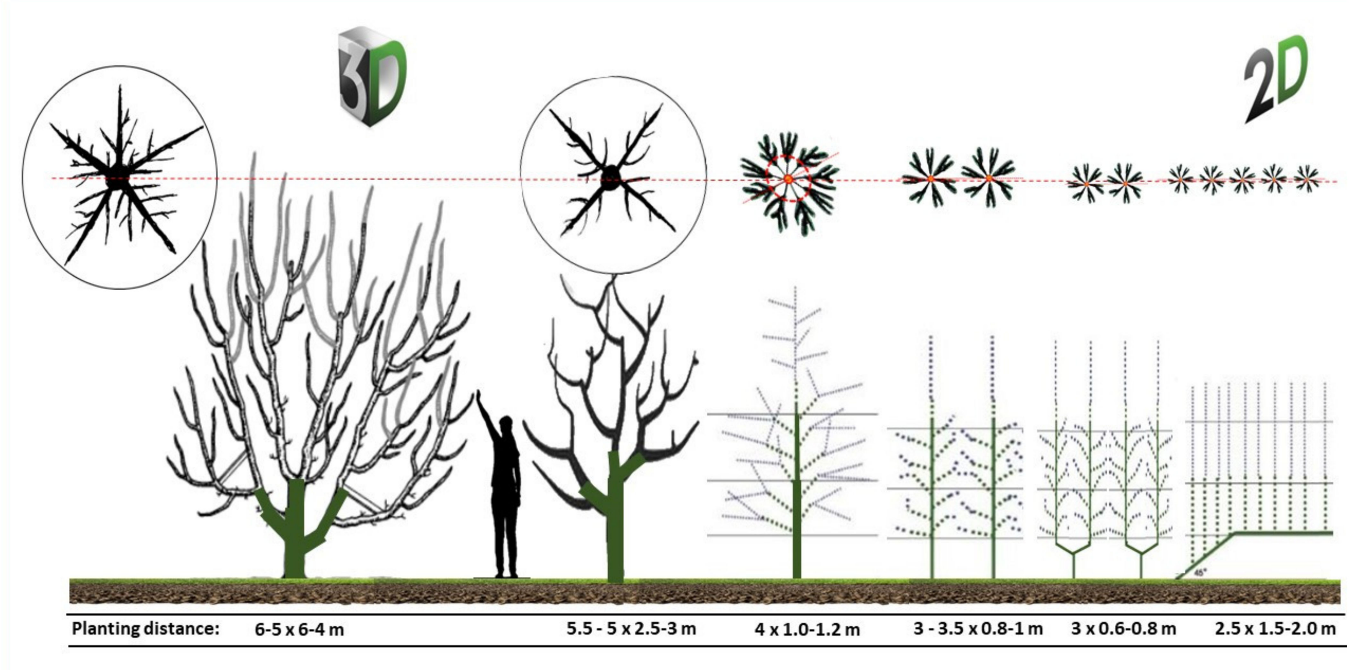

Figure 3. Evolution of training systems used or currently in use in pear over the last decades: from the traditional open vase through the modified central leader, axis, bi-axis, and multi-axis. The top part of the figure showcases the cross-section projection of the canopy [43].

This change, from volume or tri-dimensional canopies to planar or bi-dimensional canopies, has been linked to a progressive reduction of the spacing through the intensification of the orchards. Several authors reported this intensification as key for the efficient use of inputs in current and future fruit production [35,46]. Considering planar canopies, different options have been developed or are being developed in several countries, and are mostly based on bi-dimensional tree architecture. Several examples of these intensive and bi-dimensional training systems are illustrated in Figure 4.

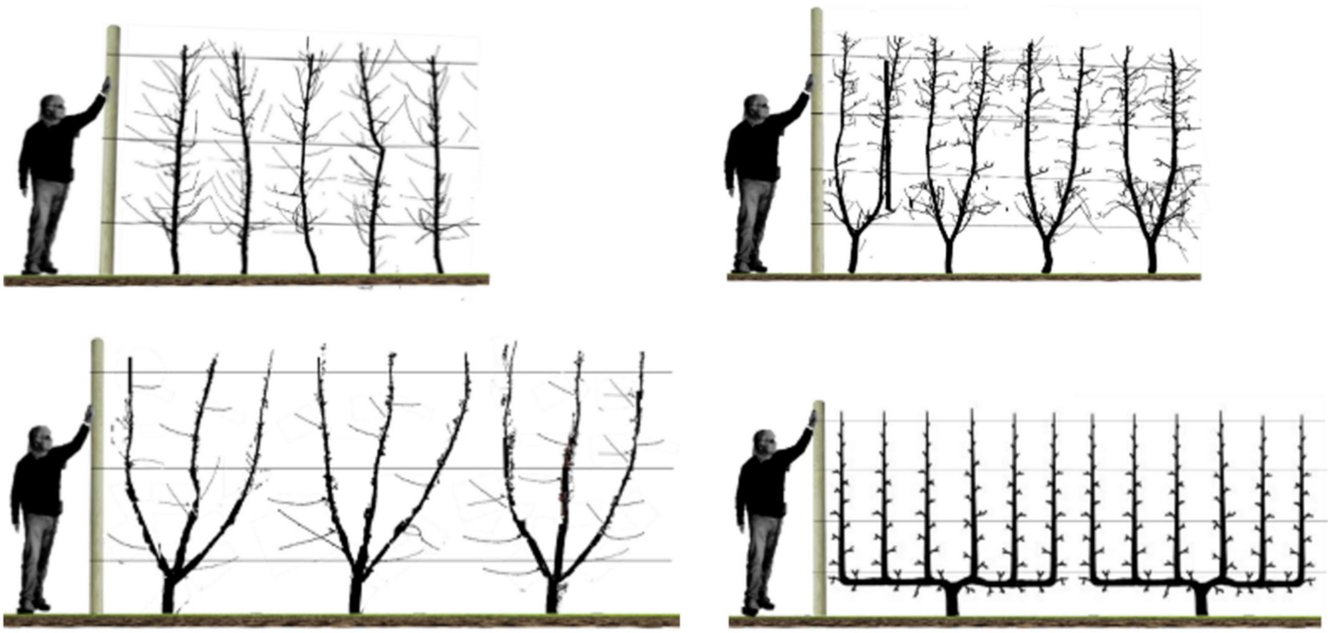

Figure 4. Different options for intensive orchards systems in pear: from the central axis to bi-axis, tri-axis, and multileader.

5.1. Low-Density Training Systems (Open Center, Palmette, Candelabro)

5.1.1. Open Center

This training system is typical of production districts like the Pacific Northwest (PNW) in USA and Argentina in South America. The reason for the use of this system is mainly related to the lack of new orchard plantings and new cultivars. In the PNW, quince rootstocks are not utilized, since they are severely damaged from cold weather during winter. In Argentina, the use of flooding irrigation limits the use of quince, due to too frequently very wet and dry soil conditions (superficial waterlogging and drought). Therefore, in these regions, the rootstocks utilized are often seedlings, which promote larger-sized canopies and deeper root systems. The structure of the open vase (globe-shaped canopy) is mainly formed by three or four leaders distributed respectively with an angle of 120° or 90° [47,48]. Each leader is pruned accordingly to allow light penetration into the center of the canopy. The high vigor level at the top of the tree and the growth of waterspouts complicates light penetration into the lower part of the canopy. For this reason, to reduce intra-tree shading, summer or fall pruning strategies are adopted to improve light distribution in the canopy [48,49]. The canopy position influences fruit characteristics such as color, soluble solids concentration, and fruit size. A broad level of differences has been described in the fruit produced with this training system by Zhang et al. [18]. Additionally, flower bud formation, fruit set, and fruit size are negatively influenced by poor light penetration, as reported in a study by Khemira et al. [50]. Furthermore, this training system requires a high volume of water/chemicals to spray the canopy and control pests/diseases [47,48]. Another drawback of the system is the difficulty of mechanizing harvest and pruning operations, which are currently performed with ladders [47,48]. A more sustainable approach using vigorous rootstocks (including in vitro propagated Conference used as rootstock) in central Italy (Mediterranean climate) was obtained with a local variety (Angelica) trained as a small open vase in rain-fed orchards with winter production pruning and summer heading back of the vigorous branches [37,51].

5.1.2. Palmette (Hedgerow) with Vigorous Rootstocks or Self-Rooted Cultivar

The Palmette maintains its validity in some areas of pear cultivation, such as Italy, Chile, and Argentina. This training system is traditionally utilized due to particular pedoclimatic conditions, especially where the use of dwarfing rootstocks has not spread. In fact, areas with high levels of active lime make it difficult to use dwarfing quince rootstocks due to the high incidence of iron chlorosis. Additionally, districts characterized by strong spring frosts prefer this training system, as it was developed with increased heights to minimize the frost damage on flowers. In an alternative to quince, for the Palmette, it is possible to use clonal rootstocks such as Farold® 40 or Farold® 69 or, in extreme cases, the self-rooted cultivar with low planting densities (1000–1500 tree/ha) [32,33]. However, it is possible to use this training system combined with the more vigorous quinces such as BA29. The most widespread typology of Palmette is called "free Palmette". Initially, this training system requires trees characterized by a high presence of feathers. The formation of the canopy is not organized with a rigid structure, and several branches are present and oriented with a crotch angle of 30–45° in the direction of the intra-row. This training system is based on a minimum initial pruning principle and on bending the most vigorous branches. The containment of vigor, especially in the case of the self-rooted cultivar, is very difficult, and pruning interventions, especially at the beginning, must be limited to support the tree's growth. In the initial phase of training, it is possible to bend the main axis of the tree to obtain a new leader and a very strong branch to limit the growth of the central axis. Pruning involves the removal of very vigorous waterspouts, when they are still in the herbaceous phase while trying to keep the branches of the current season less vigorous to ensure the formation of buds in the following year. This system hardly goes into full production before the fifth-sixth year. To enhance the early onset of the production, "taille long" is frequently used in organic pear production with a self-rooted Palmette of Abbé Fétel. Heading back is not used, waiting for the production on the three-year-old limbs; only after the second heavy production will each branch be pruned to allow the renewal of one-third of the fruiting spurs. Moreover, whenever possible, the inclination of the watersprouts during winter is applied to stimulate the fruiting bud formation in the basal-medium portion of the limb in the second-third year without any heading cuts. Over the years, the use of both systems, the free Palmette and the regular Palmette, has been declining due to specialized labor required to train the trees during the unproductive period. The advantage of the bi-dimensional canopy is important when thinking about mechanization and efficiency in the use of pesticides [37]. The increasing availability of size controlling rootstocks offers different options to make the Palmette more efficient in terms of inputs use, especially labor. Once in production, it is necessary to try to maintain a good renewal of the branches with periodic pruning to eliminate the ones that have already produced and are exhausted. Furthermore, a shortening to 3–4 buds on the shoots that are 2–3 years old can increase fruit set by reducing the competition between the various reproductive organs. In some cases, a pruning strategy with three cutting levels is also proposed: one-third of branches is not shortened, one-third is reduced by 50% of the length, and the remaining one-third is cut to 3–4 buds in order to have a high fruit set. This allows the branches to be productive for several years as fruit set is normally quite low in the non-renewed shoots, and it is possible to observe new spur formation [32,33]. The free Palmette can also be pruned mechanically, both in the winter and in the summer. However, hedging requires attention to preserve enough fruiting spurs while summer pruning must be carried out, avoiding the very dangerous resprout of several diseases and pests.

In the case of excess vigor, this training system can be associated with root pruning as soon as the tree has reached its final size and occupied the assigned space. This will reduce vegetative development and favor fruiting. Root pruning can also be performed in the following years (in the case of very unbalanced trees) with machines equipped with specialty L-shaped blades for cutting the large pivotal roots, typical of the self-rooted pear [12,32].

5.1.3. Candelabro, Multileader System (Planar Cordon)

The Candelabro is a particular system, in terms of canopy architecture and how the vigor is distributed on one or more horizontal cordons (Figure 5). It was used in the last century and even throughout the 16th to the 19th century in France and Italy for gardening purposes. This system was primarily used in pear and apple with some experiments in peach. The objective is to build a planar canopy from numerous small and vertical axes inserted into a horizontal cordon in one or different levels. The process of training requires a high specialization to achieve perfect symmetry between the axis and cordon(s). This system was developed using semi-vigorous rootstocks and required at least 6 years to reach mature trees, with full yields obtained in 7 or 8 years [52]. Common planting distances are from 1.5 to 2.5 m between trees and from 3.5 to 4.5 m between rows. A lot of variations of Candelabro were developed depending on the country, the variety, and the sophistication required. Different options used in the past and present are illustrated in Figure 5. This system is more adapted to varieties producing in spurs and small brindles (Group III and Group IV) rather than ones that are more acrotonic and fruiting on long brindles in a weeping habit (Table 4). There are important similarities in canopy architecture with finished Candelabro trees and the current multileader systems (Figure 5). In all cases, the canopy is very narrow and based on a small and vertical axis, where fruit are directly inserted. As a result, light interception, yield efficiency, and canopy accessibility for labor, machines, and treatments (pesticides, fungicides, growth regulators) are more or less similar. The main difference when comparing different systems is how to train the trees during the first three years before arriving at mature, finished trees. In the Candelabro (Figure 5A,B), much highly specialized labor is required, something that was not limited in the past and that is almost impossible to find today. The need to head the tree back during the first two or three years results in a delayed production compared with the multileader (Figure 5D). The multileader can be based in one or two horizontal arms depending on the vigor of the specific combination rootstock/variety (Figure 5C,D). In the near future, as in apple, the plant could be pre-formed in the nursery for this specific training system, either for one or two cordons. Subsequently, the main labor in the field would be training the vertical axes, tying them to the support wires (Figure 5).

