AgroLife Scientific Journal - Volume 2, Number 1, 2013
ISSN 2285-5718; ISSN CD-ROM 2285-5726; ISSN ONLINE 2286-0126; ISSN-L 2285-5718

DEVELOPMENT IN FRUIT TREES PRODUCTION SYSTEMS

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Abstract

The development during the last decades in fruit tree orchard systems resulted in the dominance "pedestrian orchard concept" for fruit species produced for fresh market. Trees trained to different conic shaped canopies (central leader, slender spindle, vertical axis, SolAxe, super spindle) and planted in single row system can be harvested easily from ground. Besides pip fruits (apple and pear) training and pruning systems were developed for stone fruits (peach, plum, apricot and cherry), however the open centre canopies are still widespread applied for these species. Research focused to maximize light interception, optimizing spacing, fruiting wood formation and leaf distribution within the canopy contributed to refining the pedestrian orchard concept. For fruit species produced for processing industry, where the fruits are harvested mechanically, the limb and trunk shakers are applied on vase shaped trees or trained to modified central leader. As new trend the continuously moving harvesters occurred in North America and East-Europe, which requires different tree shape and training. The paper gives and overview on the above topics.

Key words: fruits, light interception, orchard systems, sustainability.

INTRODUCTION

Sustainability is a complex and continuously developing approach today in agriculture and also in horticulture. Principles of sustainable fruit production systems are based on optimal use of natural resources (light, water, soil fertility) where the input (labour, energy, fuel, other material) and output (yield) are well balanced and the resources remain renewable. In such a system the minimizing of environmental polluting input (fuel and agrochemicals) is essential (Sansavini 1997).

Fruit orchards can be considered as artificial ecosystems converting the energy of photosynthetic active radiation (PAR) into edible, marketable fruits for human consumption. The core of this system is the bio-factory of leaves driven by the absorbed PAR. Several data support that the light interception is the basic factor for the modern orchard systems, albeit further factors as LAI, the spacing the trees, training and pruning systems, the species specific fruiting wood development, rootstocks also influence the orchard efficiency. From this point of view this paper gives a short review on the recent development in the orchard systems in complex approach of light interception, yield efficiency, vigour control, rootstock selection, tree architecture and fruiting wood management.

MATERIALS AND METHODS

Tree architecture and training in orchard systems developed for hand picking as "pedestrian" orchard

In the sustainable fruit production the orchard system should allow an input of natural origin material if possible, maximize the yield in the early years and provide high yields after the trees are mature until the planned age of the orchard. The tree architecture, training and pruning should provide optimum light interception, optimum light penetration and air circulation into the canopy and allow an economic orchard management. Natural like tree architecture is preferable. Recent development in the tree architecture has produced some promising tree training and pruning systems as well for high density stone fruit orchards.

After several trials and attempts the single row system is applied widespread in orchards planted for handpicking. Attempts in planting double or triple row, or "bed" system in the last decades of last century did not get through mainly because of the shading inside the row centre and picking difficulties. Albeit the light interception and the crop increased in the different bed systems, due to the harvest difficulties, the high cost of planting material and the cost of special equipment their spreading was limited (Robinson 2003, 2005).

Nowadays the fruit trees in hand picked orchards are trained to conic-shaped canopy with one central leader or to V or Y shaped canopy. However the light interception characteristics of V or Y shaped canopies is more favorable (Robinson 2003, Cittadini et al. 2006), probably due to the higher planting and support system costs are less popular in Europe, but spreading in the USA and countries of southern hemisphere. Central leader and different spindle forms (central leader, slender spindle, vertical axis, SolAxe, super spindle) are usually applied for apple, pear, peach, apricot and plum and nowadays for sweet and sour cherry too (Fideghelli 1990, Timon 1996, Laurie and Claveri 2005, Hrotkó et al. 2010). As the third canopy shape should be mentioned the open centre canopy applied mainly for stone fruits (peach, apricot and sweet cherry) in southern part of Europe (Negueroles 2005).

Considering the sustainability in fruit production the concept of "pedestrian orchard" provides the advantage in the possibility of hand picking from the ground and from low picking stands. In the high density orchard picking is more cost efficient, and the danger of accidents are reduced. One of the points is the improved fruit quality from the small-sized trees. As the fruiting branches on the trees are young, and the leaf/fruit ratio is higher, the fruit size is excellent. The conical tree shape and the young, fine fruiting wood allow better light penetration into the canopy thus the higher exposure to sunlight results better fruit color and taste. Spraying a smaller tree canopy is more precise and economical, and reduces the emission of chemicals into environment. It is possible to use a bird-net or rain-cover above the small-sized trees.

