Current trends and future perspectives towards sustainable and economically viable peach training systems

(Article begins on next page)

Current trends and future perspectives towards sustainable and economically viable peach training systems

Davide Neri[1], Samuele Crescenzi[1], Francesca Massetani[2], George A. Manganaris[3], Veronica Giorgi[1,*]

[1]*Department of agricultural, food and environmental sciences, Università Politecnica delle Marche, Ancona, Italy*

[2]*HORT Soc. Coop.–Via Cardeto n.70, 60121 Ancona, Italy*

[3]*Cyprus University of Technology, Department of Agricultural Sciences, Biotechnology & Food Science, 3603 Lemesos, Cyprus*

*Author to whom correspondence should be addressed: Veronica Giorgi, D3A Università Politecnica delle Marche, via Brecce Bianche 60131 Ancona, Italy. Email: v.giorgi@staff.univpm.it

Abstract

Considering the limited areas suitable for peach cultivation, the short life cycle of the orchards, as well as aspects regarding appropriate rootstock availability and soil properties due to replant conditions, the sustainable intensification became increasingly necessary on peach production systems. Based on the local environment and labor availability, two new training systems have been introduced and are being widely adopted towards efficient small canopies for high- and medium-density orchards, respectively. The so-called two-dimensional (2-D) fruiting walls is an intensive, highly-mechanized/high-density training system and is commonly accompanied by multifunctional net protection in order to counteract the adverse effects of climate change. On the other hand, the medium-density three dimensional (3-D) small open vases is suitable for low frost-risk areas and farms with fully available manpower. In both cases, the decisions taken during the orchard establishment and the first years regarding soil fertility and orchard mechanization have strategic importance to guarantee a sustainable peach production system on both quantitative and qualitative terms. The employment of both spring and summer pruning increases work efficiency and improves fruit quality, as well as fruit thinning, management efficiency and mechanization. Sustainable intensification not only reshapes the use of chemicals and irrigation, but also weed control and soil amendment with organic matter to support the complexity and heterogeneity of the agroecosystem with the circular economy.

Keywords: sustainable orchard management, intensification, high density planting, pruning, labor efficiency, netting systems, *Prunus persica*

1. Introduction

The increase in consumption of horticultural commodities as high-quality fresh produce food is now a major trend in the world (**Cerdà et al., 2021**). Agricultural production for human consumption has implications for the environmental sustainability, therefore modern agronomic techniques need to be developed to support the new planting systems that must balance the increase of the demand and their negative environmental impact. Nowadays, China is the major producer of peaches worldwide with *ca.* 15 million metric tons (Mt) per year, followed by Spain (1.8 Mt), Italy (1.3 Mt), Greece (0.9 Mt) and the United States (0.8 Mt). Production volumes may vary from year to year depending on the climatic conditions that may occasionally cause reduced production due to frost damage, yet peach is still ranked as the most important temperate fruit crop in terms of production volumes, besides apple.

Notably, fresh peach consumption has registered over the recent years a descending trend in several countries due to inferior fruit quality in the market that has turned away consumers from fresh peaches (**Cirilli et al., 2016; Crisosto, 2002; Iglesias and Echeverría, 2009**). Thus, optimizing consumer quality is necessary to promote fresh peach consumption. Sensory and nutritional quality of peach fruits are the output of a system of interaction between different factors. These include rootstock-cultivar interactions, but also the training system, and the cultivation techniques adopted (**Minas et al., 2018**).

Moreover, the globalisation and competition among flesh fruits from different parts of the world renders it necessary to engage in continuous innovation and refinement of orchard management techniques, in order to ensure the profit margins that are indispensable for the success of peach fruit industry. Over the recent years, the main challenge towards enhanced peach production was related to the selection of elite cultivars, as a result of several efficient breeding programs worldwide. In one of the most active breeding periods, from 1997 to 2006, almost 1000 new cultivars were registered in the world (516 peaches, 419 nectarines, 50 rachis peaches), in 18 different countries (**Fideghelli and Della Strada, 2008**). Nowadays the cultivar selection is a key aspect for farmers who have to meet the needs of a rapidly evolving supply chain, and in the meantime, they have to cultivate the new orchard to be productive with marketable fruit, knowing that the fruits of a given cultivar can be appreciated on the market for a limited period, that can be eventually even shorter than the return on investment. It is worth considering that, to pursue an environmentally sustainable production, the choice of the production location is fundamental, especially considering climate changes, for a production that requires lower inputs. Another great challenge is to choose the appropriate cultivation techniques, which have to be efficient, adapted to the cultivar characteristics, economically viable and environmentally-friendly towards more sustainable production systems.

The goal to pursue in peach production is to meet the final consumer needs within a global context, with a high-quality end product, and at the same time rationalize management costs and logistics to guarantee sustainable production and commercialization. The major cost in peach production is labor for tree pruning and training, fruit thinning and harvest operations. Preliminary works of our group showed that, in Italian peach orchards, harvesting requires from 20 to 30% of the total cost per hectare, pruning around 14% and thinning from 10 to 16% (data not shown). Such results are in accordance with those presented by Iglesias and Echeverria (2022) in Spain. However, during the recent years the lack of local labor in the main producing countries in Europe and the United States has led to modifications on planting systems to counteract the lack of specialized workers. Therefore, simplified operations dealing with pruning and thinning can be additionally conducted mechanically (**Foschi et al., 2012; Anthony and Minas, 2021**).