Table 4. Group of pear cultivar classified by habit (Modified from [19,53]).

Group	Characteristics	Similar Cultivar
Group I—Williams (Bartlett)	Fruiting in this group occurs mainly on one-year-old branches (brindles). With the tree's progressive aging, it is possible to observe fruiting even on spur carried on wood for 2 or 3 years.	Coscia, Santa Maria and Butirra Precoce Morettini.
Group II—(a) Doyenné du Comice and (b) Abbé Fétel	Both these cultivars produce fruit on 2–3-year-old wood-borne spurs. They require a three-year pruning cycle, which allows one-year branches to be covered with spurs the following year. These will be shortened to 3–4 buds to promote fruit set.	
Group III—Conference	A very fertile cultivar that produces spurs, inserted on 3–4-year-old branches bearing a complex of spurs. Therefore, it requires constant pruning as to remove at least 1/3 of the spurs to allow its renewal. An excess of mixed buds can lead to the formation of small-sized fruit.	Beurré Hardy and Beurré Anjou
Group IV—Beurré Bosc	This cultivar tends to crop on spurs born on old wood, or on branches of 2 or 3 years. The branches can be kept for a few years, although the formation of blind wood and the extinction of vegetative points must be avoided.	Clapp's Favourite and Packham's Triumph
Group V—Passe Crassane	This cultivar has branches that, in the juvenile stage, produce various spur and short lateral brindles. With the aging of the branches, short "rooster legs" formations are formed on which almost all of the production takes place.	

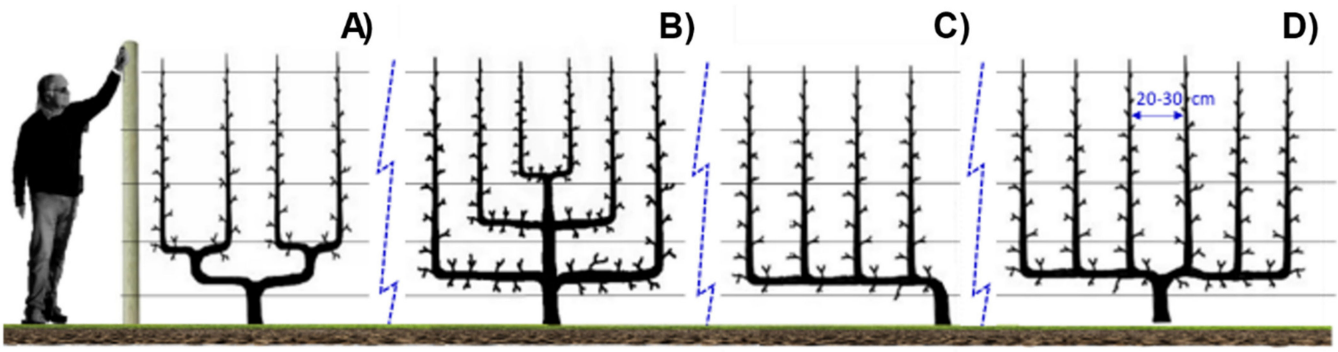

Figure 5. Two options of Candelabro system (**A**,**B**) and two options of multileader system (**C**,**D**) in pear.

The multileader or planar cordon systems can be considered as an evolution of the Candelabro training system. In the last ten years, multileader systems have been tested in several species, such as apple, peach, cherry, and plum [42,54,55]. The main objective of this system is to change the traditional architecture of the canopy based on axial structures bent horizontally, on which the leaders are inserted directly at a distance ranging from 20 to 30 cm apart (Figure 5C,D). This allows better control of the vigor, resulting in a very narrow canopy and reducing the planting density. Two options are developed: tall orchards and pedestrian orchards, depending mainly on the rootstock and spacing used. The standard spacing used in apple is 2.0 to 2.5 m in between the rows and 1.5 to 3.0 m between trees [54,56]. In pear, the first experiments started in New Zealand and Italy more than ten years ago using similar concepts from apple. Most of the current orchards are experimental, and some commercial experiences are also in process in these two countries.

5.2. Medium-Density Training Systems (Spindle, Bi-Axis)

5.2.1. Spindle

The spindle is the most used training system in Europe in medium-high density orchards because it allows the intensification of the planting density without excessive structural and labor costs. The spindle is generated using nursery trees with at least 4–6 feathers [12,32,33]. These branches are important for reducing the tree's unproductive period. Branches that are too large, with a diameter greater than 30% compared to the trunk caliper where they are inserted, are usually removed from the tree. The branches, in this case, must have a crotch angle of about 40° (they are usually tied to two wires carried by spacers that facilitate their positioning) with respect to the vertical. Some technicians propose a greater inclination to make the branches almost horizontal. In this case, the bending of the branches that will form the first branch stage must take place in the spring of the second year. These must be topped to cause a vegetative outbreak at the apex of the branch, control the vigor in the basal and median part of the branch, and avoid the emission of excessively vigorous branches. Subsequently, the branches can be shortened on one-year-old wood ("click" pruning) in order to bring the vigor towards the external part of the tree [57], or as is done in traditional pruning on a mixed bud. The varieties particularly suitable for this training system are the ones that produce mainly on two or three-year-old wood, like Abbé Fétel and Conference. In the second-third year, pruning management depends on the control of the vigor implemented by the previous interventions. The varieties particularly suitable for this training system are the ones that produce mainly on two or three-year-old wood, like Abbé Fétel and Conference. Pruning management depends on the control of the vigor implemented by the previous interventions. If the root system has been pruned, it is possible to remove the shoot (with a Dutch cut) that does not end with a fertile bud and leave only the ones that carry a mixed bud at the end. On the contrary, if the root system has not been pruned, the removal of the shoot must be limited only to the most vigorous ones. From the third year onwards, there may be problems with the aging of the branches, especially when the trees have undergone heavy root pruning to control vigor. In this case, it is necessary to stimulate the formation of "new" wood with renewal cuts on the extension shoot of the branches [32,33].

5.2.2. Bi-Axis

This training system is based on a bi-axis tree pre-formed in the nursery (Bibaum®) or obtained by heading back the tree's trunk at planting and then raising two new axes. The double-axis technique in the nursery allows to avoid the topping (i.e., heading) of the tree in the field and the consequent loss of a year to complete the canopy formation. The pruning of this training system that forms a continuous row needs to be considered "hybrid", meaning that this shape is not a classic Palmette nor a vertical axis. Given the planting density currently suggested for combinations with medium-high vigor quince trees (about 3000 tree ha^{-1}), bi-axis trees have the advantage of doubling the number of productive axes with a given number of trees per hectare. This can be done without having to double the number of trees required at planting, which helps to reduce the upfront costs of planting. Due to the development in the height of this training system, which can exceed 3.5 m, a possible imbalance between the basal zone and the apical zone of the tree can occur [13]. For this reason, it is necessary to renew exhausted branches and avoid removing the collar at the base of the branches (i.e., leave 2–4 nodes), which will extinguish the portion of the trunk, creating "blind wood". To prevent this problem during the spring growth in the first two years, the lateral shoots in the apical part of the scion can be trimmed if they are too vigorous and upright. Another option based on the bi-axis concept is narrowing the planting distances as mentioned previously in Paragraph 3 in HDPs. In this case, a one-year-old tree without feathers is used. After planting, the tree will be headed back to 60 cm and will be attached to the first wire, scoring it at 40 cm from the ground to induce a natural open departure angle of the two axes.

Another aspect to take care of is the management of the top of the tree. The top can be managed in two different ways, depending on the desired vegetative reaction to be induced within the tree. The first scenario is a too vigorous tree and there is a need to direct excess growth at the top, to maintain better control of the cropping area in the middle and basal zones of the tree. In this case, heading cuts on one-year-old wood will be adopted to drive the vigor mainly to the top. On the contrary, if the tree requires more vegetative activity to produce renewal shoots in the bottom zone, a lateral cut of the trunk over a crowned shoot is preferred. This solution will reduce the vigor in the tree's apical zone and increase the vigor in the basal zone [12,33,58].

To avoid a possible imbalance between the basal zone and the apical zone, reducing the distance between rows and decreasing tree height has been demonstrated to be very efficient, in particular in acrotonic varieties where vigor control and optimum light distribution in the canopy is more difficult.

5.3. High-Density Training Systems (V-System and Vertical Axis)

5.3.1. V-System

The V-shapes, obtained by alternately tilting the trees at an angle of 15° from the vertical, are particularly suitable for the vegetative-productive habit of pear and have the great advantage of exploiting a productive double-wall, maximizing light interception. This training system has higher costs for the trellis material and requires more time-consuming pruning. Furthermore, it is not possible to utilize mechanical pruning with hedging equipment. Pruning, in general, is not very different from the spindle or the vertical axis depending on variety and planting density, as general principles follow. However, it is necessary to be very careful on the inside of the V, where the branches naturally tend to grow more due to the gradient of vigor induced by the inclination of the trunk. It is, therefore, necessary to remove excessively vigorous branches to avoid shaded areas within the canopy [17].

5.3.2. Vertical Axis

The vertical axis is suitable for very high planting densities and is made with reduced planting distances. Spacings include no more than 30–35 cm within the row and 2.5–2.75 m between the rows. The tree is formed only by the main axis and short branches carrying spurs, which are periodically renewed. The initial installation cost is very high due to the high number of trees to be purchased. It should be emphasized that this system can only be achieved using dwarfing rootstocks, like quinces MC and Adams, because the other rootstocks are too vigorous. Initially, these trees require several feathers from the nursery that will be trimmed short to produce short growing formations with spurs to control the tree's vigor, and favor flower bud formation. The data relating to the use of quince MC show how this rootstock has been progressively abandoned. In this training system, it is necessary to pay close attention to the renewal of productive wood because without adequate fertilization, rapid aging of the fruiting structures can occur [17].

5.3.3. Hedge for Industry or Processing

This system originally has been developed in olive, almond, peach, and plum [42,43], when the fruit destination is for processing or industry. In Spain, several producers from the Ebro Valley show interest in this system [59]. The objective is to utilize a hedger in orchards with a planting distance ranging from 3.0 to 3.5 m between the rows and from 1.0 to 1.3 m in between trees, as illustrated in Figure 6A. After planting, the unproductive period is reduced to two years, achieving full yield (40–45 t ha^{-1} with cv. Williams) in the fifth or sixth year, depending on the variety. The pruning is then performed only mechanically once per year (Figure 6B). During the formation period, the green pruning (lateral and/or topping) will be applied 2–3 times per year, depending on the cultivar. Harvest can be performed mechanically (Figure 6C).

Figure 6. Schematic of the hedge system used for pear production (**A**), photos of the hedge system being pruned mechanically (**B**) and harvested by over-the-row harvesters (**C**) (Photos: courtesy of A. Blanco, INTIA).

5.4. Small Guided Fruiting Wall Systems (Pantograph)

Small guided espaliers have been proposed at various times to create forced forms of reduced height (2.2 m) fully manageable from the ground (Bouché Thomas, Lépage, pantograph). These forms take advantage of medium or weak grafting combinations and repeated curvatures or inclination changes on the primary and secondary branches. The pantograph is a training system without a central vertical axis that uses the inclination of all branches to induce an extreme tree size reduction (1.9 m in height with dwarfing quince) [60]. It has a great organization of the production wall, which is of reduced thickness (40–50 cm). It is the most accessible for manual operations, which are facilitated by the presence of a vertical plastic net that guides the inclination of the branches and supports them. The pantograph is an easy training system to obtain and put into production, with lower costs than those of other high or very high-density systems. Manual operations are less time-consuming and with lower cost due to the intrinsic simplicity of their execution, thanks to easier access inside the production wall. There is also a natural balance in this training system that provides a skeleton suitable to produce on spurs carried by two- to four-years-old branches. Varieties like Conference and Abbé Fétel largely benefit from this training system, especially when the trees achieve the adult stage.

