Developing high-density training systems in *Prunus* tree species for an efficient and sustainable production

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Abstract

In Spain, the total surface occupied by deciduous fruit species in 2019 was 190,414 ha. Peach is the second most important *Prunus* species in Spain. China leads the ranking, followed by Spain with 77,464 ha. Cherry has experienced an important increase in production with a special development in Chile. In Spain, the surface in 2019 was 27,604 ha for cherry. Almonds accounted for 700,100 ha in 2020 and is one of the species that experienced the most significant increase in production in the last decade. The common trend of all these species concerning orchard design is the intensification, which combines mid to low vigour rootstocks and training systems based on bidimensional canopies. In peach, size-controlling rootstocks, such as 'Rootpac 40', and intensive orchards allowed both earlier and higher yields, with a 105 t ha^{-1} in 7-year-old trees, compared to the Spanish open vase. Planar canopies efficiently used mechanical flower thinning and mechanical pruning, improving the harvest rate efficiency. As a result, a reduction of the production cost of 20% was recorded, with an additional increase in fruit colour and size, due to a more uniform light distribution into the canopy. Similar results were obtained in cherry with planar canopies, increasing the harvest rate by 72% compared to the control. Those results were obtained with "Sweet series" cultivars grafted on 'Gisela 5' rootstock, early and high yields, from 25 to 30 t ha^{-1} of cumulative yields in the 4th leaf, with an average fruit size of 28-32 mm. In the French plum for dehydration, the development of hedge allowed complete mechanisation of the harvest, early yields and excellent fruit quality for fresh consumption. In almonds, super high density (SHD) development, using the size-controlling rootstock 'Rootpac 20', allowed from 1.7 to 2.3 t ha^{-1} of kernel in the third year, complete mechanisation of pruning and harvest and a reduction of production cost compared with the traditional open vase.

Keywords: intensification, hedge, planar canopies, production cost, profitability, efficiency, sustainability

INTRODUCTION

Prunus species, particularly peach, cherry, and almond, are among the most important in some such as Spain, Italy, United States, Chile, and Australia. The European Union is the second-largest producer of peach after China, with an average annual production of 3,612,000 t in the period 2018-2020 and a total harvested area of 206,660 ha in 2019. Spain is the first country in the ranking with 1,480,000 t, followed by Italy and Greece. The main training system used in all countries is the open vase or gobelet with different versions depending on the country. In Spain, the Spanish open vase has been developed in the last two decades using vigorous rootstocks as 'GF677' or 'Garnem' (Montserrat and Iglesias, 2011) and represents 92% of the total (Iglesias and Echeverria, 2021). In the last decade, new intensive orchards have been planted using size-controlling rootstocks to avoid the use of bio-regulators, common in the traditional Spanish open vase. The bi-dimensional planar canopy on-axis and bi-axis have been developed to increase the efficiency of inputs, reducing the production cost through better accessibility to the canopy of workers and machines (Iglesias and Torrents,

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2020).

China and the United States lead cherry world production. In Europe, the main producing countries are Italy and Spain with 109,315 and 107,173 t in 2019, respectively. Apart from China, Chile is the country with the most important increase in surfaces and production, accounting in 2019 for a total surface planted of 38,391 ha, with a production of 239,834 t, mainly destinated in Chinese markets. The open vase is still the most popular training system for cherry in its different versions. Despite that, other countries such as the USA, Chile, Italy and Spain, introduced in the last two decades new agronomical models based on dwarfing rootstocks to develop intensive orchards with planar canopies to get better efficiency in the use of inputs, particular labour and mechanisation, increasing fruit quality and yield (Ghelfi and Palmieri, 2015; Lugli et al., 2015; Iglesias et al., 2020). When its destination is for industry or dehydration, European French Plum cultivation is important in some countries like the United States, France, and Spain. With the adoption of edge, the complete mechanisation of pruning and harvesting using over-the-row harvesters can offer interesting perspectives for the future.

Almond's world production has increased constantly during the last decade, led by the State of California (USA), representing 79.2% of the world production (1,684,395 t in 2020). Spain is the second producer, followed by Australia, with around 7% each (Iglesias et al., 2021). For peach, cherry, and plum, the different versions of open vase are by far the main training system used. The traditional almond cropping system, with a low density of big trees per hectare that delays the full crop, makes the efficiency of inputs difficult, and mechanisation is continuously being replaced with other training systems characterized by a medium to a high-density system more efficient (Camposeo et al., 2011; Iglesias and Laghezza, 2020). The latest innovation in almond trees has been achieved by applying and adapting the experience of over 25 years in super high-density (SHD) olive orchards. The first SHD almond orchard was planted in 2010 in Lleida, and in a very short period of time, all almond producing countries started planting SHD orchards (Iglesias et al., 2021). In 2020, the SHD almond orchards accounted for 5,304 ha, mainly grown in Spain and Portugal. This new cropping system is also called 'Sustainable and Efficient System' or 'SES' due to the efficient use of natural resources, such as soil and water, and agronomic inputs, such as fertilisers and pesticides, compared to the open centre orchards (Casanova-Gascon et al., 2019). The main objectives are to get early yields through intensification and develop fully mechanised orchards. This later includes pruning and harvesting by over-the-row harvesters. Both will decrease the production cost by improving the efficiency of the inputs, including labour.