The decisions taken at orchard establishment and in the first years became of prime importance towards enhancement of fruit production at the lowest production costs (**Loreti and Massai, 2006).** Environmental and social impact of the decisions need to be considered to guarantee a sustainable peach production, while the limited areas suitable for peach production and the short life cycle of the orchards create the need for replantation with several problems regarding appropriate rootstock availability and soil sickness.

2. Sustainable peach orchard intensification

Intensive fruit production systems are characterized by increasing planting density, early fruit bearing, small tree size, high crop loads, short orchard life-span, easy mechanical management, efficiency in the use of inputs and frequent replanting (**Musacchi et al 2021**). The achievement of constant high fruit quality depends on the efficient management of canopy architecture from the nursery to the orchard. Environmental sustainability requires soil management practices to increase and maintain soil fertility such as minimum tillage, multispecies ground cover (**Mia et al., 2020a,b**), supply of amendments and regulated deficit drip irrigation. Innovation in crop-management regimes need strategies to control plant and root development, able to optimize and, where possible, to simplify orchard management.

The achievement of these goals requires the active participation of farmers and accurate extension services (**Neri et al. 2020**). Integrated fruit production strategies 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 do not occur at the farm level, but at the landscape 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, technicians, extension specialists) is thus a precondition for successful sustainable land management (**Neri et al., 2020**). For this reason, it is important a spatial scale match between the RDP and the ecological processes controlling the target agri-environmental issues. As an example, peach production should be carried out towards increment of carbon soil content, reduction of soil erosion and augmentation of carbon sequestration. Moreover, the use of plastic netting systems and drip irrigation with plastic tubes should be organized with circular economy criteria which include plastic recycling at the end of their life cycle in the field.

The competitiveness of peach industry is highly based on the efficient use of labor and other inputs, in particular irrigation and use of agrochemicals, such as fertilizers and pesticides. All of them require small and accessible trees according to social and environmental conditions. Flatted canopies, commonly also named as planar or bidimensional canopies, tend to be more efficient for enhanced fruit quality and use of external inputs, being more accessible to workers and machines or robots compared to volume, or 3D canopies. On the other hand, the latter are more autonomous, resilient to climate change, but they can be considered as a profitable approach only if the trees are of small and compact size, fully manageable from the ground. All these benefits about the efficiency of labor, combined with environmental concerns, can be achieved through a sustainable intensification (**Willett et al., 2019**). Most of the options provided in the section “Training systems” are based on flatted canopies or small open vase systems, which are fully in line with the objectives of the “Green Deal” and the strategy

"From Farm to Fork" of the European Union concerning the sustainable fruit production (**EC, 2020; Musacchi et al. 2021**).

It is worth noting that the Next Generation EU program (**EC, 2020**) requires to dramatically reduce the use of the fertilizers and pesticides per hectare, and therefore any training and pruning systems, which will be proposed from now onwards, should be efficient not only for the production cost and the labor use but also for the easiness in nutritional and soil fertility control and for precise fruit and pest management.

3. Training systems for peach innovation

The choice of the training system is depending on several factors interacting each other (**Figure 1**Errore. L'origine riferimento non è stata trovata.); it is therefore imperative to demonstrate which is the best solution, but this should be considered on a case by case basis. Biological characters of a given cultivar, labor requirements, mechanization and protection systems need to be considered. In addition, the socio-economic conditions which determine the efficiency of cash flow (farming and territory organization, food chain and type of commercialization) and the level of ecologization or eco-sustainability of the orchard system must be taken into account.

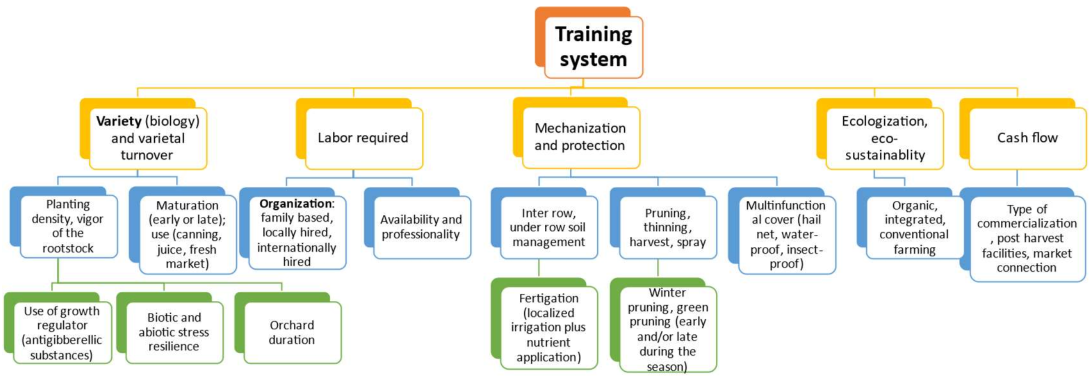

Figure 1. Factors affecting the choice of a training system –

Technical and varietal renovation are necessary to cope with a market demand of standardized quality products, but the answer to this renovation must be flexible, capable to adapt to different techniques and planting systems available for the farmers and able to face different socio-economic situations. As a result, in recent years there are different solutions with a common intensification tendency. Intensification of the planting systems aims not only to reduce unproductive period and rapidly reach full production but, also, must facilitate mechanization and reduce labor cost per yield unit (**Neri, 2015**).

