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

3

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26

27 **Abstract**

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

47

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

50

51

52 **1. Introduction**

53 The increase in consumption of horticultural commodities as high-quality fresh produce
54 food is now a major trend in the world (**Cerdà et al., 2021**). Agricultural production
55 for human consumption has implications for the environmental sustainability, therefore
56 modern agronomic techniques need to be developed to support the new planting
57 systems that must balance the increase of the demand and their negative environmental
58 impact. Nowadays, China is the major producer of peaches worldwide with *ca.* 15
59 million metric tons (Mt) per year, followed by Spain (1.8 Mt), Italy (1.3 Mt), Greece
60 (0.9 Mt) and the United States (0.8 Mt). Production volumes may vary from year to
61 year depending on the climatic conditions that may occasionally cause reduced
62 production due to frost damage, yet peach is still ranked as the most important
63 temperate fruit crop in terms of production volumes, besides apple.

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

72 Moreover, the globalisation and competition among flesh fruits from different
73 parts of the world renders it necessary to engage in continuous innovation and
74 refinement of orchard management techniques, in order to ensure the profit margins
75 that are indispensable for the success of peach fruit industry. Over the recent years, the
76 main challenge towards enhanced peach production was related to the selection of elite

77 cultivars, as a result of several efficient breeding programs worldwide. In one of the
78 most active breeding periods, from 1997 to 2006, almost 1000 new cultivars were
79 registered in the world (516 peaches, 419 nectarines, 50 rachis peaches), in 18 different
80 countries (**Fideghelli and Della Strada, 2008**). Nowadays the cultivar selection is a
81 key aspect for farmers who have to meet the needs of a rapidly evolving supply chain,
82 and in the meantime, they have to cultivate the new orchard to be productive with
83 marketable fruit, knowing that the fruits of a given cultivar can be appreciated on the
84 market for a limited period, that can be eventually even shorter than the return on
85 investment. It is worth considering that, to pursue an environmentally sustainable
86 production, the choice of the production location is fundamental, especially considering
87 climate changes, for a production that requires lower inputs. Another great challenge is
88 to choose the appropriate cultivation techniques, which have to be efficient, adapted to
89 the cultivar characteristics, economically viable and environmentally-friendly towards
90 more sustainable production systems.

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

102 with pruning and thinning can be additionally conducted mechanically (**Foschi et al.,**
103 **2012; Anthony and Minas, 2021**).

104

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

112

113 **2. Sustainable peach orchard intensification**

114 Intensive fruit production systems are characterized by increasing planting density,
115 early fruit bearing, small tree size, high crop loads, short orchard life-span, easy
116 mechanical management, efficiency in the use of inputs and frequent replanting
117 (**Musacchi et al 2021**). The achievement of constant high fruit quality depends on the
118 efficient management of canopy architecture from the nursery to the orchard.
119 Environmental sustainability requires soil management practices to increase and
120 maintain soil fertility such as minimum tillage, multispecies ground cover (**Mia et al.,**
121 **2020a,b**), supply of amendments and regulated deficit drip irrigation. Innovation in
122 crop-management regimes need strategies to control plant and root development, able
123 to optimize and, where possible, to simplify orchard management.

124 The achievement of these goals requires the active participation of farmers and
125 accurate extension services (**Neri et al. 2020**). Integrated fruit production strategies can
126 provide many different ecosystem services (ES), defined as the benefits of nature to
127 human well-being. The ES conceptual framework assumes a dynamic interaction

128 between people and ecosystems and requires a multiscale approach. Many biophysical
129 and ecological processes in agriculture do not occur at the farm level, but at the
130 landscape scale, while European Rural Development Programmes (RDP) typically
131 neither require nor encourage landscape coordination.

132 The integration of knowledge from different stakeholders (e.g., farmers,
133 scientists, technicians, extension specialists) is thus a precondition for successful
134 sustainable land management (Neri et al., 2020). For this reason, it is important a spatial
135 scale match between the RDP and the ecological processes controlling the target agri-
136 environmental issues. As an example, peach production should be carried out towards
137 increment of carbon soil content, reduction of soil erosion and augmentation of carbon
138 sequestration. Moreover, the use of plastic netting systems and drip irrigation with
139 plastic tubes should be organized with circular economy criteria which include plastic
140 recycling at the end of their life cycle in the field.