In all the species previously explained (peach, cherry, plum, and almond). In other species, such as apple and pear, it started decades ago because of the availability of dwarfing rootstocks as 'M.9' or quince selections and the labour cost for pruning and harvesting. The result is always smaller and more bi-dimensional canopies than the goblet or open vase. With this particular tree architecture, mechanisation is key to improving efficiency and productivity, and it represents the main guideline for modern fruit production. It can significantly reduce labour needs, increasing the efficiency of inputs and reducing the production cost (Iglesias, 2019). Orchard design in these intensive orchards has been studied to reach the optimum irradiance absorption due to the least canopy interception (Trentacoste et al., 2015). Inter-row space will depend mainly on the height of the canopy and the latitude being the most used, the 1/1.0 to 1/1.2 ratio (inter-row distance/tree height) (Iglesias et al., 2021; Maldera et al., 2021).

Labour is one of the most critical production costs in deciduous fruit trees, particularly cherry or peach, but less important in nuts (almond, walnut or hazelnut) (Iglesias, 2019). The trend over the last decade shows a significant increase in cost and labour scarcity in all countries, with a cumulative increase of cost higher than the prices perceived by the growers. In this scenario and, even in a typical scenario, an efficient way to gain competitivity is to replace part of this labour with mechanisation (pruning, thinning, harvest) and, when that is not possible (harvest specifically), to do it more efficiently with planar canopies. These bidimensional canopies are more accessible to workers and machines than automotive platforms or pedestrian orchards. All these benefits about the efficiency of labour, combined with environmental concerns in the case of almond harvest from the ground and the increased efficiency of the use of inputs, can only be achieved through intensification. This is the only way to produce environmentally and economically sustainable fruit (Willet et al., 2019; Iglesias, 2021).

Experiences and results

This section reports several results from different experimental and commercial orchards of peach, cherry, European plum and almond from Spain, Italy, Chile, and the USA. In peach, the cost of production in Spain is mainly dependent on labour, which represents 45% of the total, with the traditional Spanish open vase (Figure 1). Labour use can be reduced by changing the tree architecture and replacing it with mechanisation (Iglesias, 2019). Crop protection, fertilisation and soil management represent the highest production cost, followed by harvesting and thinning. Flower and fruit thinning, pruning, harvesting and crop protection costs can be significantly reduced by changing the tree architecture to smaller and bidimensional canopies more accessible to labour, machines, and light, resulting in more efficient use of inputs and better fruit quality (Iglesias, 2019; Iglesias and Echeverría, 2021). The combined effect of the training system and spraying equipment in fruit trees increased leave coverage, reducing drift from 65% in an open vase to 15% in narrow-planar canopies using side-by-side spraying equipment (Iglesias, 2021).

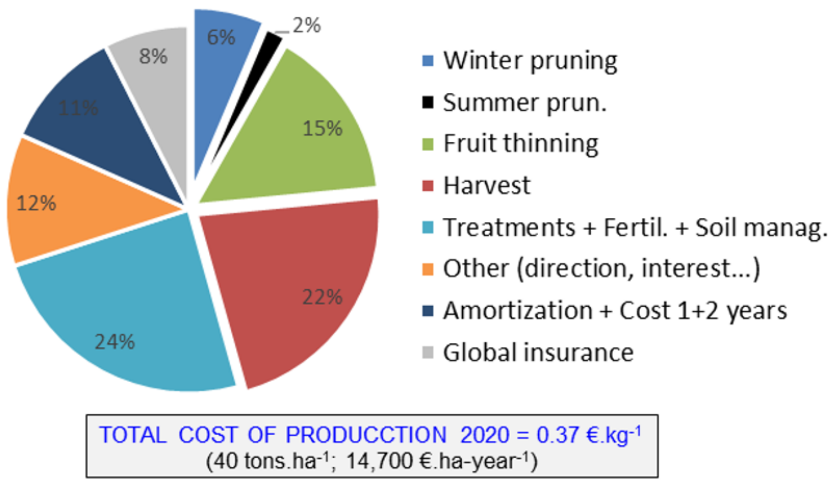

Figure 1. Cost of production for a mid-season nectarine cultivar 'Luciana' (40 t ha^{-1}), trained in Spanish open vase, spacing 5×3 m and expected lifespan of 12 years.