The pantograph can be obtained in various ways. It is simpler to plant inclined feathered scions, where the anticipated branches are removed if they are too low or bent. Branches are then curved to form future productive branches. A vigorous dorsal branch originates 50 cm from the ground and is tilted in the opposite direction to the scion to form the second branch of the "Y", with branches at 45° along the row (Figure 7A). The resulting shape is suitable for medium- and high-density plantings, up to 3000 trees/ha. The plants are supported with 2.2 m poles that allow a good anchoring to two supporting wires (one at 50 cm from the ground and one at 2 m) on which a 15 to 40 cm mesh plastic net is inserted, draping over the trees. This is an integral part of the system, which helps tilt the branches or anchors the branches more easily. In late spring, green bending operations are carried out for any developed suckers, along with adjustments to the angle of inclination for the main branches and/or scion to balance their overall growth. These interventions are rapid due to the systems' design and the minimal number of trees, which require a few hours per hectare. Just a few hours per hectare are necessary. In the second year, production is removed, and green pruning is repeated. In the third year, the production is consistent, comparable to that of the spindle [60]. Pruning is less extensive than in the other HDP forms, with a reduced need for winter pruning than the super spindle [60].

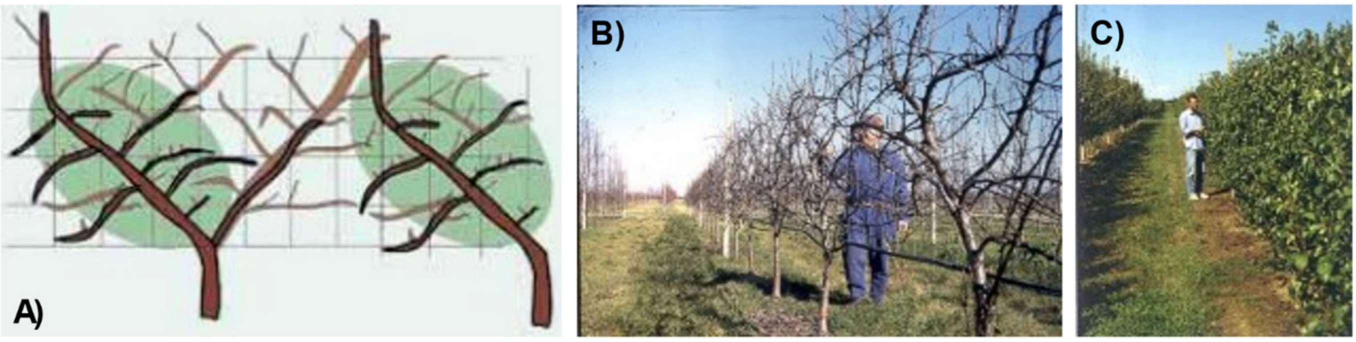

Figure 7. The feathered tree and trunk and shoot orientation are shown in (**A**). The green shaded area in (**A**) is already able to produce in the 2nd year if the management of the 1st year is optimal. The size of the mesh of the plastic net in the drawing (**A**) is 40 cm, but it can be reduced to 15 cm [60]. (**B**) Shows the tree structure in winter, while (**C**) shows the tree close to harvest.

6. Pruning

Pruning can be defined as a pool of practices controlling growth and maximizing profitability in the orchard [61,62]. Pruning affects the habit of a cultivar, improves light penetration, and increases yield and fruit quality. The pruning techniques for one cultivar can differ in relation to the planting distance and training system adopted. Furthermore, pruning can promote flowering and modify fruit maturity and mineral uptake [61–63]. Some general pruning concepts can be valid in many different orchard designs. In general, avoiding heavy pruning promotes rapid canopy development and enhances cropping. This is normally possible when the orchard is established with pre-formed trees from the nursery with 4–6 feathers, and the spindle training system is adopted. To reduce the tree's vigor, summer pruning may be adopted when necessary. This includes removing overgrown shoots and stimulating the fruit-bud formation, which improves carbohydrate partitioning to fruitlets. In HDPs, orchard production can occur from the second year; therefore, it is important not to overload trees too early with fruit. An excessive level of crop load can penalize the overall growth of the tree and negatively impact fruit quality [11]. It is important to underline that the root growth is strictly dependent on the carbohydrates that the canopy produces and allocates to the roots during the competition with fruit. Later on in the season, before winter dormancy, the roots are strong sinks from the reservoir when sufficient carbohydrates are available. Dwarfing quince rootstocks have root systems that are genetically weak, superficial, and fasciculate. In that case, there is a need to maintain the renewal of the roots with a specific strategy over the years. Otherwise, the system collapses under Mediterranean climatic conditions.

For this reason, in VHDPs, it is important to limit yield during the 2nd and 3rd years to reduce the risk of an excessive shortage of the orchard life cycle. Early production is important for a successful system, but also long-term cumulative yields must be taken into account to get a profitable return on the investment. The vigorous rootstocks with low planting density match the same need for economic return, but with a very different physiological approach. Spring and summer pruning are preferred to winter pruning, while root pruning and regulated deficit irrigation must be added accordingly to achieve limited vegetive growth and high/constant production. In accordance with the results obtained in other deciduous fruit species, mechanical pruning can be considered as a tool to reduce production costs and control vigor. The development of more efficient equipment, able to hedge and top at the same time in one or two rows, results in an interesting gain of efficiency and cost reduction.

6.1. Tree Architecture and Habit Models

Understanding how to train and prune pear requires specific knowledge about how the various cultivars grow and crop. Pear is an acrotonic species that produces branches partially controlled by apical dominance [64]. Apical control is exercised by the terminal extension growth over the growth of lateral shoots [64].

Sansavini [19,53] analyzed the production habit of 22 cultivars and identified five fruiting models linked to the prevailing branch type where production takes place, and the tree's habit (Table 4). This information allows the calibration of pruning techniques and the optimization of planting distances for each cultivar. Pear cropping habits will change during the life of the tree. A young pear tree crops mainly on "brindles" (shoots that carry only one fruit bud at the apex) and mixed branches. However, when the tree becomes older, the tree tends to form more spurs than brindles in most cases. One clear example of this difference related to the age of the tree is the variety Passe Crassane, in which the onset of bearing occurs on spurs in the early stage (9.6%); however, when the tree progressively gets older (by year 8–10) it increases this rate to 75.6% [19]. On the contrary, cultivars like Williams and Coscia mainly crop on brindles throughout their lifetime (70%). Between these two extreme situations, we have some other groups like Conference, a very high-yielding cultivar that mainly produces on spurs originating on limbs of two-three years, which still crops on spurs even as the branches age. Beurré Bosc is a typical spur-cropping cultivar, and when their branches age, spurs can become exhausted, which can reduce fruit number, leading to alternate bearing. Other cultivars such as Doyenné du Comice, Abbé Fétel and Beurré Anjou are 80–95% spur croppers in their adult years. At an early stage, Doyenné du Comice can crop on brindles and then mainly on two-year-old wood. In this cultivar, the vegetative buds will turn into spurs in the following year. These productive branches are required to be shortened to five or six spurs to increase the fruit set. For cultivars belonging to groups II a and b (Table 4), it is important to renew the old, exhausted branches periodically. Abbé Fétel's bearing habit is quite similar to Doyenné du Comice. The main difference is that Abbé Fétel's limbs are longer. This cultivar requires very short pruning, leaving three to five spurs to maximize fruit set.

Du Plooy et al. [65] analyzed the tree architecture of seven cultivars Forelle, Abbé Fétel, Flamingo, Packham's Triumph, Golden Russet Bosc, Rosemarie and Beurré Anjou (Table 5). The habit of this group of cultivars ranges from "upright" to "weeping". They measured shoot density per class of upright branches and performed a cluster analysis determining the presence of four groups ranging from upright, with no lateral shoots, to weeping, with many long shoots [65].

Table 5. Group of pear cultivars classified by habit (Modified from [65]).

Group	Characteristics
Group I—Flamingo	Spurred habit with no lateral branches and strong apical control.
Group II—Forelle	Intermediate apical control with short shoot formation.
Group III—Rosemarie, Abbé Fétel and Beurré Anjou	Low apical control with several shoots.
Group IV—Packham's Triumph and Golden Russet Bosc	Very weak apical control. Many lateral buds develop into long shoots.

Lauri et al. [16] described the tree architecture of four cultivars Conference, Doyenné du Comice, Williams and Angelis. In the first year, they noticed that the number of nodes was similar for Conference, Doyenné du Comice and Williams, while Angelis showed a higher value. In the second year of data collection, they described a decrease in the percentage of branching nodes in Williams, while the other three cultivars exhibited less than 10% variation compared to the previous year. In year four, Doyenné du Comice and Angelis showed a similar extinction level and return bloom, while Conference and Williams showed an opposite trend.

6.2. The Case of Abbé Fétel

The fruiting habit of Abbé Fétel is attributable to Group II b characterized by the production on mainly two-year-old wood and sometimes even three-year-old branches. This cultivar requires periodic renewal of the productive wood, and it is, therefore, necessary that the tree carry three different age branches at the same time: one-year-old wood that will not be shortened and on which the spurs will form in the following year; two-year wood of different sizes that will be shortened to three to four mixed buds; three-year-old wood that will only be kept if it is productive. Otherwise, it must be eliminated (with a heading cut) to favor the formation of new shoots. The intervention period runs from the end of November or the beginning of December until the end of February, depending on the size of the company. Whenever possible, the pruning period tends to be delayed; the ideal moment for pruning is in the phenological phase of bud enlargement (i.e., bud swelling). In fact, interventions up to bud break normally have a positive effect on the fruit set. Interventions after flowering must be avoided because they can compromise the fruit set [13].

6.3. Green Pruning

The green pruning operations that can be employed during tree training are mainly shoot bending, shoot tipping, shoot heading or removal, and weak limb thinning when the fruit set fails. Green pruning needs to be done early in the season to eliminate suckers, reduce the number of top shoots, head shoots, and promote branching (pruning at the height of the new couple of lateral branches typical in Palmette) and structural formation. During the late season, the need is usually to eliminate internal and top suckers to promote greater light interception and shoot lignification. It is important to avoid any subsequent growth response. For this reason, shoot twisting is practiced with vigorous shoot to reduce new growth in an undesired area without sacrificing leaves. The mid-to-end summer period is also suited for bending to promote flower differentiation and uniform bud burst the following spring [23,24]. In adult trees and planar canopies, summer pruning consists of hedging and/or topping to provide better light distribution into the canopy and for controlling vigor. In varieties like Conference, different experiments in adult orchards show the possibility of managing the canopy with almost only green or autumn mechanical pruning and nearly no intervention in winter by hand.

6.4. Root Pruning

Root pruning is a much-debated practice. It appears valid and is frequently applied in HDP and VHDP in Belgium and the Netherlands [23,24]. It is impossible to predict the effects (although sometimes very positive) of root pruning in any way. It is important to control tree growth in Integrated Fruit Production and organic orchards where guidelines ban growth retardants. There are not enough experimental trials to generalize its utility, except in HDPs and VHDPs, because it generates a further complication. Offsetting due to new growth may mask, in whole or in part, the reduced, post-cut active root area. It is reasonable to expect very different results not only because it is difficult to gauge root development, but, above all, its extent at pruning. To prevent growth imbalances leading to excess shoot density, root pruning can be employed regularly, or once only, at the winter's end or early spring to reduce root volume and promote equilibrium in the tree. Even occasional root pruning at the peak of shoot growth can be applied. However, this may induce adverse effects: the resulting out-of-phase growth cycles can prompt significant and highly dangerous return growth during the summer, as well as problems in controlling fruit size [23,24].

In HDPs and VHDPs, root pruning is a good solution to contain the vigor. However, root pruning has some drawbacks, such as reducing the absorption of water and nutrients due to the elimination of abundant portions of the root system and modifying hormonal relationships. This type of intervention strongly reduces the production of cytokinins localized in the root tips [66]. The optimal time of execution is towards the end of February-beginning of March, depending on the environment. However, it must be done before flowering. When pruning is done correctly, there is a reduction in vigor and a high production of mixed buds. Another positive effect is the reduction of alternate production.

Experiments conducted on root pruning have shown that this practice can cause early fruit ripening. The effect of radical root pruning persists over time, and even after several years, it is possible to observe a reduction in vigor [67].

7. Orchard Management (Nutrition, Irrigation, Weed Control, Growth Regulators)

Pear orchard management varies according to the rootstock and training system utilized. In traditional orchards with low planting densities and seedling rootstocks, the cultivation techniques can differ from those necessary for orchards on quinces with high or very high planting densities. Sometimes these interventions require contextualization to the farm, due to the different nutritional and management needs of the orchard.

7.1. Nutrition

For the mineral nutrition of fruit trees, the criterion of restitution of removals is frequently used [68,69]. In fact, for each species and cultivar, it is possible to identify the quantity of macro and microelements that are removed, and, as a practice, they need to be reintegrated [70].