Historically, peach has been planted into low-density orchards, which were characterized by wide inter and intra-row spacings, thus the trees had three-dimensional canopy and were tall and robust, resulting very autonomous, productive and long lasting but with a very high labor requirement and with difficult pest control. As in several different fruit orchards, in peach the tendency nowadays is to increase planting density and reduce the tree dimension. The aim is pursued with genetic and horticultural studies to select cultivars and rootstocks that are suited for high density orchards, training and pruning techniques that maintain the plant highly productive in a smaller volume with high quality fruit. In particular, the new training systems manipulate the canopy architecture to achieve various goals. In short, an ideal training system maintains optimal levels of light interception, uniform light distribution and facilitates high yields of premium quality fruit. Light interception and distribution are considered optimal if all canopy parts are receiving more than 30% of incident light, meaning that shading is not excessive in the lower and central part of the canopy to reduce efficiency (**Anthony and Minas, 2021**). In this respect, the breeding programs try to select highly productive cultivars with well ramified habitus and rootstocks able to grow well in vigor also in replant conditions and able to support the growth of peach trees in a compact form (canopy and root system). In every case, the rootstocks are not fully dwarfing because most peach cultivars need yearly renewal of strong brindle and mixed-shoot to sustain a continuous production along with fruit quality.

These goals can be reached with a wide variety of training systems due to the fact that peach tree is characterized of high plasticity. Peach training systems varies from more traditional 3D canopy architectures, with multiple leaders per tree that are adapted to low-density plantings, to modern planar or flatted systems (mostly 2D designs) with single or multiple leaders per tree adapted to high-density. Modern 3D training systems that are now adapted to medium density orchards are the “delayed open vase” in Northern Italy and the ‘Catalan bush vase’ (Spanish goblet) in Spain which is wide spreading in all the Mediterranean climatic conditions (**Mazzoni et al., 2022**).

The “delayed open vase” is a technical variant of the traditional open vase with empty center, which is widely managed with winter pruning from the ground. It is trained in a free globe shaped canopy to induce early bearing but reducing the central leader vigor with summer pruning. Finally, to open the center at the 4 year (with very high vigor it can be anticipated at the 3rd year) the central axis is drastically pruned (**Figure 2**). Therefore, the final vase form with stable production is delayed and can be reached at the 4th -5th year with head back of the primary branches.

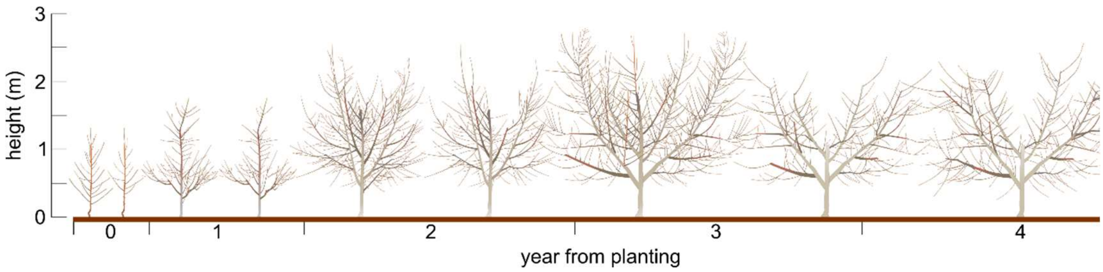

Figure 2. Pruning sequence during training of the "delayed open vase" from planting to the end of 4th year (trees before and after winter pruning in the first three years, and after pruning in the 4th year)

The "Catalan bush vase" is planned to be mechanically pruned and managed from the ground with repeated summer pruning (**Figure 3 and Figure S1**) and completed with a limited winter pruning according to the yield and quality control. It may have a significant production at the 3rd year and full at 4th year.

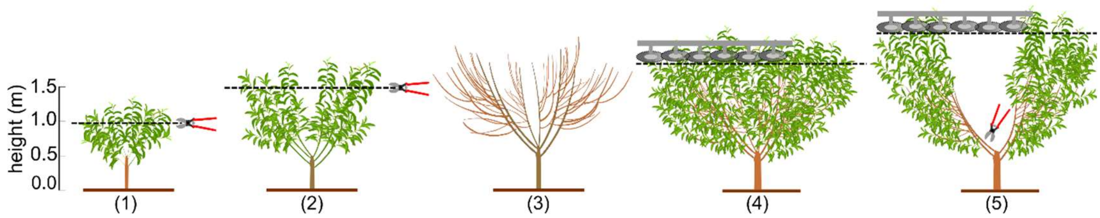

Figure 3. Catalan vase during the first (1, 2 and 3) and second growing seasons (4 and 5). (1) First manual topping when the shoots exceed 100 cm from the soil. (2) Second topping (manual or mechanical) when the shoots exceed 150 cm from the soil. (3) The plant in the winter at the end of the first year. (4) First mechanical topping when the shoots exceed 200 cm from the soil. (5) Second mechanical topping when the shoots exceed 250 cm from the soil and manual thinning of the main branches to open the center in very late summer, in case of high-yielding varieties (**Neri and Massetani, 2011**).

The branches with a curvilinear behavior are more efficient in producing mixed shoots, therefore the amount of pruning is reduced per unit of fruit production (**Figures S2, S3**). We can assume that modern peach orchard training systems are moving from a regular geometrical approach to a more functional approach, which favors the natural growth habit of the most common peach cultivars. The geometric shapes require intensive labor and structure, and thus are less used, even if they are very efficient in collecting light energy and in improving light distribution inside the canopy, such as the Y system (e.g., Tatura) and the V system.