Intensification in peach can be achieved similarly to other species such as apple and pear by using size-controlling rootstocks, which induce low to mid vigour. Different peach seedlings, plums and interspecific *Prunus* hybrids such as 'Nemaguard', 'Controller 5', 'Controller 6', 'Montclar', 'Adesoto 101', 'Montizo', 'Isthara' or 'Penta', have been used as peach rootstocks, and some of them for vigour control (DeJong et al., 2005; Iglesias, 2018). Additional rootstocks have been introduced in experimental and commercial plots in the last decade. The "Rootpac series" developed by Agromillora deserves special mention (Iglesias et al., 2020). In particular, the largest experience in Spain for intensive orchards is with 'Rootpac 40', 'Rootpac 20', and some plums such as 'Adesoto 101'. Much experience has been developed in the last decade, demonstrating the clear effect of the rootstock on fruit size and yield efficiency (Iglesias, 2018; Reig et al., 2020). The development of the rootstock on the agronomical performance of 'Big Top' nectarine grafted on 20 rootstocks was evaluated in a long-term trial carried out at IRTA in the Ebro Valley (Spain). Among the rootstocks, 'Rootpac 40' provided the best fruit size distribution and the best average yield harvested in the first pick, improving the maturity in around 8 days, and showing one of the best yield efficiencies. One of the most interesting benefits of intensification using size-controlling rootstocks is reducing the unproductive period compared with the standard vigorous rootstocks. The annual and cumulative yields of ‘Noracila’ (early-season) and ‘Luciana’ (mid-season) grafted on ‘Rootpac 40’, trained in axis, and on ‘GF 677’, trained in Spanish open vase, under the climatic conditions of the Ebro Valley (NE-Spain) are shown in Figure 2. Planting distances used were 3,5×1,1 m and 5×3 m for axis and open vase, respectively. Tree height was 3.2 m for the axis and 2.4 m for the Spanish vase. Fruit size was obtained as a mean value for both systems, with similar crop load management. Fruit size was 60-67 mm Ø for ‘Noracila’ and 71-75 mm Ø for ‘Luciana’.

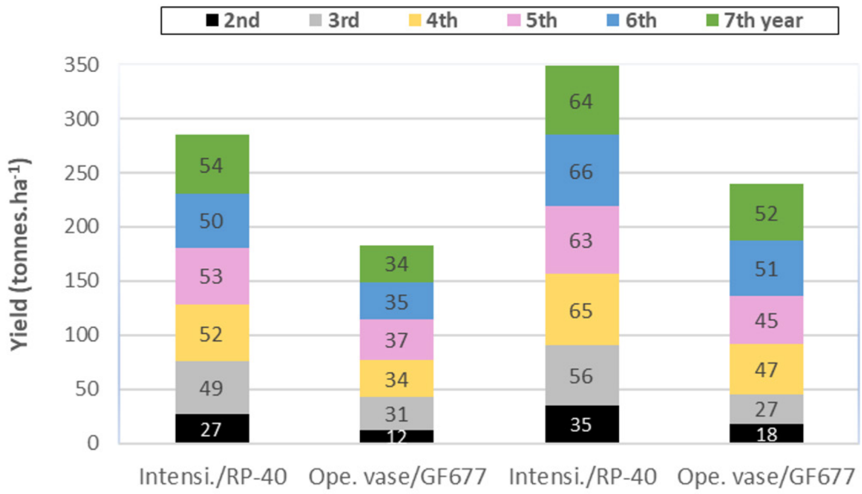

Figure 2. Annual and cumulative yields of 7-year-old trees of nectarine cvs. ‘Noracila’ (early season) and ’Luciana’ (mid-season) grafted on ‘Rootpac 40’ (Intensive) and ‘GF 677’ (Spanish open vase) as mean values of different orchards in the Ebro Valley (Spain). Different letters for the same cultivar mean differences at $P \leq 0.05$.

Flower/fruit thinning represents a significant production cost (Figure 1), especially in high blooming intensity and early harvest cultivars. The effect of crop load management on fruit quality has been widely reported in peach (Sutton et al., 2020). Also, fruit quality (fruit size, colour, SSC) is directly related to prices that growers perceive, particularly with early-season cultivars (Iglesias and Echeverría, 2009). In Spain and Italy, the use of Darwin equipment for flower thinning is a common practice in intensive peach orchards, applying it at 40-80% of bloom (Vittone et al., 2010). The results obtained using this technique on 8-year-old trees of ‘Ambra’ (early season), applying either the standard fruit thinning or mechanical flower thinning and a complimentary hand thinning of fruits, clearly illustrated the benefit of flower thinning on fruit size distribution and some quality parameters, leading to an increase in SSC and fruit weight. In addition, the total cost of thinning (hand fruit thinning vs mechanical with Darwin plus complimentary hand) was reduced from 1,870 to 836 € ha^{-1}, respectively.