Traditionally the application of fertilizers can take place on the surface with granular products. In this case, it must be associated with optimal humidity conditions (irrigation or rain) that allow the product to dissolve and reach the roots. More recently, fertilizers can be applied in solutions and combined with localized drip irrigation (i.e., fertigation). Nutrient application in HDP is substantially different from that in low and medium densities. The success of HDP depends on spurs and brindles for cropping and very limited vegetative growth. Leaf number and efficiency should therefore be maximized from the onset of spring for fruit to set properly, and at the same time, to prepare for return bloom, which is crucial for stabilizing fruit production. In fact, if we look at nitrogen, it is evident that uptake from the soil in spring is used mainly for building new leaves on shoots but not to grow spur leaves, which grow very rapidly and are extremely important for fruit set. Thus, the stored nitrogen is used in spring for spur leaf growth, while spring soil application is important for the new vegetative shoots. Sanchez et al. [71], Tagliavini et al. [72], and Quartieri et al. [73] support this hypothesis, noting too that nitrogen applied close to harvest is stored in the root systems, but early application induces an increase in shoot leaves. Spring N remobilization is thus involved in spur leaf growth. The application of nutrients to the soil, even when spread over more than the critical periods such as spring shoot growth, summer fruit growth, and in fall, may not be enough to control nutrient (or at least nitrogen) partitioning in HDP as to prevent excess vegetative growth or poor fruit quality. In fact, excess nitrogen in the soil may induce intense spring shoot growth, and in summer may induce fruit with less storability (due to high nitrogen content). Therefore, as found in other species with an intense spring growth of fruit that can determine root starvation [74], it seems suitable to introduce foliar applications in at least two sensitive periods (fruit set and after harvest), to increase spur leaf growth without interfering with root and shoot growth [23,24].

Pear annual removals of nitrogen (N) can vary from 70 to 90 kg/ha [67]. These quantities must therefore be returned to maintain constant productivity. In the past, annual nitrogen administrations were over 120–150 kg/ha. These quantities, clearly in excess for the tree, have increased the readily mineralizable organic fraction and nitrogen reserves in the tree to the point that the suspension of fertilizer supplies for a few years rarely compromises the productive outcome of adult orchards [68,69]. Quince rootstocks, in general, require more nitrogen than seedlings. Regardless of nitrogen requirements, excessive use of nitrogen causes a deterioration in fruit quality, which becomes less storable and favors the onset of physiological disorders such as cork spot (CS). The N:Ca ratio is correlated to cork spot at harvest and after storage. Richardson and Al-Ani [75], reported a significant correlation between cork spot and fruit Ca or N:Ca 120 days before harvest. The minimal critical concentration for Beurré Anjou is about 7 mg Ca per 100 g fresh weight for fruit showing symptoms of cork spot [75]. Richardson and Al-Ani [75] also defined ranges of Ca concentration in fruit non-lesioned, light, medium, and severely lesioned. These were 8.1, 5.7, 4.8 and 3.8 mg Ca per 100 g fresh weight, respectively. Cork spot in some pear cultivars, such as Beurré Anjou, can cause damage in over 30% of the fruit [76].

Boron (B) is an essential microelement utilized in the tree's multiple physiological processes, including the metabolism of carbohydrates and the germination of pollen [77]. Kienholz [78] postulated that pear has a high B requirement. In the case of deficiency, it is possible to observe the dieback of flowers before full bloom and poor fruit set [79,80]. Furthermore, other disorders can be observed in the case of B-deficient fruit, which can be small, deformed, cracked and corked. Wojcik and Wojcik [81] demonstrated that foliar applications of B before full bloom or after harvest increased fruit set and yield. For this reason, this element is applied in autumn to create reserves in the tree and again in spring to facilitate good availability during bloom.

Iron (Fe) is an important element in pear cultivation, especially on quince rootstocks, which are notoriously very sensitive to iron chlorosis. Iron (Fe) is a necessary element for the synthesis of chlorophyll, and its deficiency causes the classic manifestation of chlorosis, consisting of yellowing of the internerval spaces of the apical leaves, followed by necrosis in the most serious cases. Fruit trees are multi-year species and, consequently, the iron chlorosis that occurs in a vegetative season also negatively affects the ferric nutrition in the following year [28]. The most effective way to overcome chlorosis in fruit trees is to choose tolerant rootstocks. Pear seedling rootstocks are generally more tolerant to ferric chlorosis than quinces [28].

7.2. Irrigation

Worldwide there is an increase in demand for water for civil, industrial, and irrigation uses. Climate change is increasing the problems due to the irregularity of precipitation. Especially in arid and semi-arid climates, irrigation is an essential technique for improving quantitative/qualitative results and promoting fruit farms' economic sustainability. There are very few cases of dry cultivation of pear cultivation worldwide. An example of this dry cultivation is in Emilia-Romagna (Italy), where over 70% of the 26,000 ha cultivated are irrigated, with an overall consumption estimated at around 40 million cubic meters of water per year [82]. In particular, irrigation allows rapid entry into production, homogeneous and large fruit sizes and reduces biennality [83].

To optimize irrigation and allow for more rational use of water, replacing poorly efficient methods with those capable of reducing waste is necessary. For example, flooding irrigation and furrow irrigation (still widespread in some productive pear areas such as Argentina) are methods, in general, to be avoided. This is due to the significant waste of water and its ability to facilitate the leaching of nutrients in-depth and in surface waters, the heterogeneity of soil wetting, the anoxia of the root systems, and the onset of fungal diseases. It is necessary to maximize the ratio of CO_2 fixation and water consumption. Leaf evapotranspiration varies and water efficiency can increase ten-fold between well exposed and shaded leaves. Shaded leaves consume water but have reduced or null (i.e., below the offset curve) photosynthesis, whereas efficiency increases up to the light saturation curve. When fruit load is high, trees consume more water via increased leaf transpiration. In a HDP pear trial, water efficiency increased despite the notable reduction of per-tree water supply, even when maintaining equal amounts of water returned to trees based on evapotranspiration and crop coefficients. Indeed, the increase in dry matter per unit of water volume registered an average 15% rise when planting density grew from 4–8000 trees/ha [23,24].

The irrigation inputs must be modulated according to the phenological phase, also considering the type of plant adopted and the rootstocks. In MDPs, it is necessary to control vegetative excess in the post-harvest period because it could compromise the formation of flower buds for the following year. Localized irrigation is the technique that has had the greatest diffusion in modern pear orchards in the last twenty years, due to the possibility of combining it with the application of fertilizers, thus increasing the level of water use efficiency (90–95%) [82].

Irrigation can play a role in the development of the fruit. In fact, Lee et al. [84] reported that the formation of sclereids or "stone cells" in the pulp of Asian pear is related to water stress. Water stress seems to depress the root activity and decreases the water potential of the leaves, which also leads to a reduction in the radical absorption of mineral elements (in particular calcium). Furthermore, water stress increases the peroxidase activity (POD), which enhances the lignification of cell walls and the formation of sclereids in fruit, which translates to a reduced appreciation of the product from the consumers.

The scarcity of low salinity water is one of today's most significant problems. Salinization is becoming a significant problem for many pear-growing districts [85]. Although pear is a fairly tolerant species against salt, a reduction in the growth of the shoots can occur when salinity is higher than about 5.0 dS/m^{-1}, regardless of the rootstock. Quince rootstocks used in HDPs cannot resist a high salinity level in soils and fail to prevent the absorption and accumulation of Na^+ and Cl^- ions in the leaves. On the contrary, seedling rootstocks adopt a strategy of excluding Na^+ and Cl^- ions to reduce their absorption [86]. Therefore, HDPs may not be achievable in highly saline soils, as quince are less tolerant than pear rootstocks.

7.3. Weed Control

Sustainable tree-row management in fruit orchards is crucial for healthy tree growth, quality fruit yield, sustaining soil quality, and promoting orchard biodiversity [45,87]. Tree-row management entails managing orchard weeds as they can compete aggressively with fruit trees for available nutrients and water. Pears are inferior competitors because of their low root density per unit of soil compared to weeds. A standard management method is to eradicate weeds, either permanently or temporarily, through herbicide use and traditional tillage along the tree row, or more rarely inter-row. Maintaining bare soil from 0.6 to 2.0 m along the tree row with herbicides has proven to be easy, cost-effective, and favorable for tree growth and fruit yield. However, the continuous use of chemicals is detrimental to human and environmental health. The consequences generated by herbicide applications include declines in weed biomass, weed biodiversity, and soil quality. Additionally, these practices foster the development and evolution of herbicide-resistant weed species and favor an insurgence of soil sickness. Therefore, various herbicide mechanisms of action, especially using a mix of herbicides in the same tank, or practicing rotating herbicides from season to season, have been advocated to overcome the spread of herbicide-resistant weeds.

Currently, the concept of weed management has achieved a broader meaning than in past decades, as it regulates the knowledge of orchard agroecosystems and turns into a consistent part of the agroecological approach in fruit orchards [87]. Ground cover with living vegetation can deliver several agroecosystem services by promoting functional agro-biodiversity in the orchard. Hence, adopting a sustainable orchard management strategy is vital for enhancing weed biodiversity, providing ecological protection by offering feed and shelter to beneficial organisms, and improving soil fertility by hosting mycorrhizae, thereby promoting nutrient availability and resilience in the soil. It can also play a crucial role in overall soil quality improvement by reducing soil erosion and increasing humification with improved organic matter in the soil. In contrast, the opposite results may be found under the coverless ground system conditions. Maintaining soil vegetation while augmenting biomass production and species diversity can be considered fundamental goals in sustainable pear orchard management systems. The key is to practice more sustainable weed control strategies that support covered soil with spontaneous or selected living species by keeping them at a density level that does not negatively impact tree performances. Several alternatives to chemical weed management, such as minimum tillage, mowing, mixtures of living mulching species, distribution of organic mulch, uses of plastic mulch, and physical weed control (i.e., flaming and steaming) have been studied with relatively negative results.

Therefore, researchers are still seeking a more sustainable strategy that might reduce weed competition and improve weed biodiversity without compromising fruit production and quality. Priority has been given to the integrated approach for the enhancement of long-term orchard sustainability. The wide availability of sustainable management practices has directed us towards seeking further advances in mechanical weed control. These include integrated tillage, integrated mowing, and the use of a modern finger weeder as sustainable techniques that reduce soil disturbance. Based on traditional soil tillage, weed control demonstrated several adverse impacts on tree growth, fruit production and quality, tree roots, and soil fertility. However, it might be possible to minimize those problems and optimize orchard biodiversity by integrating advanced shallow tilling tools. The effects of sustainable alternative weed management methods on orchard biodiversity, fruit yield, and quality were obtained in different species without declining tree growth, fruit yield and quality in fruit orchards, managed with drip irrigation and a usual fertilization regimen [88–90].

7.4. PGRs on Pear

The use of bioregulators, especially anti-gibberellins, presents several problems.

The first is the possible banning or severe limitation of their use in most countries, as fruit and environmental residues of the active ingredient are toxic or highly persistent (e.g., paclobutrazol and cycocel). However, prohexadione-calcium (ProCa, registered in North America as Apogee® and in Europe as Regalis®) seems to prevent this problem for the moment. Regardless of the product, Pro-Ca has shown some contraindications. In fact, if the dose of 1.5 kg/ha is exceeded, there may be a negative effect on return bloom in the following year [91]. Pro-Ca was born as a product to control the vegetation in apple, where the effects have been very positive for both the control of shoot development and for floral bud differentiation. Pro-Ca acts as a 2-oxoglutarate dependent inhibitor of the synthesis of gibberellins, causing a reduction in the length of the shoots. This sprout development arrest is not permanent and, for this reason, fractionation of the applications is suggested up to a maximum of 1.5 kg/ha. In addition, this action on growth also reduces the damage caused by fire blight by inducing a change in the metabolism of flavonoids [92,93].

The second is shoot-growth management over time in relation to cropping factors, such as fruit set, flower differentiation, return bloom, and fruit development. The use of anti-gibberellins, which are not particularly persistent, but do not control shoot growth well enough, means higher input rates to secure the desired response and leads to unforeseeable disruptions of other plant growth functions. The differing cultivar response in this connection was clearly underscored by Smit et al. [94], who demonstrated that treatments at end-bloom reduced shoot growth in cultivars: Rosemarie, Golden Russet Bosc, Flamingo and Early Bon Chretien but not in Forelle or Packham's Triumph. Fruit set improved significantly only in Forelle and Rosemarie. Fruit growth and return bloom were largely unaffected in several retardant trials, responses that were very similar to untreated control. These findings corroborate observations by those who use bioregulators in the orchard to the effect that the plant offsets exogenous hormonal stress via alternative metabolic pathways. As a result, if the orchard is far from equilibrium with reduced growth and high cropping, anti-gibberellins can help only when coherently applied with other management practices to achieve the desired result. Treatments can thus be applied in HDP to bring the plant back to equilibrium if there is a slight excess of shoot growth, especially early in the season [23,24].

Fruit set is certainly the most delicate phase for pear due to the well-known fertility problems that characterize many cultivars. However, it should be noted that cultivars can exhibit different behaviors depending on the environmental conditions in which they are grown. This is the case of Abbé Fétel, which is cultivated in conditions of high light intensity and mild temperature ranges and requires fruit thinning. These conditions allow an increased balance between carbohydrates produced and respired, which is typical of the Rio Negro in Argentina. In contrast to Argentina, when this cultivar is grown in environments with high temperatures, no variation between the day and night (such as in Emilia-Romagna (Italy)), and high levels of air humidity that reduce the available radiation (conditions that therefore worsen the photosynthesis/respiration ratio), it requires interventions with products that are able to stimulate fruit set and promote parthenocarpy. To mitigate the poor fruit set of Abbé Fétel in Emilia-Romagna, applications of exogenous plant growth regulators (based on gibberellins), and particular nutritional elements such as B or Ca have been developed. The treatment to promote fruit set and stimulate parthenocarpy is mainly based on gibberellins or mixtures of gibberellins and cytokinins [95]. Usually, two to three treatments are performed from the beginning of flowering to the end. This practice is very common in the case of frost damage that causes necrosis of the seed embryos. In this case, GA_3-based products must be applied within 48 h from freezing [95].