The most common and traditional flattened hedgerow systems (so-called 2D) in Italian conditions were the palmette with several variants in the North. They require support structures (stakes, wires, etc.), training of the branches by bending and intensive and time-consuming winter pruning for training. Therefore, the growers are choosing to train peach trees with simpler and less labor requiring systems.

Among the new hedgerow or flatted systems for peach, the central leader has substituted the palmette, with a planting density up to 1000-1667 trees per hectare (4-5 m x 1.5-2 m, **Figures 4 and S4**). Higher planting density requires more summer pruning to enable light penetration to the basal portion of the plants. This form requires support (e.g., post and wires) and is composed of one permanent central axis and only 3-5 branches (less than 1 m long, according to the intra row distance between trees) inserted at 60-90 cm and oriented in all directions.

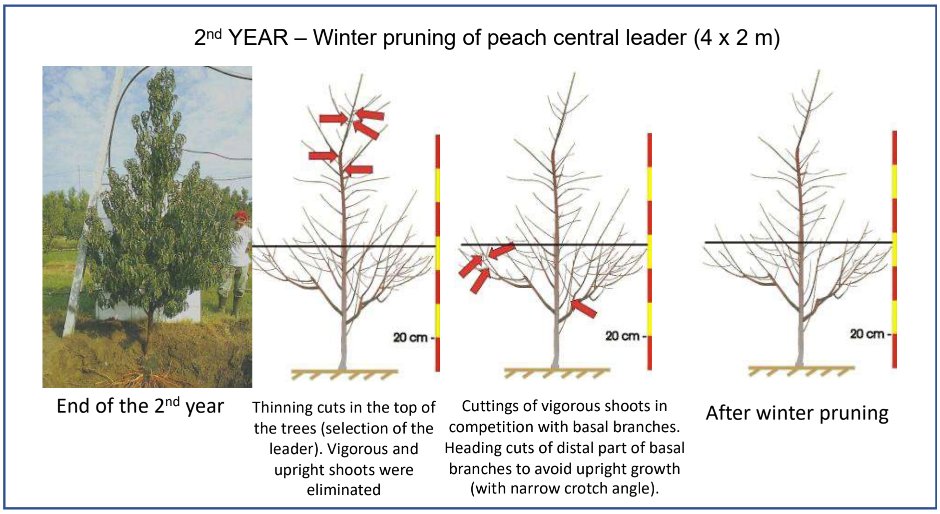

Figure 4. Description of the pruning for central leader during winter, at the end of the second growing season. The picture on the left shows a plant grown as central leader at the end of the 2nd year summer season in medium density plantations.

The objective of this system, also called spindle or fuse, is to keep the one-year-old wood emerging from the central leader and/or from short pruned spurs. If the planting density is higher, up to 2500-3300 trees per hectare (3.5-4 m x 1 m), the central leader is well feathered and the branches is spur pruned in a columnar shape and can be assimilate to a fruiting wall (**Figure 5**).

Figure 5. Central leader in high density planting (4x1m), at the end of the fourth growing season and before winter pruning (Cuneo, Italy).

For training high density peach orchards, well feathered scions from the nursery must be used to obtain fruit production in the second year. Above the basal scaffold, the axis is almost empty for 35-45 cm and above that bears short renewable fruiting branches oriented in all the directions with wide angles. The decreasing length of branches from the scaffold to the top of the plant give the plants the typical spindle shape. Even if summer pruning is essential for this system the demand for pruning is low. After two years of almost free growth, precise pruning is applied to form a hedgerow during the winter while minimum mechanical pruning can be applied in the following summer. Training can include summer pruning to trim overcrowded branches in the middle of the tree and to avoid the proliferation of vegetative shoots that shade the tree's interior canopy and to retain only good fruiting shoots (**Neri et al., 2015**; **Figure 6**). In the central leader when tree homeostasis is achieved, major part of net photosynthesis during each growing cycle is used for the proper bud formation, production and fruit quality of the subsequent cycle (**Hoying et al., 2005**), root formation and functioning. In addition to presenting higher productivity per hectare, the central leader system maintains the quality of the fruit, whether in size or sugar content (**Uberti et al., 2020**) investing a little into new branches and trunk, but this reduces the life span of the tree.

Figure 6. Summer mechanical pruning to improve shoot quality: top left – response to early summer pruning with sylleptic growth; top right – mechanical pruner (Rinieri, FC, Italy); bottom right – modern central axis training system; bottom left - low part of the canopy with high quality fruits.

High-density peach orchards demonstrated significant horticultural and economic benefit compared with the traditional systems. Increasing tree density may overcome the loss of crop-bearing shoots as well as reduce pruning time (**Glenn et al., 2011**). An orchard trained with a narrow canopy has several advantages in management (all manual operations are facilitated and can be done from ground, management of the sub-row is easier), agronomic (more efficient light penetration in the canopy) and environmental aspects (lower quantities of spraying products, easier to use multifunctional nets) (**Dorigoni, 2016**).

4. Limitations towards intensification

The tendency to increase planting densities has been driven primarily by the need for early production to pay back the initial investment cost and improve profitability. In modern high-density peach orchards, production starts at the second growing season and reach a maximum at the 4^{th} or 5^{th} year. With higher tree planting densities, cumulative fruit production over the first 10 years of an orchard's life has drastically improved. Another reason for the intensification in orchard production systems has been the need to reduce tree size to facilitate tree management. In addition, fruit color is often poor in the center of the canopy of large trees. As the market standards for fruit quality have increased, it has been difficult for fruit growers to achieve satisfactory pest control and fruit quality with large trees. The switch to smaller trees and higher tree planting densities has allowed significant improvements on fruit quality (**Robinson, 2007**).