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

154 “From Farm to Fork” of the European Union concerning the sustainable fruit production
155 (EC, 2020; Musacchi et al. 2021).

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

161

162 3. Training systems for peach innovation

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

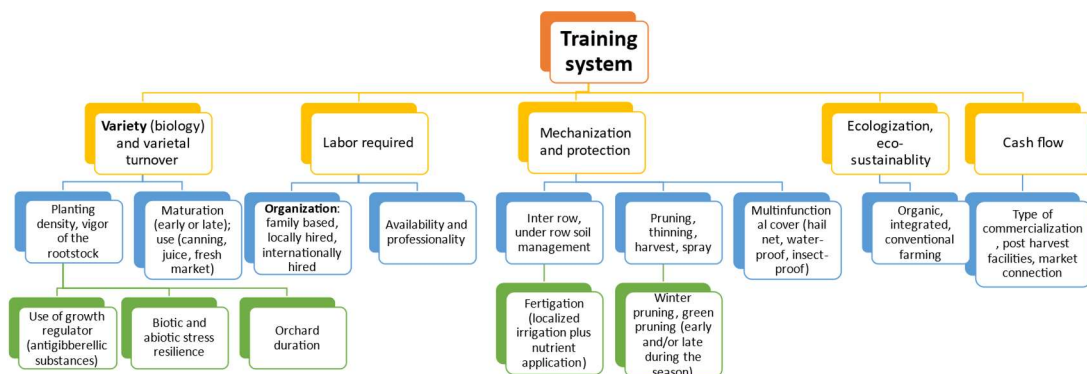


Figure 1. Factors affecting the choice of a training system –

171

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

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

197 (canopy and root system). In every case, the rootstocks are not fully dwarfing because
198 most peach cultivars need yearly renewal of strong brindle and mixed-shoot to sustain
199 a continuous production along with fruit quality.

200 These goals can be reached with a wide variety of training systems due to the
201 fact that peach tree is characterized of high plasticity. Peach training systems varies
202 from more traditional 3D canopy architectures, with multiple leaders per tree that are
203 adapted to low-density plantings, to modern planar or flatted systems (mostly 2D
204 designs) with single or multiple leaders per tree adapted to high-density. Modern 3D
205 training systems that are now adapted to medium density orchards are the “delayed
206 open vase” in Northern Italy and the ‘Catalan bush vase’ (Spanish goblet) in Spain
207 which is wide spreading in all the Mediterranean climatic conditions (**Mazzoni et al.,**
208 **2022**).

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

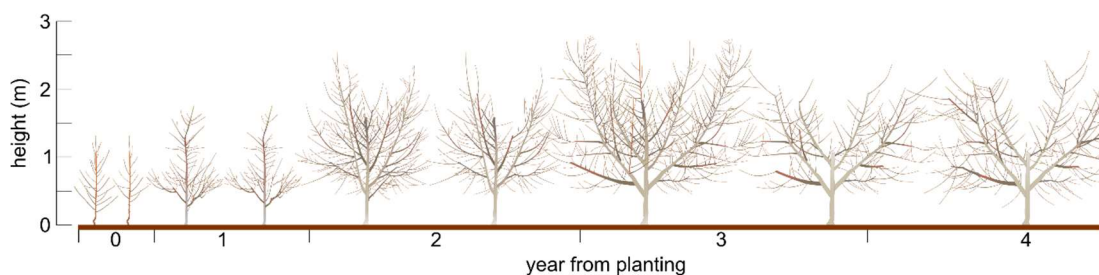


Figure 2. Pruning sequence during training of the “delayed open vase” from planting to the end of 4th year (trees before and after winter pruning in the first three years, and after pruning in the 4th year)