The control of the fruit set is therefore essential for maintaining regular cropping and assuring proper returns. The worst risk is late frost before or during bloom. Securing a good fruit set after a late frost can be achieved using gibberellins (combining GA_3 and GA_{4+7}) at low rates and spraying at the beginning, or just after, full bloom [91]. Gibberellin application can increase fruit set inducing parthenocarpy and reduce the number of gamic fruit (GA may trigger early abortion of the embryos). In any case, the treatment produces a fruit set increase [95,96] of parthenocarpic fruit and yield per ha. The tendency is to use parthenocarpic fruit production in HDP for some cultivars, and, in special conditions, even in normal years, to maintain better cropping control; growers sometimes eliminate pollinators to prevent gamic fruit production. Low application rates and limiting use around bloom do not compromise return bloom and fruit quality. In several pear cultivars, there is no negative influence on the shape (abnormally elongated) of the fruit treated with low rates of gibberellins.

8. Environmental Sustainability

8.1. Light, Humidity, Temperature, and Their Relations with Yield and Fruit Quality

Orchard design significantly impacts the light interception of the tree and consequently yield efficiency. Pear exhibit a plethora of training systems (Tables 2 and 3) with tree canopy shapes ranging from round (open vase) to thin walls (bi-axis and vertical axis). With this variability of situations, we must also consider the variability of orchard climate. In fact, the solar radiation can vary from district to district, partially explaining the crop's high variations in yield [11]. In 2018, the average yield per hectare worldwide was 18.5 t/ha. If we analyzed the average yield of the main pear-producing countries, we notice a broad level of differences. In 2018, the average yield per hectare in Italy was 24.2 t/ha, while other producing countries have much higher yields per hectare, such as Switzerland (53 t/ha), New Zealand (51 t/ha), Holland (40 t/ha), the United States (38 t/ha), Belgium (36 t/ha), and Chile (34 t/ha) [1]. This variability results from the interaction among cultivar/rootstock/training system/climate/management. The space assigned to each tree (distance in between trees), and the correct ratio between tree height and interrow distance, are two key components to consider when designing an orchard for optimum yield.

In a trial between two different locations in Europe, characterized by different latitude: Bologna (Northern Italy, 44.5° latitude) and Wilhelminadorp (the Netherlands, 51° latitude), Wertheim et al. [97] noticed that the Dutch site received less light starting from 43 days after full bloom (DAFB) due to shorter days and their specific climate. This difference can influence fruit set, initial development, and ripening time [11]. Wagenmakers and Callesen [98] postulated that this radiant energy difference could induce a 25% increase in yield potential in Bologna. This is mainly due to the 4.5 months from bloom to harvest and optimum production of 1 g dry matter per MJ of intercepted light (PAR) [11].). It was noticed from Italy's low average yield per hectare data that other factors like low productivity cultivars and disease pressure can limit the climate's advantage. Lakso [99] and Wunsche and Lasko [100] demonstrated a linear relation between tree-intercepted light and yield. This relation is linear, up to 50%, after which the response seems to become affected by other factors like light distribution in the canopy. Wagenmakers and

Tazelaar [101] in the Netherlands found that this relationship is linear up to 60–70% of available light in pear and apple plantings, postulating that higher light interception may result in a loss of quality production, flower-bud formation, and a low yield per hectare. Light penetration is the fraction of available PAR that is being transmitted through the canopy, which is affected by several factors like tree spacing, canopy architecture, rootstock, and orchard management practices, such as pruning and thinning [102]. Canopy light microclimate can be modified by the use of reflective fabrics [47,48] and by management practices such as pruning and growth regulator application [18]. Reflective fabrics could increase the PAR in the lower part of a large open vase tree [47]. Wagenmakers and Tazelaar [101] found that a 1% increase in light interception can increase 2.3 t in yield in an eight-year study. The same authors in the same study noticed no yield increase when light interception rose from 67% at 2000 trees/ha to 77% at 4000 trees/ha in multi-row systems. It appears that other factors like leaf distribution, shade, and leaf area index (LAI) can modify canopy efficiency inducing yield saturating levels. Light microclimate strongly affects fruit quality. In a study on Beurré Anjou, pear quality was investigated in open vase canopy architecture [18]. Fruit born in the more exposed position of the canopy showed an increase in the percentage of blush. Several other differences were found in the internal quality. Index of absorbance difference (I_{AD}) correlates with fruit physiological maturity [103], and fruit from the more exposed zone of the canopy had lower values (i.e., more advanced maturity). Soluble solids concentration, titratable acidity, and firmness were also affected by different light penetration levels within the canopy [18]. Temperature (T) and relative humidity (RH) also play an essential role in the orchard's performance. Temperature could impact orchard production positively or negatively at bloom. In mild climates, fruit set, bud differentiation, and, subsequently, fruit and shoot development can be promoted. On the contrary, when T at bloom drops to 0 °C it can compromise that season's crop. Certain pear cultivars can produce fruit by parthenocarpy, which can partially mitigate possible frost damage.

Spring frosts can compromise the production, and the severity of the damage is linked to the phenological stage of the flower and the water content of the organs [104]. The higher the water content, the lower the organ's tolerance to cold. However, there are various techniques to mitigate the damage. The most effective methods include anti-frost irrigation (applied in many cultivation areas of Argentina), ventilation systems (largely adopted in the USA), and the application of hormones (gibberellins) to stimulate the production of parthenocarpic fruit (a widespread practice in Europe) [105]. In many pear districts, low temperature at bloom is one of the critical key points to overcome to have a consistent crop every year. Zhu et al. [105] showed that the optimum T for photosynthesis appears to be 20 °C in apple and at least 24 °C in pear, with the photosynthetic capacity varying from 10 to 15 µmol (CO_2) m^{-2} s^{-1} [106]. Temperature and RH also play a fundamental role in promoting inocula and infections of fire blight, insects, and fungal diseases [11].

8.2. Orchard Resilience to Climate Change

To overcome the winter dormancy, pear needs 900 to 1100 h with winter temperatures below +7 °C [107]. The main factor limiting affecting pear cultivation is the temperature. In fact, winter (early) and spring (late) frosts can ultimately compromise production or damage the quality of the fruit. In the most serious cases, the fruit show severe symptoms such as "frost ring". This consists of a rusty skin ring that forms near the calycin area of the fruit. Winter frosts can damage both mixed buds and, in severe cases, the tree's structure (cambium, phloem, and xylem). Some cultivars appear to be more resistant than others to winter cold damage. These include Passe Crassane and Beurré Hardy. On the contrary, the mixed buds of Beurré Bosc, Coscia and Santa Maria are susceptible to low winter temperatures. In these cultivars, temperatures of −15 °C can damage over 60% of the productive buds [107].

During the summer, in very arid environments characterized by high temperature and light intensity, the sunburn damage can be very serious. Depending on the type of training system, the damage can exceed 40% [108]. This problem is typical of pear districts like Washington in the USA and the Rio Negro region in Argentina. Additionally, in Mediterranean countries such as Spain, Italy, and Portugal, a decay of tree vigor in adult orchards has been observed over the last two decades when quince is used as a rootstock, affecting negatively yields, fruit size, and reducing the lifespan of orchards.

Most of these modern orchards have been designed to include hail net protection. Selecting the specific colors and material of the nets could be an option to counteract the effects of climate change, in particular reducing the tree stress and improving fruit quality [109].

8.3. Environmental Protection and E.U. Green Deal

Integrated management strategies of fruit production can provide many different ecosystem services (ES), defined as the benefits of nature to human well-being. The ES conceptual framework assumes a dynamic interaction between people and ecosystems and requires a multiscale approach. Many biophysical and ecological processes in agriculture occur at the landscape level, rather than at the farm scale, while European Rural Development Programmes (RDP) typically neither require nor encourage landscape coordination. The integration of knowledge from different stakeholders (e.g., farmers, scientists, experts) is thus a precondition for successful sustainable land management [45]. For this reason, it is important to create sustainable pear production by implementing the Agri-Environmental Measures and the ecological processes controlling the target agri-environmental issues. For example, pear production should be carried on improving the soil's carbon content, reducing soil erosion, and augmenting carbon sequestration. Moreover, plastic netting systems and drip irrigation with plastic tubes should be organized with circular economy criteria, including plastic recycling at the end of their life cycle in the field.

The competitiveness of the current and future pear industry is based on the efficient use of inputs, particularly labor as the main cost, fertilizers, and pesticides, requiring planar canopies and small trees. These bi-dimensional canopies are more accessible to workers and machines/robots compared to 3D canopies. An efficient way to gain competitivity is to replace part of labor with total or partial mechanization (pruning, thinning, harvest). Benefits related to the efficient use of inputs can be achieved through intensification. Most of the options provided in the section "Training systems" are based on small and planar canopies, which fit the concept of sustainable intensification, hence producing more with fewer inputs per unit surface. This means producing more with fewer inputs per unit of surface [110]. It is demonstrated that the small canopies obtained combining size controlling rootstocks and training systems based on small bidimensional canopies results in early yields, increasing high-quality output and better efficiency of inputs, increasing the environmental sustainability of the orchards [35].

Environmental sustainability requires soil management practices to increase and maintain soil fertility, such as minimum tillage, multispecies ground cover, and the supply of amendments. Innovation in crop-management regimes needs strategies to control plant and root development to optimize and simplify orchard management. This is the main challenge for future pear orchards, making fruit tree production economically, socially, and ecologically sustainable. All these concepts are fully in line with the objectives of the "Green Deal" and the strategy "From Farm to Fork" from the European Union concerning sustainable fruit production [35,111]. The achievement of these goals requires the active participation of farmers and extension services.

The current global food system requires an agricultural revolution that is only possible and should be based on sustainable intensification and driven by sustainability and production system innovation, as clearly reported by "The Lancet Commissions" [110]. This change would entail radical improvements in the efficiency of pesticides, fertilizers, water use, and labor, thanks to innovations in crop systems management. In addition, to achieve negative emissions globally as per the Paris Climate Agreement, the global food system and food production systems must become a net carbon sink from 2040 and onward. The European "Green Deal" and the "Farm to Fork Strategy" is the plan to make the EU's economy sustainable [111]. We can do this by turning climate and environmental challenges into opportunities, including, of course, a sustainable chain of food production, distribution, and consumption. Sustainable production is the response of the Green Deal for food production.

8.4. Netting

Netting was developed initially for anti-hail protection and later found other uses, such as protection from environmental stresses like sunburn. In a semi-arid climate such as Washington or Rio Negro in Argentina, netting is becoming more popular due to its several advantages.

In fact, netting in arid climates can replace standard practices such as evaporative cooling (EC) to mitigate sunburn by reducing fruit surface temperatures [15,109,112]. The main advantages of netting compared to EC are saving water and reducing the pressure from diseases such as Sphaeropsis rot (*Sphaeropsis pyriputrescens*) and fire blight (*Erwinia amylovora*). In fact, both benefit from elevated humidity [113].

In Europe, the increase in hail insurance costs and the problems related to fire blight has led to widespread anti-hail coverings in various pear production areas. In most cases, the damage caused by hail can compromise the production of the year in which the event occurs and those of the following year in cases of severe damage which impacts the developing flower buds. For these reasons, many productive districts are opting for anti-hail covers.

In Italy, there are various kinds of anti-hail coverings. Alongside the traditional "Capannina" systems, new flat or semi-flat net protection systems have emerged. In general, the costs of these two typologies of coverage are comparable. In the "Capannina" system, the net is installed with a 15–30° angle compared to the horizontal to naturally discharge the weight of hail into the intra-row space. Traditional systems require lower material costs but higher labor costs for installation. On the contrary, flat systems require a greater number of poles and therefore increased costs of materials, but lower costs for their installation. Flat systems use poles of shorter lengths and, therefore, are easier to handle.

The netting color commonly used is black, which guarantees a longer net life. New net products are represented by the mixed net, where only the ridge and seams are black, while the rest is white. Photoselective nets are characterized by different colors, corresponding to the light quality spectra (i.e., color) they transmit through them [114]. These nets make it possible to stimulate different physiological responses on trees and fruit by modifying the light spectrum [109,115,116]. Various colors are available: red, blue, green, and yellow, which are used depending on the effect desired [116].

The use of a net reduces the available light and increases shade in the canopy. If shade became excessive, adverse effects on fruit overcolor and yield can occur. Shades can lead to higher vigor and growth [115,117]. The use of nets is becoming multifunctional compared to the original use against hail. The new products are also able to block insects (Alt'Carpo) [118] or protect against rain (e.g., "antiaqua") [119]. Initially, the system against rain has been developed for cherry production to cover single rows with a plastic foil on the top to minimize rain on fruit and leaves, while lateral nets are "antinsect" [119]. Nowadays, these systems are spreading in pear HDP orchards where relevant pests are difficult to be controlled with less expensive systems. These new netting systems can be installed on single row or medium size plots concerning different orchard designs and farm organizations.