In species that bear fruits on short branches (apple, pear and cherry) it is possible to greatly intensify planting density up to 3000 trees/ha and optimize space occupation. With species that are fruiting in mixed shoots and/or in brindles (30-50 cm long) like peach, planting densities have a limit that is the space between trees that allows the easy renewal of the mixed shoots. In this case it is possible to augment density up to 2000-2500 trees/ha with vertical axes distanced 1 m along the row, but the central leader is easier to be trained with 800-1,200 trees per hectare with a distance of 2 m along the row (**Neri, 2015**).

In both cases, the rootstock cannot be neither dwarfing because it excessively reduces the renewal nor too vigorous as it creates excessive competition. Several medium vigorous peach rootstocks have been developed by breeding programs in Italy, Spain, France and the USA. However, they have not been adopted widely in Italy due to the risk of reducing fruit size and too limited tree vigor that could excessively reduce mixed shoot growth. Despite the lack of the ideal medium vigor rootstock, significant increases in tree planting density have occurred in stone fruits, as improved canopy management strategies were developed (**Robinson, 2007**). Moreover, the propagation cycle of grafted peach trees helped in this direction producing small grafted scions in short nursery cycle, reduced to less than 6 months using the mini chip-budding (**Musacchi and Neri, 2019**). With this technique, *in vitro* propagated rootstocks in pot are chip budded and 3 months later the bud is swelling. The plantlets with such fast-growing shoots are then transplanted directly in the orchard to originate the central axis during the first growing season (**Figure 7**). This solution requires an efficient irrigation system, but the roots are reactive and able to grow in very diverse conditions, while the main growing shoot can be easily guided. Attention should be taken to control the weed competition, protecting the young plant with a shelter.

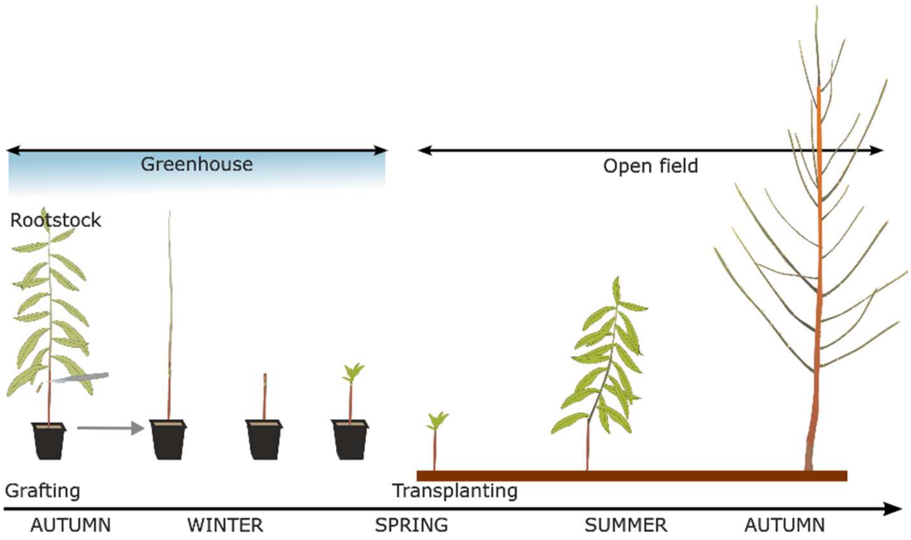

Figure 7 Short nursery cycle for the production of scions by means of mini chip-budding on micropropagated rootstocks

5. Training system and economical sustainability of the orchard

Different training systems show a very different carbon balance during the growing season, related to light interception (**Monteith and Moss, 1977**) that is dependent on several features of the orchard e.g. plant density, canopy size, thickness, leaves density, resulting a higher carbon accumulation of dry organic matter per hectare in high density systems (**Figure 8**). Moreover, in structures as the central leader, with a limited presence of secondary wood, only a small amount of plant energy is stocked in permanent structures. It is important hence to adapt cultural practices with the aim of addressing nutrients towards fruits, reproductive buds and roots, to increase yield efficiency and economical sustainability of the orchard.