216

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

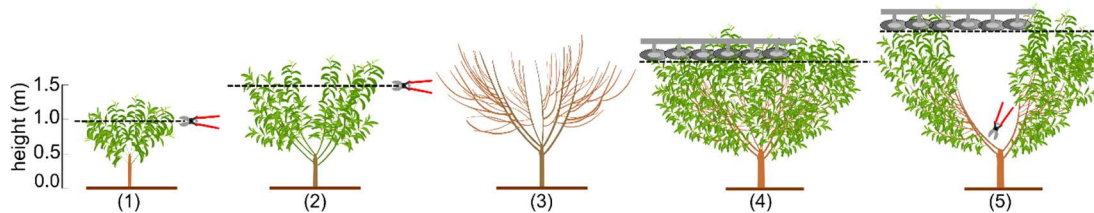


Figure 3. Catalan vase during the first (1, 2 and 3) and second growing seasons (4 and 5). (1) First manual topping when the shoots exceed 100 cm from the soil. (2) Second topping (manual or mechanical) when the shoots exceed 150 cm from the soil. (3) The plant in the winter at the end of the first year. (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**).

221

222 The branches with a curvilinear behavior are more efficient in producing mixed
223 shoots, therefore the amount of pruning is reduced per unit of fruit production (**Figures**
224 **S2, S3**). We can assume that modern peach orchard training systems are moving from
225 a regular geometrical approach to a more functional approach, which favors the natural
226 growth habit of the most common peach cultivars. The geometric shapes require

227 intensive labor and structure, and thus are less used, even if they are very efficient in
228 collecting light energy and in improving light distribution inside the canopy, such as
229 the Y system (e.g., Tatura) and the V system.

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

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

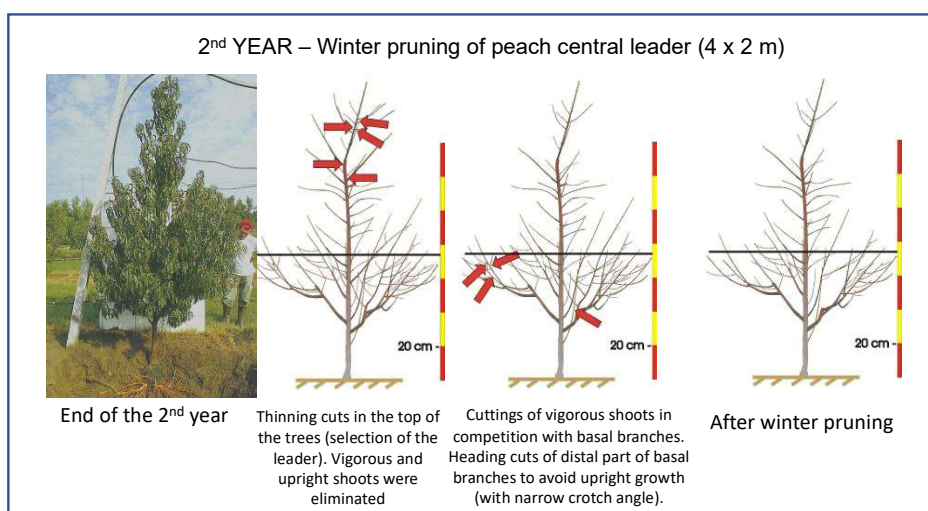


Figure 4. Description of the pruning for central leader during winter, at the end of the second growing season. The picture on the left shows a plant grown as central leader at the end of the 2nd year summer season in medium density plantations.

242

243 The objective of this system, also called spindle or fuse, is to keep the one-year-
244 old wood emerging from the central leader and/or from short pruned spurs. If the
245 planting density is higher, up to 2500-3300 trees per hectare (3.5-4 m x 1 m), the central
246 leader is well feathered and the branches is spur pruned in a columnar shape and can be
247 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).