9. Conclusions

This paper reported the main aspects of pear production from the current situation, varieties, rootstocks, training systems, climate change, and future challenges for the fruit industry. As in other deciduous fruit species, several training options are available for the growers, all with a common goal: to achieve higher efficiency in using inputs and reduce the cost of production while maintaining high fruit quality, increasing profitability, and high profitability pack-out production. In addition, increasing efficiency in the use of inputs will result in a more environmentally sustainable industry for the future of pear production in all countries.

Most of the training systems proposed are based on intensive orchards, planar canopies, and size controlling rootstocks, usually quince and some pear selections. Single-axis and bi-axis are the most interesting and commonly used in all countries, adapting planting densities to the specific cultivar and edaphic-climatic conditions of each area of production. Planting distances from 3.0–3.5 m between rows and 0.5 to 1.2 m between trees are the most commonly proposed for very high-density orchards. Considering this spacing, the system based on the central axis is the easiest and cheapest to train during the formation period. The bi-axis is also interesting as far as it provides two leaders on the same number of trees, but it requires more management strategies. V-system is not a common training system used as it requires more cost for the support structure, and mechanization is not as efficient as planar systems. Multi-leader systems offer some advantages with lower planting densities and are in development in several countries.

With whatever training system that is chosen in these high-density orchards, the financial risk for the grower is high when compared with the traditional systems, such as the open vase or Palmette. In addition, they require a high level of control and an outstanding interaction between growers, technical consultants, and researchers. On the other hand, the planting density allows the use of less dwarfing rootstocks and more resilient systems that are able to last longer compared to the very and ultra high-density planning orchards. It is possible to maintain a certain amount of biodiversity by maintaining a more natural ground cover and avoiding herbicides and/or excess tillage. However, this solution can be sustainable only if the yields are high, the training systems are well managed, and labor costs are kept minimal. Intensive fruit production systems are characterized by increasing planting density, early fruit-bearing, small tree size, high crop loads, short orchard lifespan, easy mechanical management, efficiency in the use of inputs, and frequent replanting. Planar canopy systems can make more sustainable pear cultivation in the southern districts of Europe. The new 2D-training systems can allow a high level of mechanization of harvest utilizing platforms or bins train. Future development in orchard management also includes the so-called ‘smart orchards’ where the use of remote sensing can move irrigation from soil probe to sensors over the tree, able to determine the level of stress in real-time. Further, these remote sensing tools can improve fruit quality with the efficient management of canopy architecture. Finally, new genetic material obtained by breeding programs can provide solutions to replace the existing roster of cultivars that, in general, are over 150-year-old.

Supplementary Materials: The following are available online at https://www.mdpi.com/article/10.3390/agronomy11091765/s1, Table S1: Main pear producers in the world. Table S2: Main pear rootstock breeding programs worldwide.

Author Contributions: Conceptualization S.M., I.I. and D.N.; methodology S.M., I.I. and D.N.; software, S.M., I.I. and D.N.; validation S.M., I.I. and D.N.; formal analysis S.M., I.I. and D.N.; investigation, S.M., I.I. and D.N.; resources, S.M.; data curation, S.M., I.I. and D.N.; writing—original draft preparation, S.M., I.I. and D.N.; writing—review and editing, S.M., I.I. and D.N.; visualization, S.M., I.I. and D.N.; supervision, S.M.; project administration, S.M.; funding acquisition, S.M. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by USDA National Institute of Food and Agriculture Hatch project 1014919, titled “Crop Improvement and Sustainable Production Systems” (WSU reference 00011).

Acknowledgments: We want to thank Brendon Anthony for the accurate revision of the manuscript.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Information and history of commonly used rootstocks.

Appendix A.1. Quince Rootstocks

Appendix A.1.1. BA29

BA29 is the reference rootstock for the Italian pear production region. Obtained in France at INRA, it belongs to the quince group of Provence. It was introduced towards the end of the 1960s, and since the 1980s, it has spread to become the main quince rootstock. It is easy to propagate through a stoolbed or layering. It is considered one of the least susceptible quince cultivars to iron chlorosis and is partly suitable for heavy and calcareous soils. Its susceptibility to phytoplasmas (pear decline), with symptoms starting from the end of August to the beginning of September, can induce an early red coloration of the leaves [21].

Appendix A.1.2. MA

MA was obtained in East Malling through a selection from a population of the Angers quince. It is easy to propagate by stoolbed or layering, but it produces a high number of suckers in orchards (Table 1). It was largely surpassed by Sydo and BA29 in a lot of European countries, but in others, such as Spain, it is still the most important [9].

Appendix A.1.3. Sydo®

Sydo® is a clone of Angers quince and is very popular, especially in Italy and Central Europe. It propagates by stoolbed or layering and appears less susceptible to phytoplasmas than BA29. In less calcareous soils, it can replace BA29 [21].

Appendix A.1.4. Adams

Adams is a rootstock that was spread in the 1970s by a Belgian nurseryman. It is widely used in the Netherlands and Belgium. In Italy, it has replaced the MC quince in HDP orchards. It has an intermediate vigor between MC and Sydo. Adams is quick to enter into production, but it is sensitive to low temperatures due to its superficial and shallow root system [21].

Appendix A.1.5. MH

MH is characterized by a 15–20% higher vigor than MC with a variability linked to the cultivation area. It is less precocious than MC, but it has demonstrated improved fruit size. It was initially introduced to replace Sydo [21].

Appendix A.1.6. MC

MC is the most dwarfing quince suitable for high- and very high-density plantings from 4–5000 trees/ha up to 10–12,000 trees/ha. It has a high graft incompatibility with some cultivars, and in the past, it was widely used for Abbé Fétel [21]. It prefers colder growing environments than Italian ones. It is widespread in northern Europe, especially in Netherlands and Belgium, where it is used for 'Conferences'. Due to its superficial root system, it requires a controlled water supply. In terms of production, the tree tends to reduce the fruit size dramatically. The reduced fruit size combined with the graft-incompatibility and iron chlorosis susceptibility has led to its disappearance in the new plantings of Italy and the lack of use in Spain [9]. In 2018, only 6691 trees were produced using MC, while in 2011, with 413,101 trees, it was the third most widely propagated pear rootstock in Italy.

Appendix A.2. Pear Rootstocks

Appendix A.2.1. Seedlings

These are seedlings obtained from the free pollination of cultivars characterized by medium-high vigors, such as William sand Winter Nelis. Currently, their main use is in marginal soils, even ones that are dry and calcareous. They maintain good graft compatibility and allow for sufficient tree anchoring, given its large and deep root system. However, seedling rootstocks induce excessive vigor, a slow entry into production and a lack of homogeneity between the grafted trees.

Appendix A.2.2. Clonal Pear Rootstocks

This group is mainly propagated in vitro due to their poor capacity to produce roots in traditional methods like layering or stoolbed [29].

Appendix A.2.3. OHxF Series (Farold®)

This is a series of clonal rootstocks that Oregon nurseryman, Lyle Brooks, crossed in the 1960s [47,120]. They are a cross between two varieties, Old Home and Farmingdale, which are resistant to fire blight. In general, they are difficult to propagate with traditional techniques, so in vitro propagation is preferred. Below are the most used:

- Farold® 40 Daygon and Farold® 69 Daynir are widespread in Italy, in marginal soils with high levels of lime where quinces present difficulties of adaptation and manifest iron chlorosis symptoms. Farold® 40 Daygon is mainly used in combination with Williams, where it induces good fruit size. Farold® 69 Daynir is more vigorous and has a reduced production yield efficiency compared to quinces [14,21,27].
- Farold® 87 and Farold® 97 are mainly used in the USA. Both are suitable for plants characterized by low or medium-low planting densities. Farold® 97 is 20–30% more vigorous than Farold® 87 and is mainly adopted for traditional orchards, although it is possible to envision a potential use for multi-axis training systems with these rootstocks [14,21]. Farold® 87 has been developed at a commercial scale in recent years in the South of France and Spain, mainly with William sand Guyot cultivars, with very interesting results.

Appendix A.2.4. Fox Series

This series, obtained at the University of Bologna, has produced three notable rootstocks: Fox 9, Fox 11 and Fox 16. They originated from an open pollination of the Volpina pear, an old variety of pear belonging to the native germplasm of Emilia-Romagna [121,122]. Among these, Fox 9 is the one that has had the greatest commercial success. It propagates in vitro, is adaptable to heavy clay soils, and is tolerant to calcareous and sub-alkaline soils. It has good graft compatibility with the main pear cultivars and a higher vigor classification than BA29 (about 20% of the vigor), when combined with Williams and Abbé Fétel, and about 40% when it is combined with Conference. The earliness of fruiting is slightly lower than the BA29 quince, as well [123].

Appendix A.3. New Rootstocks and Perspectives

The need for new size vigor controlling rootstocks with good compatibility, tolerance to iron chlorosis, high yield efficiency, optimum fruit quality, and good adaptation to climatic stress periods related to climate changes are priority breeding objectives. The last objective is becoming more important in recent years due to the effects of climate change. This research is now in progress in different research centers. It seems clear that all of these positive traits can only be achieved by selecting new rootstocks from *Pyrus* interspecific hybrids, instead of from quince accessions [30,31]. In Europe, this work was started by INRAE-Angers more than two decades ago. Later on, this program was extended towards Spain with collaborative cooperation with the INRAE-IRTA program to test the new selections in the Ebro Valley conditions, characterized by hot, dry climatic conditions and soils inducing iron chlorosis. This program is in progress, and currently, 54 elite selections from five species of *Pyrus* are in the last phase of agronomical evaluation. Similarly, other breeding programs in Italy, South Africa, and United States are working towards these goals. In Northern Europe, other breeding programs are focused on quince because of its enhanced yield efficiency and fruit quality, while attempting to add a superior tolerance to winter frost for some local selections.