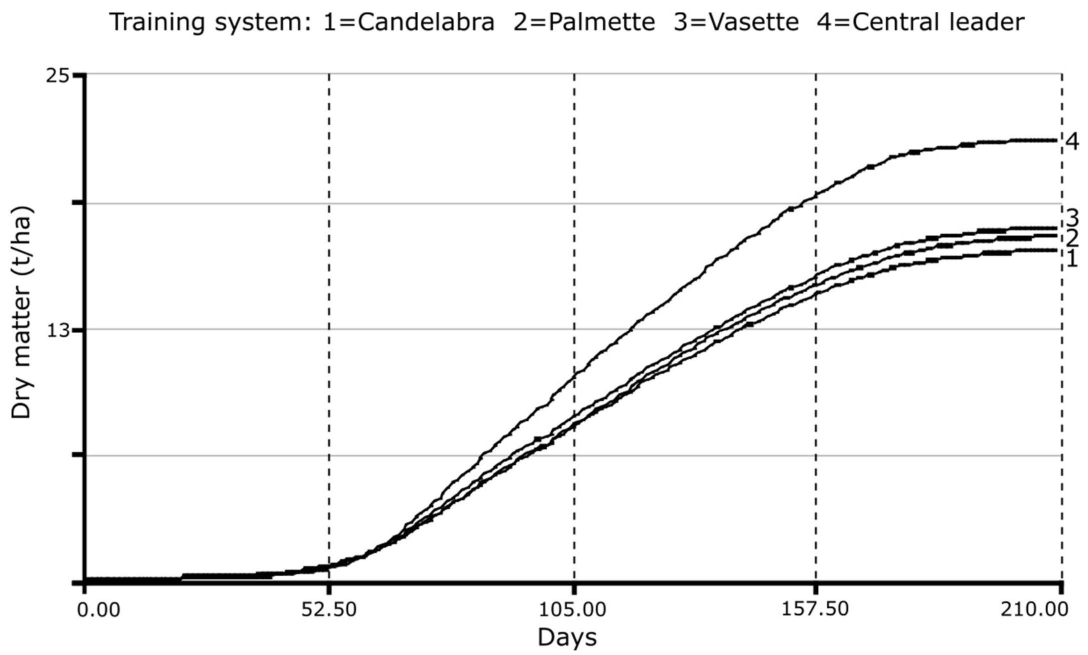

Figure 8 Cumulated dry matter produced during the growing season (0 means bud break) in the peach orchard according to the training system (**Silvestroni et al. 2004**)

The final aim of the orchard management is to obtain yield and fruit quality high and constant in time, and to do so, the energy that is stocked in the orchard must be used for the benefit of economically valuable plant organs, without dispersions. This high efficiency can be reached only with a system approach which includes regulated deficit irrigation, fertigation and eventually nutrient foliar application, precise minimum winter pruning, mechanical summer pruning and accurate fruit thinning (likely anticipated by mechanical flower thinning). In this way the plants will bear a higher number of fruits per canopy unit. The fruits can be more exposed to light and must be protected with shadowing nets from the excessive light insolation during the summer periods when excessively high temperatures occur (**Figure 9**). Netting was developed initially for anti-hail protection and later has been proven beneficial also for other purposes. The use of photo-selective netting systems allows a reduction up to 10-20% of excess light, maintaining high photosynthetic level thanks to the selective light absorbance. The use of nets is becoming multifunctional compared to the original use against hail, they help to reduce sunburn and cracking on the fruits while favoring brilliant coloring and high sugar accumulation through supporting a high photosynthetic capacity. The new net models are also able to block insects or protect against rain (**Neri et al., 2021**).

Figure 9 Photo-selective nets on peach orchard, trained as Y-shape.

6. Environmental sustainability

A reduction in pesticide is nowadays an obligation for agriculture. Training systems that allow a more efficient foliar product distribution are preferable. Especially in cases where mechanical innovations are available as tower sprayers that direct air fluxes horizontally towards the canopy wall and need a training system in flattened systems so to efficiently spray all the canopy at once. Training systems can be designed to be adapted to spraying machines, like the recycling tunnel sprayers. This type of machines require training systems with compatible specific dimensions and currently are mainly being used in vineyards, since current fruit orchard architecture are not amenable (3D training systems, narrow spaces between rows, canopy height).

Sustainability of an agro-ecosystem may increase if the system is efficient in terms of energy use (**Mao et al., 2015**). Primary energy in the orchard is light that leads to CO_2 assimilation through photosynthesis. These processes are common to all plant species in the orchard, including the grass cover, if present, that can increase the rate of intercepted light and contribute to carbon balance of the system. A soil with a grass cover has a reduced mineralization of organic matter in comparison with tilled soil and, if the cover is adequately diversified, it can promote a high biodiversity level (**Mia et al., 2020**). In such conditions, microbiological activity is high in the upper soil layers where the root systems of the trees are developing. This biodiversity is of primary importance for sustainability of modern orchards that are commonly composed of cloned plants. The lack of biodiversification and low organic matter content in an orchard can cause soil sickness and thus limitations during replantation (**Polverigiani et al., 2014**). Elevated organic matter content and increased soil structure are effective in maintaining the highest roots proliferation rate. All agronomical interventions aiming to create the most suitable environment for root activity and proliferation have to be studied as a tool in preventing the replant symptomatology. Conservation and enhancement of soil physical, chemical and biological fertility can minimize the negative effects of replant disorders on root proliferation and functionality (**Polverigiani et al., 2014**).

The organic matter of the grass cover residues is triggering a humification cycle in the soil that bring to an improvement of soil fertility during orchard lifespan. Ground cover with living vegetation can deliver several agroecosystem services by promoting functional agrobiodiversity in the orchard (**Canali et al., 2015**). Hence, adopting a sustainable orchard management strategy is vital for enhancing weed biodiversity, which can provide ecological protection (**Granatstein et al., 2010**) by offering feed and shelter to beneficial organisms, and improving soil fertility by hosting mycorrhizae, and thereby promoting nutrient availability and resilience in the soil (**Gangatharan and Neri, 2012; Mia et al., 2020**).