One of the most important production costs of peach is harvest. Changing the canopy from the traditional volume to a planar canopy increases efficiency. In the midseason cultivar ‘Luciana’, the harvest rate was 130 kg h-person^{-1} in adult trees of Spanish open vase to 215 kg h-person^{-1} in planar canopies assisted by platforms. This represents a mean increase of 65%. Considering a mean price of labour of 8.5 € h^{-1} (2020), the equivalent harvest cost of kg^{-1} is 6.5 and 3.9 cents € kg^{-1} for open vase and planar canopy, respectively. The main production costs of peach are affected by tree architecture. Developing planar canopies and using mechanisation for pruning, thinning and harvesting, plus a more efficient spraying, the total cost of production can be reduced in this mid-season by around 2,819 € ha^{-1} or 7.0 cents € kg^{-1} (considering a yield of 40 t ha^{-1}). In spite of this advantage, for intensive orchards, the cost of planting will increase about 2 times compared with the standard open vase.

Cherry is the most labour-demanding fruit crop. In Spain, only harvest represents around 70% of the cost of production (Figure 3). Changing the current Spanish bush for more intensive/planar canopies is an interesting option to improve the accessibility of labour and machines and, consequently, reduce the cost of production as reported in peach.

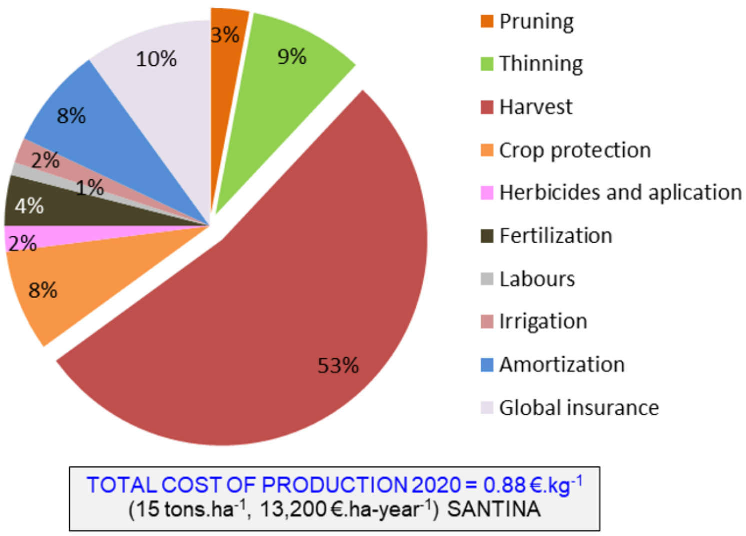

Figure 3. Cost of production for a mid-season cherry 'Santina' (15 t ha^{-1}), trained in "Spanish bush", spacing 5×3 m and expected lifespan of 15 years.

Different training systems have been developed worldwide in the last two decades (Long et al., 2015). Still, the open vase and its different modalities (Open centre, KGB, Spanish bush, etc..) are the most widely used ones globally. Several experiences from different countries concerning planar canopies, such as UFO system, axis, bi-axis or multiaxis, demonstrate the increase in labour efficiency and a better fruit quality (Ghelfi and Palmieri, 2015; Lugli et al., 2015). Data from Whiting (2018) illustrated the clear effect of canopy accessibility on harvest efficiency by reporting an increase of 72% when the UFO system was compared with the open centre (Table 1).

Table 1. Orchard system, cultivar and rootstock affecting harvest rate in cherry (WA, USA). Source: M. Whiting pers. commun. (2018).

Cultivar/rootstock	Training System	Mean harvest rate (kg min^{-1})
Bing/Mazzard	Traditional open centre	0.51±0.12 (reference)
Sweetheart/CAB-6P	Gracés Tunnel	0.51±0.15 (+9%)
Chelan/Mazzard	Steep leader (4-5 upright leaders)	0.53±0.13 (13%)
Tieton/Gisela-5	Central leader	0.64±0.19 (36%)
Sweetheart/Mazzar	KGB	0.72±0.17 (+53%)
Cowiche/Gisela-12	UFO	0.81±0.18 (+72%)

As in apple, in cherry, the intensification results in early yields from shorter branches than in less intensive orchards, reducing the cost of bending the branches toward the fruiting position (Long et al., 2015). Additionally, more planar canopies resulted in better access to labour and machines, improving light distribution in the whole canopy and, in turn, increasing fruit quality (size, SSC and colour) (Ghelfi and Palmieri, 2015). The results obtained by applying this concept in commercial orchards of the Emilia Region (Italy), combining different "Sweet series" cultivars with dwarfing rootstocks as the dwarfing 'Gisela 5' are shown in Table 2. Their efficiency in reducing the unproductive period, increasing yield and fruit quality, especially fruit size, is clear.