248

249 For training high density peach orchards, well feathered scions from the nursery
250 must be used to obtain fruit production in the second year. Above the basal scaffold,
251 the axis is almost empty for 35-45 cm and above that bears short renewable fruiting
252 branches oriented in all the directions with wide angles. The decreasing length of
253 branches from the scaffold to the top of the plant give the plants the typical spindle
254 shape. Even if summer pruning is essential for this system the demand for pruning is
255 low. After two years of almost free growth, precise pruning is applied to form a
256 hedgerow during the winter while minimum mechanical pruning can be applied in the

257 following summer. Training can include summer pruning to trim overcrowded branches
258 in the middle of the tree and to avoid the proliferation of vegetative shoots that shade
259 the tree's interior canopy and to retain only good fruiting shoots (Neri et al., 2015;
260 **Figure 6**). In the central leader when tree homeostasis is achieved, major part of net
261 photosynthesis during each growing cycle is used for the proper bud formation,
262 production and fruit quality of the subsequent cycle (Hoying et al., 2005), root
263 formation and functioning. In addition to presenting higher productivity per hectare, the
264 central leader system maintains the quality of the fruit, whether in size or sugar content
265 (Uberti et al., 2020) investing a little into new branches and trunk, but this reduces the
266 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.

267

268 High-density peach orchards demonstrated significant horticultural and
269 economic benefit compared with the traditional systems. Increasing tree density may
270 overcome the loss of crop-bearing shoots as well as reduce pruning time (**Glenn et al.,**
271 **2011**). An orchard trained with a narrow canopy has several advantages in management
272 (all manual operations are facilitated and can be done from ground, management of the
273 sub-row is easier), agronomic (more efficient light penetration in the canopy) and
274 environmental aspects (lower quantities of spraying products, easier to use
275 multifunctional nets) (**Dorigoni, 2016**).

276

277 **4. Limitations towards intensification**

278 The tendency to increase planting densities has been driven primarily by the need for
279 early production to pay back the initial investment cost and improve profitability. In
280 modern high-density peach orchards, production starts at the second growing season
281 and reach a maximum at the 4th or 5th year. With higher tree planting densities,
282 cumulative fruit production over the first 10 years of an orchard's life has drastically
283 improved. Another reason for the intensification in orchard production systems has
284 been the need to reduce tree size to facilitate tree management. In addition, fruit color
285 is often poor in the center of the canopy of large trees. As the market standards for fruit
286 quality have increased, it has been difficult for fruit growers to achieve satisfactory pest
287 control and fruit quality with large trees. The switch to smaller trees and higher tree
288 planting densities has allowed significant improvements on fruit quality (**Robinson,**
289 **2007**).

290 In species that bear fruits on short branches (apple, pear and cherry) it is possible
291 to greatly intensify planting density up to 3000 trees/ha and optimize space occupation.
292 With species that are fruiting in mixed shoots and/or in brindles (30-50 cm long) like
293 peach, planting densities have a limit that is the space between trees that allows the easy

294 renewal of the mixed shoots. In this case it is possible to augment density up to 2000-
295 2500 trees/ha with vertical axes distanced 1 m along the row, but the central leader is
296 easier to be trained with 800-1,200 trees per hectare with a distance of 2 m along the
297 row (Neri, 2015).

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

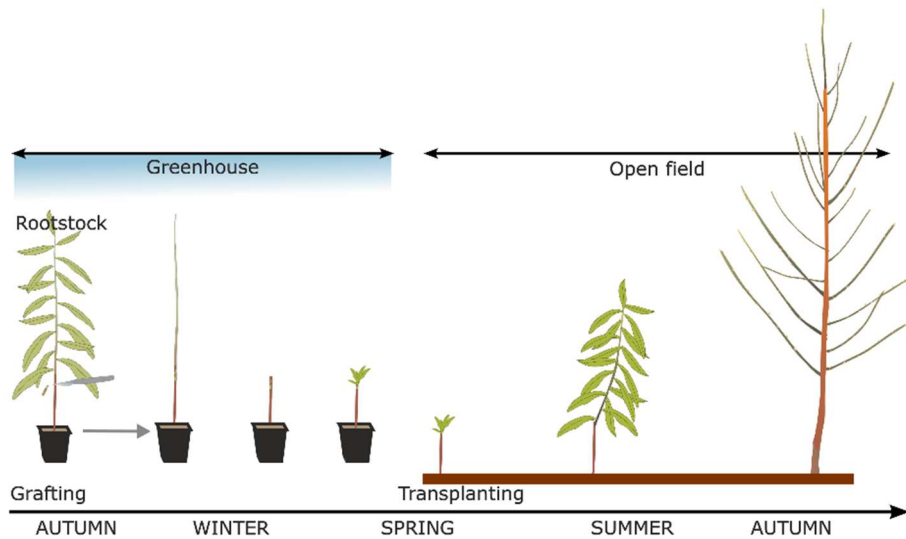


Figure 7 Short nursery cycle for the production of scions by means of mini chip-budding on micropropagated rootstocks