Inter-row ground is nowadays frequently managed with a temporary or perennial grass cover, but the tree-row ground is often kept free from vegetable cover (with chemical or mechanical means). Since it is vital to reduce the use of chemicals and reduce the ecological impact of agriculture, while maintaining a production of high quality and quantity (**Palmer, 2011**), research in weed management is therefore focusing in optimizing the inter-row management with a plant cover. Tree-row management involves the management of orchard weeds as they can compete aggressively with fruit trees for available nutrients and water, essential for plant growth. Therefore, proper weed management is vital in the fruit orchard to minimize weeds competition against fruit trees, assuring fruit yield (**Cavender et al., 2014; Steenwerth and Guerra, 2012**) and supporting weed biodiversity in the orchard (**Mia et al., 2020**). Live-mulch is an option for the weed control in fact, sowing or planting a selected species (or mix of species), able to efficiently cover the soil without competing with the fruit trees, is an effective way to control the growth of spontaneous undesired weeds (**Neri et al., 2021**). At the same time the presence of a plant cover of the soil is improving soil biological and nutritional qualities.

7. Conclusions and future perspectives

Many training systems have been developed in Italy to maximize tree performance in relation to rootstocks, cultivars, environment, and grower preferences. Different training systems can offer an array of options towards productivity, improved quality, and enhance labor efficiency or target market strategies. Until recently, the open center vase (mainly “delayed vase” and “Catalan vase”) has remained the system that is most extensively planted worldwide because it is easy to manage and offers many training alternatives. The Northern Italian peach industry has adopted the delayed vase and the central axis depending on the availability of motorized platforms. The first one requires reduced use of spring and summer pruning, the second one involves careful summer pruning to manage shoot growth. The delayed removal of the central axis from the vase creates strong open scaffolds without bending or spreading and provides early production. The early production of a central axis is obtained with limited winter pruning and high-density planting systems with vegetative rapid growth of small scions from the nursery. This is important to help offset costs, considering that the average useful commercial life of a peach cultivar in Europe is about 10 years.

The Catalan vase has been spreading in South climatic conditions with mild winter and it is able to organize tree pruning in a systematic and partially mechanized way, minimizing the management of the canopy and allowing the orchardist to easily train non-skilled workers with simple and programmed pruning and training operations. Nevertheless, new observations and extension research may lead to modification in the current tree training recommendations of the Catalan vase especially when adopted in different climatic growing conditions.

In all the training systems, spring and summer pruning increase the efficiency of labor (both for the ease and speed of the work and for the capability of the tree to rapidly compensate for errors and incorrect interventions) and improve fruit quality, and eventually can be mechanized, so as the fruit thinning. Late summer pruning can particularly improve management efficiency in modern peach orchards. It is necessary to remodel the agronomic peach orchard management; that includes reduction in the use of agrochemicals (in the soil and in foliar spraying), rationalization of irrigation and soil management with a sustainable weed control, amendment with organic matter from different sources to support the establishment of the complexity and heterogeneity of the agroecosystem with circular economy.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

References

Anthony, B.M., Minas, I.S., 2021. Optimizing peach tree canopy architecture for efficient light use, increased productivity and improved fruit quality. *Agronomy* 11*:*1961.

Canali, S., Diacono, M., Campanelli, G., Montemurro, F., 2015. Organic no-till with roller crimpers: agro-ecosystem services and applications in organic Mediterranean vegetable productions. *Sustainable Agriculture Research* 4:70.

Cavender, G., Liu, M., Hobbs, D., Frei, B., Strik, B., Zhao, Y., 2014. Effects of different organic weed management strategies on the physicochemical, sensory, and antioxidant properties of machine-harvested blackberry fruits. *Journal of Food Science* 79:S2107–S2116.

Cerdà, A., Daliakopoulos, I.N., Terol, E., Novara, A., Fatahi, Y., Moradi, E., Salvati, L., Pulido, M., 2021. Long-term monitoring of soil bulk density and erosion rates in two *Prunus persica* (L) plantations under flood irrigation and glyphosate herbicide treatment in La Ribera district, Spain. Journal of Environmental Management 282:111965

Cirilli, M., Bassi, D., Ciacciulli, A., 2016. Sugars in peach fruit: A breeding perspective. Horticulture Research 3. https://doi.org/10.1038/HORTRES.2015.67/6447882

Crisosto, C.H., 2002. How Do We Increase Peach Consumption? Acta Horticolturae 592, 601–605. https://doi.org/10.17660/ActaHortic.2002.592.82

Dorigoni, A., 2016. Innovative fruit tree architecture as a nexus to improve sustainability in orchards. Acta Hortic. 1137, 1–10.

European Commision (EC) 2020. Farm to Fork Strategy. For a Fair Healthy and Environmentally-Friendly Food System. Available online: https://ec.europa.eu/food/system/files/2020-05/f2f_actionplan_2020_strategy-info_en.pdf (accessed on 30 November 2021).

Fideghelli, C., della Strada, G., 2008. The recent variety evolution of the international peach industry, in: VI Convegno Nazionale sulla Peschicoltura Meridionale. SOI, Firenze.

Foschi, S., Neri, D., Massetani, F., 2012. Meccanizzare il pescheto per salvaguardare il reddito. Peach orchard mechanization to maintain profit. L'informatore Agrario 43–47.

Gangatharan, R., Neri, D., 2012. Can biodiversity improve soil fertility resilience in agroecosystems? New Medit. 11:11–18.

Glenn, D.M., Tworkoski, T., Scorza, R., Miller, S.S., 2011. Long-term effects of peach production systems for standard and pillar growth types on yield and economic parameters. *HortTechnology* 21:720–725.

Granatstein, D., Wiman, M., Kirby, E., Mullinix, K., 2010. Sustainability trade-offs in organic orchard floor management. *Acta Hortic.* 873, 115–122.