Table 2. Annual and cumulative yields, mean fruit size and fruit weight of 7-year-old trees of 'Sweet Valina', 'Sweet Sareta' and 'Kordia', grafted on 'Gisela 5' in Ferrara (Emilia Romagna, Italy). Source: M. Giori, pers. commun. (2020).

Cultivar/ Gisela 5	Planting distance (m)	Yield (t ha^{-1})						Fruit size		Fr. weight (g)
		2nd	3rd	4th	5th	6th	Cumu.	%	mm	
S. Valina	3.5×0.5	3.3	6.5	15.1	18.4	16.3[a]	59.6	100%: 28+	28-30	7.7
S. Sareta	3.5×0.5	3.8	7.7	18.3	22.8	20.7[a]	73.3	100%: 30+	30-32	8.2
Kordia	3.5×0.5	3.0	6.5	12.6	13.1	5.2[a]	40.4	90%: 28+	28-30	7.4

[a]Affected by spring frost in blooming time, 9 days at 0°C and 2 days at – 4.5°C.

European plum or French prune cultivation, mainly 'Agen' cultivar, is important in many countries. Using size-controlling rootstocks as Rootpac-20 trained in hedge system is an innovative alternative to the traditional open-vase. It allows almost complete mechanisation of pruning and harvesting using over-the-row harvesters. Results were obtained in the first commercial orchard in Peralillo, O'Higgins (Chile), with a spacing of 3.5×1.5 m provided more than 30 t ha^{-1} in the five years. It can be significantly improved by narrowing the spacing to 3.0-3.2×1.0-1.2 m, with high fruit quality and easy crop management. In addition, this productive model allows the grower to pick the fruits efficiently from the ground for fresh market (Iglesias and Fuentes, 2021).

Almond is a Mediterranean crop extensively produced in several European countries such as Spain, Portugal, Italy and Greece, Australia, and the United States. Due to the constant increase in world consumption in the last decade, almond has experienced considerable growth in surfaces in California and Spain, with a total area cultivated in 2020 of 665,000 ha and 700,156 ha, respectively. The most common training system is the open vase, with different variations depending on the country. Unlike other deciduous species such as apple, pear, peach or cherry, labour is not the highest cost because most tasks, like pruning or harvest, are partial or totally mechanised. As in other fruit crops, in all producing countries, the global trend in almonds shows a continuous process of intensification to reduce the unproductive period and canopy volume for more efficient use of inputs, the efficiency of mechanisation and reduction of the environmental impact when the almond is harvested from the ground. In addition to the open vase and its several versions, one of the most innovative tree architectures is the SHD, also named edge or SES (Sustainable and Efficient Solutions) (Iglesias et al., 2021). The partition of production and processing costs corresponding to two training systems used in Spain (traditional open vase harvest with buggies + nets and SHD harvest by over-the-row harvester) are illustrated in Figure 4. Both orchards are located in the Ebro Valley and are irrigated. The most important field costs are irrigation, crop protection, harvest and fertilisation.

In SHD, orchards canopy volume is reduced by 47% compared to the open vase (Figure 4), but the yield of both systems was similar. This particular bidimensional canopy allows for optimal light penetration into the canopy and almost a complete mechanisation of pruning and harvesting (over-the-row harvester) (Iglesias et al., 2021; Maldera et al., 2021). As a result, the total cost of production (including harvest + processing) was 1.60 € kg^{-1} kernel in 2020, significantly lower than the one corresponding to open vase harvest with buggies + nets established in 1.84 € kg^{-1} (Figure 5) or the Californian system (2.01 € kg^{-1}); in both last systems mainly due to a superior cost of harvest and dehulling. In addition, preliminary data obtained from trials carried out in 2020 and 2021 by the CRAG-UdL (Lleida-Spain) show the use of pesticides reduction of 35% of volume applied, leaf deposition increased by 11%, drift was reduced from 29.6 to 17.3%, and cost of crop protection was reduced by 28% because of the smaller, continuous and planar canopy of SHD compared to open vase (Figure 4). Because of the lower light interception of the SHD canopy compared to the open vase (Figure 4), an accurate design of the orchard is fundamental, particularly inter-row distance, inter-tree distance and row orientation. Based on the results obtained in Spain comparing the hedge with the open vase (Casanovas-Gascón et al., 2019), it seems clear that light interception can be significantly improved primarily by reducing the inter-row distance by adjusting it to the optimal ratio inter-row/tree height for each latitude (Iglesias et al., 2021; Maldera et al., 2021).