References

1. FAOSTAT. Available online: http://www.fao.org/faostat/en/#data/QI (accessed on 20 July 2021).
2. World Apple and Pear Association (WAPA). Prognosfruit 2021 Releases Its Annual Apple and Pear Crop Forecast, Showing a 10% Increase in Apple Production and a 28% Decrease for Pears. Available online: http://www.wapa-association.org/asp/article_2.asp?doc_id=641 (accessed on 30 May 2021).
3. Modesti, M.; Pallotti, G.; Nannini, R.; Bortolotti, P.P. Indagine sulla degenerazione degli impianti di pero. *Inf. Agrar.* **2020**, *9*, 51–54.
4. Sansavini, S.; Ancarani, V. Miglioramento genetico e nuove varieta' in Europa. *Frutticoltura* **2008**, *10*, 28–36.
5. Brewer, L.R.; Palmer, J.W. Global pear breeding programmes: Goals, trends and progress for new cultivars and new rootstocks. *Acta Hortic.* **2011**, *909*, 105–119. [CrossRef]
6. Collina, M. Maculatura bruan: Una nuova minaccia che impone risposte immediate. *Frutticoltura* **2019**, *9*, 18–20.
7. Mazzotti, V.; Boncompagni, S. Annata negative, dall'Emilia-Romagna un sostegno alla produzione. *Frutticoltura* **2019**, *9*, 1216.
8. Iglesias, I. Nuevas variedades de melocotón nectarina, pavía y melocotón plano: La mejora continua. *Rev. Frutic.* **2017**, *58*, 12–37.
9. Iglesias, I.; Bonany, J.; Vilardell, P.; Ruíz, S. El cultivo del peral en España: Tecnología de producción, consumo e intercambios comerciales. *Rev. Frutic. Espec. Peral* **2015**, *45*, 6–33.
10. Ancarani, V.; Spinelli, F.; Dondini, L.; Caracciolo, G.; Sirri, S.; Baruzzi, G. Le varieta' di pero adatte ai nuovi impianti. *Inf. Agrar.* **2019**, *47*, 48–50.
11. Sansavini, S.; Musacchi, S. European pear orchard design and HDP management: A review. *Acta Hortic.* **2002**, *596*, 589–601. [CrossRef]
12. Musacchi, S. Training systems and soil management for Southern European pear orchards. *Acta Hortic.* **2008**, *772*, 447–457. [CrossRef]
13. Musacchi, S. Bibaum®: A new training system for pear orchard. *Acta Hortic.* **2008**, *800*, 763–768. [CrossRef]
14. Wertheim, S.J. Rootstock Guide. In *Apple, Pear, Cherry, European Plum*; CABI: Wallingford, UK, 1998; pp. 1–144.
15. Wertheim, S.J. Rootstocks for European pear: A review. *Acta Hortic.* **2002**, *596*, 299–309. [CrossRef]
16. Lauri, P.E.; Costes, E.; Belouin, A. European pear architecture and fruiting branch management: Overview of INRA research program. *Acta Hortic.* **2002**, *596*, 621–626. [CrossRef]
17. Musacchi, S.; Ancarani, V.; Gamberini, A.; Gaddoni, M.; Grandi, M.; Sansavini, S. Response of training system planting density and cultivar in pear. *Acta Hortic.* **2005**, *671*, 463–469. [CrossRef]
18. Zhang, J.; Serra, S.; Leisso, R.S.; Musacchi, S. Effect of light microclimate on the quality of 'd'Anjou'pears in mature open-centre tree architecture. *Biol. Eng.* **2016**, *141*, 1–11.
19. Sansavini, S. Pear fruiting-branch models related to yield control and pruning. *Acta Hortic.* **2002**, *596*, 627–633. [CrossRef]
20. Lombard, P.B.; Westwood, M.N. Pear rootstocks. In *Rootstocks for Fruit Trees*; Rom, R.C., Carlson, R.F., Eds.; Wiley: New York, NY, USA, 1987; pp. 145–183.
21. Sansavini, S. Portinnesti. In *C. Fideghelli e I. Ponti (a cura di), Il pero*; Coltura & Cultura, Bayer CropScience: Milano, Italy, 2007; pp. 270–281.
22. Campbell, J. Pear rootstocks. In *AGFACTS H.4.1.15*; NSW Agriculture: Orange, NSW, Australia, 2003; pp. 1–12.
23. Sansavini, S.; Ancarani, V.; Neri, D. Overview of Intensive Pear Culture: Planting Density, Rootstocks, Orchard Management, Soil-Water Relations and Fruit Quality. *Acta Hortic.* **2008**, *800*, 35–49. [CrossRef]
24. Sansavini, S.; Neri, D.; Ancarani, V. Innovazioni tecniche per migliorare l'efficienza produttiva e la qualita' dei frutti nelle coltivazioni intensive. *Frutticoltura* **2008**, *10*, 10–26.
25. SFR Emilia-Romagna. Available online: https://agricoltura.regione.emilia-romagna.it/produzioni-agroalimentari/temi/produzioni-vegetali (accessed on 20 July 2021).
26. Lockard, R.G.; Schneider, G.W. Phenols and the dwarfing mechanism in apple rootstocks. In Symposium on Growth Regulators in Fruit Production. *Acta Hortic.* **1981**, *120*, 107–112. [CrossRef]
27. Iglesias, I.; Asin, L. Performance of Conference pear on self-rooted trees and several Old Home× Farmingdale, seedling and quince rootstocks in Spain. *Acta Hortic.* **2005**, *671*, 485–491. [CrossRef]
28. Tagliavini, M.; Rombolà, A.D. Iron deficiency and chlorosis in orchard and vineyard ecosystems. *Euro. J. Agron.* **2001**, *15*, 71–92. [CrossRef]
29. Musacchi, S.; Neri, D. Optimizing production of quality nursery plants for fruit tree cultivation. In *Achieving Sustainable Cultivation of Temperate Zone Tree Fruits and Berries*; Greg, L., Ed.; Burleigh Dodds Science Publishing: London, UK, 2019; pp. 183–242.
30. Dolcet-Sanjuan, R.; Claveria, E.; Bonany, J.; Iglesias, I.; Asín, L.; Simard, M.H. Selection for New Pear Rootstocks: In Vitro Screening and Field Evaluation for Tolerance to Iron Chlorosis. *Acta Hortic.* **2004**, *678*, 463–468. [CrossRef]

31. Claveria, E.; Asín, L.; Iglesias, I.; Vilardell, P.; Bonany, J.; Simard, M.H.; Dolcet-Sanjuan, R. In Vitro Screening for Tolerance to Iron Chlorosis as a Reliable Selection Tool in a Pear Rootstock Breeding Program. *Acta Hortic.* **2012**, *935*, 199–205. [CrossRef]
32. Musacchi, S.; Ancarani, V.; Colombo, R. Indagine sui pregi e sulle limitazioni dei sistemi d'impianto per la cv Abate Fétel. *Italus Hortus* **2008**, *15*, 36–47.
33. Musacchi, S.; Ancarani, V.; Serra, S.; Colombo, R. Indagine sui differenti sistemi di impianto per Abate Fetel. *Not. Tec. CRPV* **2010**, *82*, 29–42.
34. Camposeo, S. Altissima Densità o Altissima Sostenibilità? Available online: https://www.agromillora.com/olint/it/altissima-densita-o-altissima-sostenibilita/ (accessed on 30 May 2021).
35. Iglesias, I. La intensificación sostenible como respuesta al Pacto Verde de la Unión Europea: Retos y ejemplos en la producción frutícola y en el consumo alimentario. *Rev. Frutic.* **2021**, *79*, 45–57.
36. Sansavini, S.; Musacchi, S. Canopy architecture, training and pruning in the modern European pear orchards: An overview. *Acta Hortic.* **1994**, *367*, 152–172. [CrossRef]
37. Neri, D.; Savini, G.; Massetani, F.; Giorgi, V.; Sabbatini, P. Pear Pruning and Training for Sustainable production. *Acta Hortic.* **2008**, *800*, 747–754. [CrossRef]
38. Musacchi, S.; Costa, G. Controllo della morfogenesi dei rami anticipati del melo in vivaio. *Riv. Fruttic. Ortofloric.* **1992**, *3*, 103–106.
39. Musacchi, S. Training system and management for a high density orchard of Abbé Fétel. *Acta Hortic.* **2011**, *909*, 225–240. [CrossRef]
40. Musacchi, S.; Serra, S.; Ancarani, V. Comparison among pear training systems and rootstocks for high density planting (HDP) of the cultivar Abbé Fétel. *Acta Hortic.* **2011**, *909*, 251–258. [CrossRef]
41. Palmieri, A.; Pirazzoli, C. Cause strutturali nella crisi 2019: Carente l'organizzazione dell'offerta. *Frutticoltura* **2019**, *9*, 8–11.
42. Iglesias, I.; Echeverría, G. Overview of peach industry in the European Union with special reference to Spain. *Acta Hortic.* **2021**, *1304*, 163–176. [CrossRef]
43. Iglesias, I.; Foles, P.; Oliveira, C. El cultivo del almendro en España y Portugal: Situación, innovación tecnológica, costes, rentabilidad y perspectivas. *Rev. Frutic.* **2021**, *81*, 6–49. Available online: https://www.agromillora.com/olint/nuevos-modelos-agronomicos-para-una-produccion-eficiente-y-sostenible-de-ciruelo-europeo-y-japones/ (accessed on 30 May 2021).
44. Iglesias, I.; Torrents, T.; Zuñiga, M.; Marzo, C.; Giori, M. Nuevos modelos agronómicos para una producción eficiente y sostenible de ciruelo europeo y japonés. *Rev. Frutic. Espec. Ciruelo* **2021**, 70–99.
45. Neri, D.; Silvestroni, S.; Baldoni, N.; Belletti, M.; Bellucci, E.; Bitocchi, E.; Capocasa, F.; D'Ottavio, P.; Francioni, M.; Danilo, G.; et al. Sustainable crop production. In *The First Outstanding 50 Years of "Università Politecnica delle Marche" Research Achievements in Life Sciences*; Longhi, S., Monteriù, A., Freddi, A., Aquilanti, L., Ceravolo, M.G., Carnevali, O., Giordano, M., Moroncini, G., Eds.; Springer Nature: London, UK, 2020; pp. 583–600. [CrossRef]
46. Du Plooy, P.; Van Huyssteen, P. Effect of BPI, BP3 and Quince A rootstocks, at three planting densities on production arid fruit quality of Fore lie' pear (*Pyrus communis* L.). *S. Afr. J Plant Soil* **2000**, *17*, 57–59. [CrossRef]
47. Einhorn, T.C.; Turner, J.; Laraway, D. Effect of reflective fabric on yield of mature d'Anjou pear trees. *HortScience* **2012**, *47*, 1580–1585. [CrossRef]
48. Elfving, D.C.; Lombardini, L.; McFerson, J.R.; Drake, S.R.; Faubion, D.F.; Auvil, T.D. Effects of directed applications of Prohexadione-Calcium to tops of mature pear trees on shoot growth, light penetration pruning and fruit quality. *J. Am. Pomol. Soc.* **2003**, *57*, 45–57.
49. Goke, A.; Serra, S.; Musacchi, S. Manipulation of Fruit Dry Matter via Seasonal Pruning and Its Relationship to d'Anjou Pear Yield and Fruit Quality. *Agronomy* **2020**, *10*, 897. [CrossRef]
50. Khemira, H.; Lombard, P.B.; Sugar, D.; Azarenko, A.N. Hedgerow orientation affects canopy exposure, flowering and fruiting of Anjou pear trees. *HortScience* **1993**, *28*, 984–987. [CrossRef]
51. Sansavini, S.; Neri, D.; Grandi, M.; Lane, D. Confronto fra portinnesti nanizzanti e alberi micropropagati di pero. *Frutticoltura* **1986**, *1*, 23–30.
52. Sansavini, S. Orientamenti per l'impianto e per l'allevamento del pero. *Frutticoltura* **1986**, *5*, 21–30.
53. Sansavini, S. Ricerche sulla potatura di fruttificazione del pero 'Abate Fétel'. *Riv. Ortoflorofruttic. Ital.* **1966**, *50*, 545–554.
54. Tustin, D.S.; van Hooijdonk, B.M.; Breen, K.C. The Planar Cordon—New planting systems concepts to improve light utilization and physiological function to increase apple orchard yield potential. *Acta Hortic.* **2018**, *1228*, 1–12. [CrossRef]
55. Whiting, M. The Intersection of Biology & Technology: Orchard Systems of the Future. In Proceedings of the IV Jornadas Técnicas de Fruticultura AEAMDE, Zaragoza, Spain, 1–3 March 2018.
56. Dorigoni, A.; Micheli, F. Guyot training: A new system for producing apples and pears. *Eur. Fruit Mag.* **2018**, *2*, 18–23.
57. Anthony, B.; Serra, S.; Musacchi, S. Optimization of Light Interception, Leaf Area and Yield in "WA38": Comparisons among Training Systems, Rootstocks and Pruning Techniques. *Agronomy* **2020**, *10*, 689. [CrossRef]
58. Musacchi, S.; Lanzoni, A.; Ancarani, V.; Serra, S. Primi risultati del confronto fra fusetto e sistema a doppio asse (Bibaum®) nel pero. *Riv. Fruttic. Ortofloric.* **2009**, *9*, 28–35.
59. Benito, A.; Díaz, E.; Torrents, J. Mecanización de la recolección. Clave para mejorar la competitividad en la fruta con destino industrial. *Rev. Frutic.* **2018**, *69*, 50–59.
60. Neri, D.; Zucconi, F.; Colombo, R. Confronto fra moderne forme di allevamento del pero. *Inf. Agrar.* **1997**, *45*, 69.