315

316 **5. Training system and economical sustainability of the orchard**

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

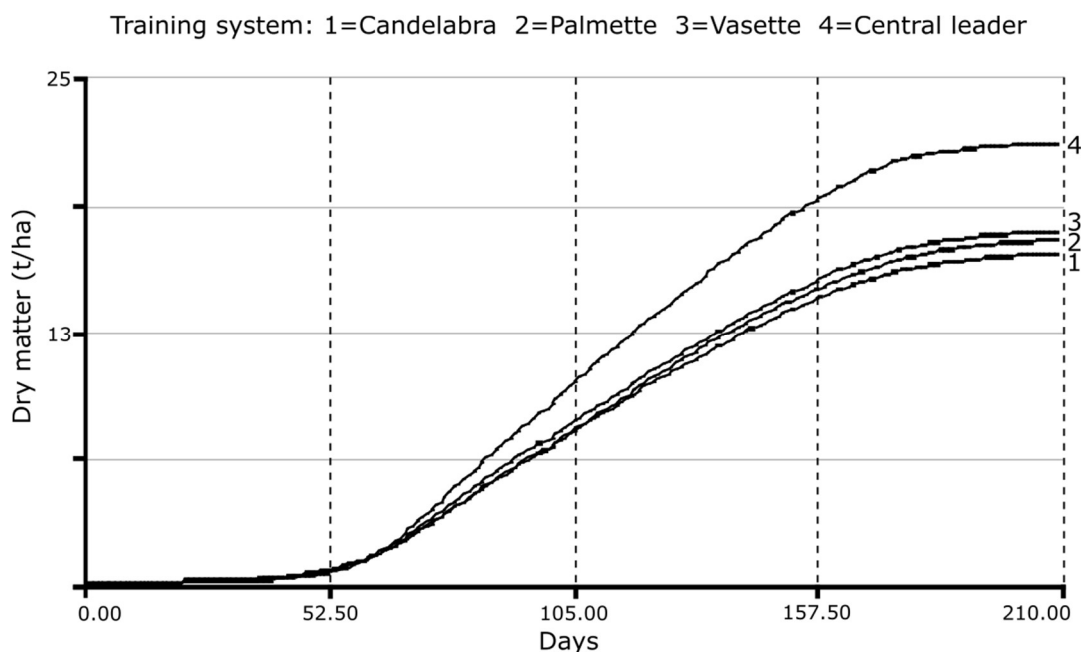


Figure 8 Cumulated dry matter produced during the growing season (0 means bud break) in the peach orchard according to the training system (**Silvestroni et al. 2004**)

326

327 The final aim of the orchard management is to obtain yield and fruit quality high
 328 and constant in time, and to do so, the energy that is stocked in the orchard must be
 329 used for the benefit of economically valuable plant organs, without dispersions. This
 330 high efficiency can be reached only with a system approach which includes regulated
 331 deficit irrigation, fertigation and eventually nutrient foliar application, precise
 332 minimum winter pruning, mechanical summer pruning and accurate fruit thinning
 333 (likely anticipated by mechanical flower thinning). In this way the plants will bear a
 334 higher number of fruits per canopy unit. The fruits can be more exposed to light and
 335 must be protected with shadowing nets from the excessive light insolation during the
 336 summer periods when excessively high temperatures occur (**Figure 9**). Netting was
 337 developed initially for anti-hail protection and later has been proven beneficial also for
 338 other purposes. The use of photo-selective netting systems allows a reduction up to 10-
 339 20% of excess light, maintaining high photosynthetic level thanks to the selective light

340 absorbance. The use of nets is becoming multifunctional compared to the original use
341 against hail, they help to reduce sunburn and cracking on the fruits while favoring
342 brilliant coloring and high sugar accumulation through supporting a high
343 photosynthetic capacity. The new net models are also able to block insects or protect
344 against rain (Neri et al., 2021).