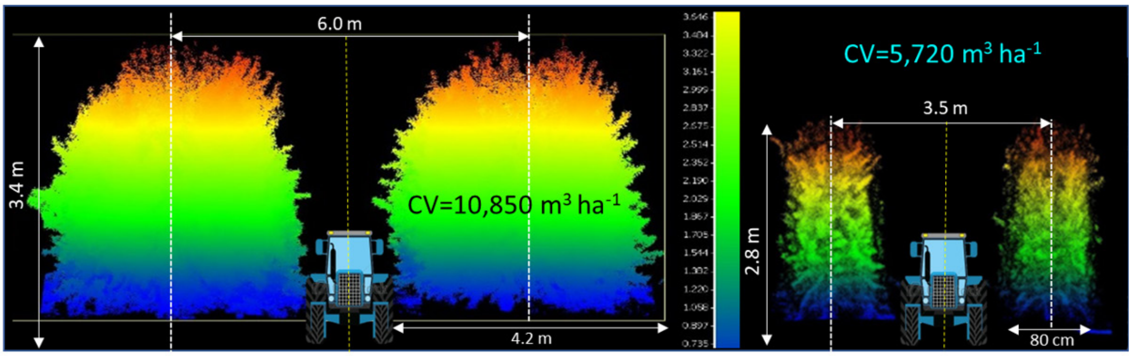

Figure 4. Different tree architecture and canopy volume (CV) corresponding to 5-years-old trees of almond trained in an open vase (left) and SHD (right) scanning the canopy by mobile terrestrial laser scanner based on a 2D light detection and ranging (LiDAR).

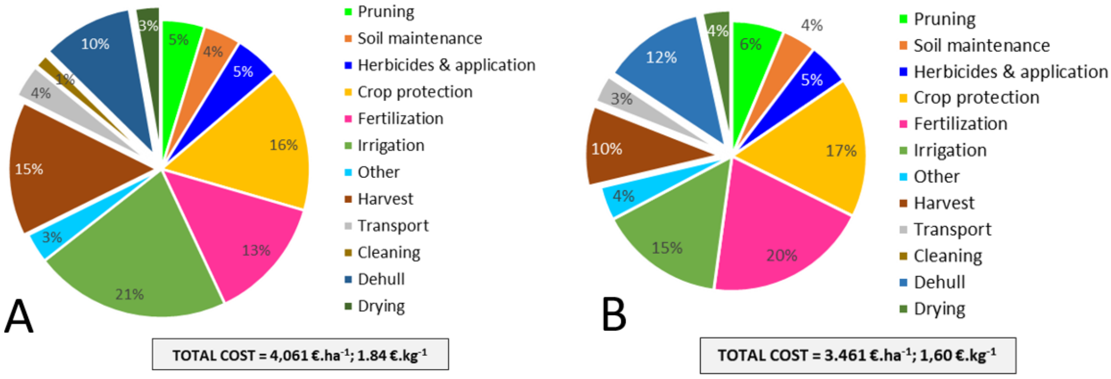

Figure 5. The total cost of production and processing of almond trained in an open vase, spacing 6×4 m, harvest with buggies + nets (A) and, trained in SHD, spacing 3.5×1.2 m, harvest with over-the-row harvester (B), under Ebro Valley (Spain) conditions. Year 2020.

Results obtained from different experimental and commercial orchards in various locations in Spain and Portugal evidence how moving into the different versions of SHD (named V1, V2 and V3) and reducing the inter-row distance from 4.0 to 3.5 and 3.0-3.2 m, respectively, allowed an increase of production of 65%, as illustrated in Figure 6. New orchards planted in the last years with the V3 version will provide additional information about the real potential yield of this system (top dashed line of Figure 6). Comparing light interception of both systems at 14:00, the open vase intercepted 27% more than V1 of SHD. Still, if we consider the mean values of PAR intercepted along the day, the difference is reduced to 15.8%. When we compare the light interception of V1, V1 and V3 versions (0.80 cm canopy width) at 14:00 time, the average light intercepted increased from 20 to 22.8 and 26.6%, respectively.