Hoying, S.A., Terence, L., Andersen, R.L., Shane, B., Andersen, R., Freer, J., Bittner, J., Robinson, T.L., 2005. Plant Higher Density Peach Orchards? *Fruit Quarterly- New York State Horticultural Society.* 13:1–34.

Iglesias, I., Echeverría, G., 2009. Differential effect of cultivar and harvest date on nectarine colour, quality and consumer acceptance. Scientia Horticulturae 120, 41–50. https://doi.org/10.1016/j.scienta.2008.09.011

Iglesias I., Echeverria G., 2022. Current situation, trends and challenges for efficient and sustainable peach production. Scientia Horticulturae 296, https://doi.org/10.1016/j.scienta.2022.110899.

Loreti, F., Massai, R., 2006. State of the art on peach rootstocks and orchard systems. *Acta Hortic.* 713, 253–268.

Mao, L.L., Zhang, L.Z., Zhang, S.P., Evers, J.B., van der Werf, W., Wang, J.J., Sun, H.Q., Su, Z.C., Spiertz, H., 2015. Resource use efficiency, ecological intensification and sustainability of intercropping systems. Journal of Integrative Agriculture 14, 1542–1550. https://doi.org/10.1016/S2095-3119(15)61039-5

Mazzoni, L., Medori, I., Balducci, F., Marcellini, M., Acciarri, P., Mezzetti, B., Capocasa, F. Branch numbers and crop load combination effects on production and fruit quality of flat peach cultivars (*Prunus persica* (L.) Batsch) trained as Catalonian vase. Plants 2022, 11, 308.

Mia, J., Monaci, E., Murri, G., Massetani, F., Facchi, J., Neri, D., 2020. Soil nitrogen and weed biodiversity: an assessment under two orchard floor management practices in a nitrogen vulnerable zone in Italy. *Horticulture* 6:96.

Mia, M.J., Massetani, F., Murri, G., Facchi, J., Monaci, E., Amadio, L., Neri, D., 2020. Integrated weed management in high density fruit orchards. Agronomy 10:1492

Minas, I.S., Tanou, G., Molassiotis, A., 2018. Environmental and orchard bases of peach fruit quality. Scientia Horticulturae 235, 307–322. https://doi.org/10.1016/J.SCIENTA.2018.01.028

Monteith, J.L., Moss, C.J., 1977. Climate and the efficiency of crop production in Britain. Philosophical Transactions of the Royal Society of London. Series B, Biological Sciences 281, 277–294.

Musacchi, S., Neri, D., 2019. Optimizing production of quality nursery plant for fruit tree cultivation, in: Lang, G. (Ed.), Achieving sustainable cultivation of temperate zone tree fruits and berries. Burleigh Dodds Science. Volume 1 chapter 6, pp. 340.

Musacchi, S., Iglesias, I., Neri, D., 2021. Training systems and sustainable orchard management for European pear (*Pyrus communis* L.) in the Mediterranean area: a review. Agronomy, 11:1765.

Neri, D., Bravetti, M., Murri, G., Nardini, G., Paroncini, M., 2021. Light spectrum modifications under photo-selective hail-nets. *Acta Hortic.* 1304: 191-200.

Neri, D., Massetani, F., 2011. Spring and summer pruning in apricot and peach orchards. *Advances Hortic. Sci.* 25: 170–178.

Neri, D., Massetani, F., Murri, G., 2015. Pruning and training systems: What is next? *Acta Hortic.* 1084:429–443.

Neri, D., Polverigiani, S., Zucchini, M., Giorgi, V., Marchionni, F., Mia, J., 2021. Strawberry living mulch in organic vineyard. *Agronomy* **2021**, 11:1643.

Neri, D., Silvestroni, S., Baldoni, N., et al., 2020. Sustainable crop production. In: The First Outstanding 50 Years of "Università Politecnica delle Marche" Research Achievements in Life Sciences. Editors: Longhi, S., Monteriù, A., Freddi, A., Aquilanti, L., Ceravolo, M.G., Carnevali, O., Giordano, M., Moroncini, G. (Eds.) Hardcover ISBN 978-3-030-33831-2, Springer CH: 583-600.

Palmer, J.W., 2011. Changing concepts of efficiency in orchard systems. *Acta Hortic.* 903:41–49

Polverigiani, S., Kelderer, M., Neri, D., 2014. Growth of 'M9' apple root in five central Europe replanted soils. *Plant Root* 8:55–63.

Robinson, T.L., 2007. Recent advances and future directions in orchard planting systems. *Acta Hortic.* 732, 367–381.

Silvestroni, O., Mattioli, S., Manni, E., Neri, D., Sabbatini, P., Palliotti, A., 2004. Seasonal dry matter production in field-grown Sangiovese and Montepulciano grapevines (*Vitis vinifera* L.). *Acta Hortic.* 640: 127-133.

Steenwerth, K., Guerra, B., 2012. Influence of floor management technique on grapevine growth, disease pressure, and juice and wine composition: A review. *American Journal of Enology and Viticulture* 63, 149-164.

Uberti, A., Santana, A.S., Lugaresi, A., Prado, J. do, Louis, B., Damis, R., Fischer, D.L. de O., Giacobbo, C.L., 2020. Initial productive development of peach trees under modern training systems. *Sci. Hortic.*272:10952

Willett, 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., et al. 2019. Food in the Anthropocene: the EAT–Lancet Commission on healthy diets from sustainable food systems. The Lancet. https://doi.org/10.1016/S0140-6736(18)31788-4