61. Giulivo, C. Principi fisiologici della potatura. In Proceedings of the La Potatura degli Alberi da Frutto Negli Anni '90, Verona, Italy, 27 April 1990; pp. 9–38.
62. Giulivo, C. Basic considerations about pruning deciduous fruit trees. *Adv. Hortic. Sci.* **2011**, *25*, 29–142.
63. Ferree, D.C.; Schupp, J.R. Pruning and training physiology. In *Apples: Botany, Production and Uses*; Ferree, D.C., Warrington, I.J., Eds.; CABI Publishing: Cambridge, MA, USA, 2003; pp. 319–344.
64. Cook, N.C.; du Plooy, P. An architectural analysis of pear cultivars grown under South African conditions and the relevance to local maintenance pruning strategies. *Acta Hortic.* **2005**, *671*, 443–450. [CrossRef]
65. Du Plooy, P.; Sadie, A.; Jacobs, G.; Cook, N. Branching habit of 2-year-old pear branches classified on the basis of length and position of 1-year-old laterals. *Sci. Hortic.* **2002**, *95*, 193–201. [CrossRef]
66. Vercammen, J.; van Daele, G.; Gomand, A. Root pruning: A valuable alternative to reduce the growth of Conference. *Acta Hortic.* **2005**, *671*, 533–538. [CrossRef]
67. Musacchi, S. Tecnica colturale. In *C. Fideghelli e I. Ponti (a cura di), Il pero*; Coltura & Cultura, Bayer CropScience: Milano, Italy, 2007; pp. 92–137.
68. Scudellari, D.; Marangoni, B.; Cobianchi, D.; Faedi, W.; Mattoni, M.L. Effect of fertilization on apple tree development, yield and fruit quality. In *Optimization of Plant Nutrition*; Fragoso, M.A.C., Beuisichem, V., Eds.; Kluwer Academic Publishers: Dordrecht, The Netherlands, 1993; Volume 53, pp. 357–362.
69. Tagliavini, M.; Scudellazi, D.; Marangoni, B.; Toselli, M. Nitrogen fertilization management in orchards to reconcile productivity and environmental aspects. In *Fertilizers and Environment, Developments in Plant and Soil Sciences*; Rodriguez-Barrueco, C., Ed.; Springer: Dordrecht, The Netherlands, 1996; Volume 66. [CrossRef]
70. Tagliavini, M.; Scudellari, D.; Marangoni, B.; Toselli, M. Nuovi aspetti della fertilizzazione azotata nel frutteto. *Frutticoltura* **1995**, *3*, 37–44.
71. Sánchez, E.E. Nitrogen nutrition in pear orchards. *Acta Hortic.* **2002**, *596*, 653–657. [CrossRef]
72. Tagliavini, M.; Quartieri, M.; Millard, P. Remobilised nitrogen and root uptake for spring leaf growth, flowers and developing fruits of pears (*Pyrus communis* L.) trees. *Plant Soil* **1997**, *195*, 137–142. [CrossRef]
73. Quartieri, M.; Millard, P.; Tagliavini, M. Storage and remobilisation of nitrogen by pear (*Pyrus communis* L.) trees affected by timing of N supply. *Eur. J. Agron.* **2002**, *17*, 105–110. [CrossRef]
74. Neri, D.; Lodolini, E.M.; Savini, G.; Sabbatini, P.; Bonanomi, G.; Zucconi, F. Foliar application of humic acids on strawberry (cv Onda). *Acta Hortic.* **2002**, *594*, 297–302. [CrossRef]
75. Richardson, D.G.; Al-Ani, A.M. Cork spot of D'Anjou pear fruit relative to critical calcium concentration and other minerals. *Acta Hortic.* **1982**, *124*, 113–118. [CrossRef]
76. Richardson, D.G.; Lombard, P.B. Cork spot of Anjou pear: Control by calcium sprays. *Comm. Soil Sci. Plant Anal.* **1979**, *10*, 283–389. [CrossRef]
77. Marschner, H. *Mineral Nutrition of Higher Plants*; Academic Press: London, UK, 1995; p. 897.
78. Kienholz, J.R. Boron deficiency in pear trees. *Phytopathology* **1942**, *32*, 1082–1086.
79. Raese, J.T. Physiological disorders and maladies of pear fruit. *Hortic. Rev.* **1989**, *11*, 357–411.
80. Satoh, K.; Fujiwara, Y. Boron deficiency and its counter measures of Kikusui pear. *Agric. Hortic.* **1962**, *37*, 1343–1344.
81. Wojcik, P.; Wojcik, M. Effects of boron fertilization on Conference pear tree vigor, nutrition, and fruit yield and storability. *Plant Soil* **2003**, *253*, 413–421. [CrossRef]
82. Mannini, P.; Anconelli, S.; Guidoboni, G. Moderne forme di gestione idrica del pero. *Italus Hortus* **2006**, *13*, 36–42.
83. Anconelli, S.; Mannini, P. Effects of regulated deficit irrigation on pear in an Italian sub-humid area [*Pyrus communis* L.-Emilia-Romagna]. *Riv. Fruttic.* **2002**, *64*, 71–74.
84. Lee, S.H.; Choi, J.H.; Kim, W.S.; Han, T.H.; Park, Y.S.; Gemma, H. Effect of soil water on the development of stone cells in pear (*Pyrus pyrifolia* cv. 'Niitaka') flesh. *Sci. Hortic.* **2006**, *110*, 247–253. [CrossRef]
85. Pitman, M.G.; Lauchli, A. Global impact of salinity and agricultural ecosystems. In *Salinity: Environmental Plants-Molecules*; Lauchli, A., Luttge, U., Eds.; Kluwer Academic Publishers: Dordrecht, The Netherlands, 2002; pp. 3–20.
86. Musacchi, S.; Quartieri, M.; Tagliavini, M. Pear (*Pyrus communis*) and quince (*Cydonia oblonga*) roots exhibit different ability to prevent sodium and chloride uptake when irrigated with saline water. *Eur. J. Agron.* **2006**, *24*, 268–275. [CrossRef]
87. Mia, M.J.; Massetani, F.; Murri, G.; Neri, D. Sustainable alternatives to chemicals for weed control in the orchard. *Hortic. Sci.* **2020**, *47*, 1. [CrossRef]
88. Mia, M.J.; Massetani, F.; Murri, G.; Facchi, J.; Monaci, E.; Amadio, L.; Neri, D. Integrated weed management in high density fruit orchards. *Agronomy* **2020**, *10*, 1492. [CrossRef]
89. Mia, M.J.; Monaci, E.; Murri, G.; Massetani, F.; Facchi, J.; Neri, D. Soil nitrogen and weed biodiversity: An assessment under two orchard floor management practices in NVZ (Italy). *Horticulturae* **2020**, *6*, 96. [CrossRef]
90. Mia, M.J.; Furmanczyk, E.M.; Golian, J.; Kwiatkowska, J.; Malusà, E.; Neri, D. Living mulch with selected herbs for soil management in organic apple orchard. *Horticulturae* **2021**, *7*, 59. [CrossRef]
91. Deckers, T.; Schoofs, H.; Smolders, E. Natural or chemical growth regulation in pear. *Acta Hortic.* **2005**, *671*, 503–516. [CrossRef]
92. Römmelt, S.; Peterek, S.; Treutter, D.; Rademacher, W.; Speakman, J.B.; Andreotti, C.; Costa, G.; Sponza, G.; Tortoreto, L.; Bazzi, C.; et al. Alteration of phenylpropanoid biosynthesis of fruit trees as a tool for enhancement of fire blight resistance. *Acta Hortic.* **2002**, *590*, 477–484. [CrossRef]

93. Rademacher, W. Prohexadione-Ca induces resistance to fireblight and other diseases 1. *Eppo Bull.* **2004**, *34*, 383–388. [CrossRef]
94. Smit, M.; Meintjes, J.J.; Jacobs, G.; Stassen, P.J.C.; Theron, K.I. Shoot Growth control of pear trees (*Pyrus communis* L.) with prohexadione-calcium. *Sci. Hortic.* **2005**, *106*, 515–529. [CrossRef]
95. Sansavini, S.; Corelli, L.; Ragazzini, D. Influenza di gibberelline A3 e A4+7 e di altri alleganti sulla partenocarpia e sulla ritenzione dei frutti del pero "Conference" con impollinazione controllata. *Frutticoltura* **1986**, *6*, 65–81.
96. Marcucci, M.C.; Ragazzini, D.; Sansavini, S. Partenocarpia e ritenzione dei frutti indotte da fitoregolatori nei peri "William", "Abate Fétel" e "Passa Crassana". *Riv. Ortoflorofruttic. Ital.* **1980**, *64*, 579–590.
97. Wertheim, S.J.; Wagenmakers, P.S.; Bootsma, J.H.; Groot, M.J. Orchard systems for apple and pear: Conditions for success. *Acta Hortic.* **2001**, *557*, 209–227. [CrossRef]
98. Wagenmakers, P.S.; Callesen, O. Light distribution in apple orchard systems in relation to production and fruit quality. *J. Hortic. Sci.* **1995**, *70*, 935–948. [CrossRef]
99. Lakso, A.N. Environmental physiology of the apple. In *Environmental Physiology of Fruit Crops*; Schaffer, B., Andersen, P.C., Eds.; CRC Press: Boca Raton, FL, USA, 1994; pp. 3–42.
100. Wunsche, J.; Lakso, A.N. Apple Tree Physiology—Implications for Orchard and Tree Management. *Compact Fruit Tree* **2000**, *33*, 82–88.
101. Wagenmakers, P.S.; Tazelaar, M. Planting systems and light utilization. *Annu. Rep. Res. Stn. Fruit Grow.* **1997**, *17*, 17–18.
102. Kappel, F.; Neilsen, G.H. Relationship between light microclimate, fruit growth, fruit quality, specific leaf weight and N and P content of spur leaves of 'Bartlett' and 'Anjou' pear. *Sci. Hortic.* **1994**, *59*, 187–196. [CrossRef]
103. Ziosi, V.; Noferini, M.; Fiori, G.; Tadiello, A.; Trainotti, L.; Casadoro, G.; Costa, G. A new index based on vis spectroscopy to characterize the progression of ripening in peach fruit. *Postharvest Biol. Tech.* **2008**, *49*, 319–329. [CrossRef]
104. Sakai, A.; Larcher, W. *Frost Survival of Plants: Responses and Adaptation to Freezing Stress*; Springer Science & Business Media: Berlin, Germany, 2012; Volume 62, 321p.
105. Zhu, L.H.; Borsboom, O.; Tromp, J. Effect of temperature on flower bud formation in apple including some morphological aspects. *Sci. Hortic.* **1997**, *70*, 1–8. [CrossRef]
106. Corelli Grappadelli, L.; Musacchi, S.; Magnanini, E. Single leaf and whole canopy gas exchange of pear as affected by graft incompatibility. *Acta Hortic.* **2002**, *557*, 377–383. [CrossRef]
107. Roversi, A. Pero. In *Frutticoltura Speciale*; Stampato Nello Stabil: Roma, Italy, 1991; 783p.
108. Racsko, J.; Schrader, L.E. Sunburn of Apple Fruit: Historical Background, Recent Advances and Future Perspectives. *Crit. Rev. Plant Sci.* **2012**, *31*, 455–504. [CrossRef]
109. Serra, S.; Borghi, S.; Mupambi, G.; Camargo-Alvarez, H.; Layne, D.; Schmidt, T.; Kalcsits, L.; Musacchi, S. Photoselective Protective Netting Improves "Honeycrisp" Fruit Quality. *Plants* **2020**, *9*, 1708. [CrossRef]
110. Willet, W.; Rockström, J.; Loken, B.; Springmann, M.; Lang, T.; Vermeulen, S.; Garnett, T.; Tilman, D.; DeClerck, F.; Wood, A.; et al. Food in the Anthropocene: The EAT–Lancet Commission on Healthy Diets from Sustainable Food Systems. *Lancet Comm.* **2019**, *393*, 447–492. [CrossRef]
111. European Commision (EC). Farm to Fork Strategy. For a Fair Healthy and Environmentally-Friendly Food System. 2020. Available online: https://ec.europa.eu/food/system/files/2020-05/f2f_action-plan_2020_strategy-info_en.pdf (accessed on 30 May 2021).
112. Evans, R.G.; Kroeger, M.W.; Mahan, M.O. Evaporative Cooling of Apples by Overtree Sprinkling. *Appl. Eng. Agric.* **1995**, *11*, 93–99. [CrossRef]
113. Kim, Y.K.; Xiao, C.L. Distribution and Incidence of Sphaeropsis Rot in Apple in Washington State. *Plant Dis.* **2008**, *92*, 940–946. [CrossRef] [PubMed]
114. Neri, D.; Bravetti, M.; Murri, G.; Nardini, G.; Paroncini, M. Light spectrum modifications under photo-selective hail-nets. *Acta Hortic.* **2021**, *1304*, 191–200. [CrossRef]
115. Mupambi, G.; Anthony, B.; Layne, D.; Musacchi, S.; Serra, S.; Kalcsits, L. The influence of protective netting on tree physiology and fruit quality of apple: A review. *Sci. Hortic.* **2018**, *236*, 60–72. [CrossRef]
116. Mupambi, G.; Musacchi, S.; Serra, S.; Kalcsits, L.; Schmidt, T.; Layne, D. Protective Netting Improves Leaf-level Photosynthetic Light Use Efficiency in 'Honeycrisp'Apple under Heat Stress HortScience. *HortScience* **2018**, *53*, 1416–1422. [CrossRef]
117. Manja, K.; Aoun, M. The Use of Nets for Tree Fruit Crops and Their Impact on the Production: A Review. *Sci. Hortic.* **2019**, *246*, 110–122. [CrossRef]
118. Romet, L.; Severac, G. Alt' Carpo, Une Alternative Efficace (Suite et Pas Fin!). Alt' Carpo, an Effective Alternative. *Phytoma* **2008**, *612*, 16–20.
119. Kelderer, M.; Casera, C.; Lardschneider, E.; Telfser, J. Field trials in apple orchards with different covering methods to reduce plant protection and yield losses due to pests and diseases. In Proceedings of the 18th International Conference on Organic Fruit-Growing, Stuttgart, Germany, 19–21 February 2018; pp. 64–70.
120. Westwood, M.N.; Lombard, P.B.; Bjorstand, H.O. Performance of 'Bartlett' pear on standard and Old Home X Farmingdale clonal rootstocks [Breeding for resistance to bacterial fire blight (*Erwinia amylovora*) and mycoplasma related decline]. *J. Amer. Soc. Hortic. Sci.* **1976**, *101*, 161–164.
121. Bassi, D.; Tagliavini, M.; Marangoni, B. Selection of clonal rootstocks of *Pyrus communis* (L.). *Acta Hortic.* **1993**, *367*, 364–371. [CrossRef]

122. Bassi, D.; Marangoni, B.; Tagliavini, M. "FOX", nuova serie di portinnesti clonali per il pero. *Frutticoltura* **1996**, *3*, 55–59.
123. Quartieri, M.; Tagliavini, M.; Marangoni, B.; Bassi, D.; Schiavon, L.; Giannini, M.; Previati, A. Fox 9, nuovo portinnesto per il pero europeo. *Frutticoltura* **2008**, *10*, 52–54.