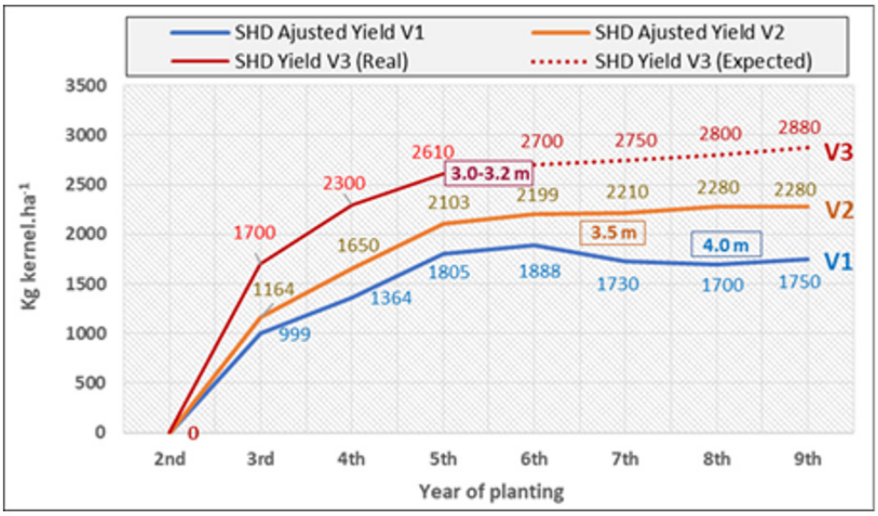

Figure 6. Effect of inter-row distance (4.0, 3.5 and 3.0-3.2 m) on annual yields of SHD almond in V1, V2 and V3 versions, respectively.

CONCLUSIONS

Different intensification models in important *Prunus* species such as peach, cherry, and almond are presented. It's demonstrated that the intensification combining size controlling rootstocks and a training system based on small bidimensional canopies results in better efficiency of inputs, increasing the sustainability of the orchards. In cherry and peach, which involve demanding tasks such as pruning, thinning or harvesting, planar canopies allow for easier access for manual workers and machines. This increases their efficiency and opens the door to the adoption of future advancements in robotics. In almonds, reducing canopies allows for complete mechanisation of pruning and harvest, avoiding environmental concerns. In addition to labour cost reduction, small and bidimensional canopies are more efficient in using pesticides, fertilisers and water. This is because narrow canopies improve chemical distribution and smaller canopies are more efficient in using nutrients since they have less structural wood. Intensification is the efficient use of inputs and achieving a more sustainable production necessary to increase high-quality output.

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 Commission. This change would entail radical improvements in the efficiency of pesticides, fertilisers, water use, and finally, labour, thanks to innovation in crop systems management. In addition, to achieve negative emissions globally as per the Paris Agreement, the global food system, particularly the food production system, 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. We can do this by turning climate and environmental challenges into opportunities, including a sustainable chain of food production, distribution, and consumption. Sustainable production is the response to Green Deal for food production.

Literature cited

Camposeo, S., Palasciano, M., Vivaldi, G.A., and Godini, A. (2011). Effect of increasing climatic water deficit on some leaf and stomatal parameters of wild and cultivated almonds under Mediterranean conditions. Sci. Hortic. (Amsterdam) *127* (*3*), 234–241 https://doi.org/10.1016/j.scienta.2010.09.022.

Casanovas-Gascón, J., Figueras-Panillo, M., Iglesias-Castellarnau, I., and Martín-Ramos, P. (2019). Comparison of SHD and open-center training systems in almond tree orchards cv. 'Soleta'. Agronomy (Basel) *9* (*12*), 874 https://doi.org/10.3390/agronomy9120874.

DeJong, T.M., Johnson, R.S., Doyle, J.F., and Ramming, D. (2005). Research yields size–controlling rootstocks for peach production. Calif. Agric. *59* (*2*), 80–83 https://doi.org/10.3733/ca.v059n02p80.

Ghelfi, R., and Palmieri, A. (2015). La qualità paga: analisi dei costi della redditività. Paper presented at: Convegno Nazionale del Ciliegio 2.0 – "Innovazioni di prodotto e di processo per una cerasicoltura di qualità" sessione 1 – Nel ciliegio la qualità paga (Vignola, Italy).

Iglesias, I. (2018). Patrones de melocotonero: situación actual, innovación, comportamiento agronómico y perspectivas de futuro. Rev. Frutic. *61*, 6–43.

Iglesias, I. (2019). Costes de producción, sistemas de formación y mecanización en frutales, con especial referencia al melocotonero. Rev. Frutic. *69*, 50–59.

Iglesias, I. (2021). La intensificación sostenible como respuesta al Pacto Verde de la Unión Europea: retos y ejemplos en la producción agrícola y el consumo alimentario. Rev. Frutic. *79*, 45–57.