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

345

346 **6. Environmental sustainability**

347 A reduction in pesticide is nowadays an obligation for agriculture. Training systems
348 that allow a more efficient foliar product distribution are preferable. Especially in cases
349 where mechanical innovations are available as tower sprayers that direct air fluxes
350 horizontally towards the canopy wall and need a training system in flattened systems
351 so to efficiently spray all the canopy at once. Training systems can be designed to be
352 adapted to spraying machines, like the recycling tunnel sprayers. This type of machines
353 require training systems with compatible specific dimensions and currently are mainly

354 being used in vineyards, since current fruit orchard architecture are not amenable (3D
355 training systems, narrow spaces between rows, canopy height).

356 Sustainability of an agro-ecosystem may increase if the system is efficient in
357 terms of energy use (**Mao et al., 2015**). Primary energy in the orchard is light that leads
358 to CO₂ assimilation through photosynthesis. These processes are common to all plant
359 species in the orchard, including the grass cover, if present, that can increase the rate of
360 intercepted light and contribute to carbon balance of the system. A soil with a grass
361 cover has a reduced mineralization of organic matter in comparison with tilled soil and,
362 if the cover is adequately diversified, it can promote a high biodiversity level (**Mia et**
363 **al., 2020**). In such conditions, microbiological activity is high in the upper soil layers
364 where the root systems of the trees are developing. This biodiversity is of primary
365 importance for sustainability of modern orchards that are commonly composed of
366 cloned plants. The lack of biodiversification and low organic matter content in an
367 orchard can cause soil sickness and thus limitations during replantation (**Polverigiani**
368 **et al., 2014**). Elevated organic matter content and increased soil structure are effective
369 in maintaining the highest roots proliferation rate. All agronomical interventions aiming
370 to create the most suitable environment for root activity and proliferation have to be
371 studied as a tool in preventing the replant symptomatology. Conservation and
372 enhancement of soil physical, chemical and biological fertility can minimize the
373 negative effects of replant disorders on root proliferation and functionality
374 (**Polverigiani et al., 2014**).

375 The organic matter of the grass cover residues is triggering a humification cycle
376 in the soil that bring to an improvement of soil fertility during orchard lifespan. Ground
377 cover with living vegetation can deliver several agroecosystem services by promoting
378 functional agrobiodiversity in the orchard (**Canali et al., 2015**). Hence, adopting a
379 sustainable orchard management strategy is vital for enhancing weed biodiversity,

380 which can provide ecological protection (**Granatstein et al., 2010**) by offering feed
381 and shelter to beneficial organisms, and improving soil fertility by hosting mycorrhizae,
382 and thereby promoting nutrient availability and resilience in the soil (**Gangatharan
383 and Neri, 2012; Mia et al., 2020**).

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

400

401 **7. Conclusions and future perspectives**

402 Many training systems have been developed in Italy to maximize tree performance in
403 relation to rootstocks, cultivars, environment, and grower preferences. Different
404 training systems can offer an array of options towards productivity, improved quality,
405 and enhance labor efficiency or target market strategies. Until recently, the open center

406 vase (mainly “delayed vase” and “Catalan vase”) has remained the system that is most
407 extensively planted worldwide because it is easy to manage and offers many training
408 alternatives. The Northern Italian peach industry has adopted the delayed vase and the
409 central axis depending on the availability of motorized platforms. The first one requires
410 reduced use of spring and summer pruning, the second one involves careful summer
411 pruning to manage shoot growth. The delayed removal of the central axis from the vase
412 creates strong open scaffolds without bending or spreading and provides early
413 production. The early production of a central axis is obtained with limited winter
414 pruning and high-density planting systems with vegetative rapid growth of small scions
415 from the nursery. This is important to help offset costs, considering that the average
416 useful commercial life of a peach cultivar in Europe is about 10 years.

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

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

432 different sources to support the establishment of the complexity and heterogeneity of
433 the agroecosystem with circular economy.

434

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