Iglesias, I., and Echeverría, G. (2009). Differential effect of cultivar and harvest date on nectarine colour, quality and consumer acceptance. Sci. Hortic. (Amsterdam) *120* (*1*), 41–50 https://doi.org/10.1016/j.scienta.2008.09.011.

Iglesias, I., and Echeverría, G. (2021). Overview of peach industry in the European Union with special reference to Spain. Acta Hortic. *1304*, 163–176 https://doi.org/10.17660/ActaHortic.2021.1304.24.

Iglesias, I., and Fuentes, M. (2021). Cultivation of the french prune in edge. Agromillora Technical Report *I*, 1–22.

Iglesias, I., and Laghezza, L. (2020). La coltivazione in Spagna innovazione tecnica-varietale e impianti intensivi. Riv. Fruttic. *10*, 51–59.

Iglesias, I., and Torrents, J. (2020). Diseño de nuevas plantaciones adaptadas a la mecanización en frutales. Horticultura *346*, 60–67.

Iglesias, I., Torrents, J., Moreno, M.A., and Ortíz, M. (2020). Actualización de los portainjertos utilizados en cerezo, duraznero y ciruelo. Rev. Frutic. *42* (*2*), 8–18.

Iglesias, I., Foles, P., and Oliveira, C. (2021). El cultivo del almendro en España y Portugal: situación, innovación tecnológica, costes, rentabilidad y perspectivas. Rev. Frutic. *81*, 6–49.

Long, L., Lang, G., Musacchi, S., and Whiting, M. (2015). Cherry Training Systems, PNW-667. Pacific Northwest (USA: Extension Publications).

Lugli, S., Correlale, R., Grandi, M., Bertolazzi, M., Taruscio, G., Ceccarelli, A., Rocchi, R., Taioli, M., Vidoni, S., and Costa, G. (2015). Qualità e sistemi di impianto. Paper presented at: Convegno Nazionale del Ciliegio 2.0 – "Innovazioni di prodotto e di processo per una cerasicoltura di qualità" (Vignola, Italy).

Maldera, F., Vivaldi, G.A., Iglesias-Castellarnau, I., and Camposeo, S. (2021). Row orientation and canopy position affect bud differentiation, LAI and some agronomical traits of a super high-density almond orchard. Agronomy (Basel) *11* (*2*), 251 https://doi.org/10.3390/agronomy11020251.

Montserrat, R., and Iglesias, I. (2011). I sistemi di allevamento adottati in Spagna: l'esempio del vaso catalano. Riv. Fruttic. *7/8*, 18–26.

Reig, G., Garanto, X., Mas, N., and Iglesias, I. (2020). Long-term agronomical performance and iron chlorosis susceptibility of several Prunus rootstocks grown under loamy and calcareous soil conditions. Sci. Hortic. (Amsterdam) *262*, 109035 https://doi.org/10.1016/j.scienta.2019.109035.

Sutton, M., Doyle, J., Chavez, D., and Malladi, A. (2020). Optimizing fruit-thinning strategies in peach (*Prunus* persica) Production. Horticulturae *6* (*3*), 41 https://doi.org/10.3390/horticulturae6030041.

Trentacoste, E.R., Connor, D.J., and Goméz-del-Campo, M. (2015). Effect of row spacing on vegetative structure, fruit characteristics and oil productivity of N-S and E-W oriented olive hedges. Sci. Hortic. (Amsterdam) *193*, 240–248 https://doi.org/10.1016/j.scienta.2015.07.013.

Vittone, G., Asteggiano, L., and Demaria, D. (2010). Buona pezzatura e costi minori diradando a macchina il pesco. Inf. Agrar. *26*, 50–53.

Whiting, M. (2018). The intersection of biology & technology: orchard systems of the future. Paper presented at: IV Jornadas Técnicas de Fruticultura AEAMDE, La Almunia de Doña Godina (Zaragoza, Spain).

Willet, W., Rockström, J., Loken, B., Springmann, M., Lang, T., Vermeulen, S., Garnett, T., Tilman, D., DeClerck, F., Wood, A., Jonell, M., Clark, M., Gordon, L.J., Fanzo, J., Hawkes, C., Zurayk, R., Rivera, J.A., De Vries, W., Sibanda, L.M., Afshin, A., Chaudhary, A., Herrero, M., Agustina, R., Branca, F., Lartey, A., Fan, s., Crona, B., Fox, E., Bignet, V., Troell, M., Lindahl, T., Singh, S., Cornell, S.E., Reddy, K.S., Narain, S., Nishtar, S., and Murray, C.J. (2019). Food in the Anthropocene: the EAT–Lancet Commission on healthy diets from sustainable food systems. The Lancet Commissions. http://dx.doi.org/10.1016/S0140-6736(18)31788-4.