Spacing of trees and light interception

Planting high density apple orchards in Hungary too, raised questions in optimal tree spacing and orchard density. To calculate the optimal spacing for a given orchard site, the best way is to consider rootstocks/cultivar vigor, quality of planting material, site conditions, planned training system, harvesting technology and machinery and light interception (Soltész 1997, Hoying and Robinson 2000, Robinson 2003).

Results of several researchers confirmed the close correlation between cropping and PAR-absorption (Palmer et al 1992, Lakso and Robinson 1997, Robinson 1997, Wünsche et al. 1996). Our investigation carried out in a seven-year-old 'Gala' and 'Jonica' apple orchard confirmed the above authors, showing close linear correlation in case of both cultivars (Németh-Csigai 2009, Csigai and Hrotkó 2005, 2007). Cumulative yield increases linearly with absorbed PAR, however a tight correlation exists only at Gala Must. There is difference in the slope of the correlation between the two cultivars.

Light interception (PAR absorption) is also very important to consider, before choosing the optimal spacing. Commonly accepted that higher plant density may lead to crowded canopy, and bare-wood formation on shaded branches. The consequence of this, cropping is concentrated to the upper part of the tree. Optimized PAR absorption is necessary not only for avoiding bare-wood formation, but to have balanced and enough number of buds and also appropriate fruit coloring. Optimal light penetration is very important in high density orchards to result high productivity and quality (Wagenmakers and Callesen 1995, Wünsche et al. 1995, Robinson 2003).

The amount of intercepted light (photosynthetically active radiation, PAR) by our results is slightly increasing when the tree distance is decreasing. Between the tree spacing and PAR absorption Hrotkó and Csigai (2007) and Németh-Csigai (2009) found on 'Gala Must' negative linear connection at 3.6 m row distance, while the same connection at 4.5 m row distance was negative quadratic polynomial. These results confirm the previous research results that more than 2700-3000 tree/ha plant density reduces the efficiency of light interception, and so PAR-absorption (Corelli and Sansavini 1989, Robinson and Lakso 1989, Wünsche and Lakso 2000). The increasing curve of orchard canopy volume and light interception flattens beyond a certain tree

density terminates (Hrotkó and Csigai 2007), thus leaf-density increases within the canopy, which decreases the light penetration into the canopy centre.
By our investigations (Németh-Csigai 2009) the ratio of intercepted PAR there are differences between the two cultivars. The vigorous Gala Must intercepted 39-56% of the PAR arriving to the orchard surface, while the cultivar Jonica showed only 26-40% PAR interception. At both cultivars there was a negative connection characterized by quadratic polynom between the in-row spacing and PAR absorption. Gala Must with 3.6 m row distance reaches the maximum point around 1m plant distance, where the PAR-absorption stops increasing (similarly to the results of Wünsche and Lakso 2000). Jonica with 4.5 m row distance reaches the maximum point somewhere below 1 m plant distance, where light absorption stops increasing.
As a conclusion our observations proved that the given rootstock-cultivar combinations showed such productivity and PAR-absorption efficiency decline with a number of 3000 tree/ha plant density, which will possibly result in unprofitable orchard in the following years, although it can not be establish in the early years.
Effect of spacing on bearing surface of the orchard and yielding characteristics of trees
In our investigation we applied as comparison the fruiting branch density. The fruiting branch number in 1 m^3 cnopy volume at Gala Must planted at 4.5 m, at Jonica planted at 3.6 m row distance shows a connection to tree spacing characterized by a quadratic polinomyal function; at last cultivar the differences between the tree spacings are significant. At Jonica cultivar planted to 3.6 m row distance there is an increasing tendency between 1.75-1.5 m distance with a maximum between 1.25 - 1.0 m tree distance, while at 0.75 m tree distance the fruiting branch number in 1 m^3 cnopy volume slightly decreased. Productivity indexes of rootstock-cultivar combinations (yield efficiency related to trunk cross-sectional area) in case of both cultivars showed maximum level around 2500-3000 tree/ha, and the correlation can be describe with a quadratic polynomial. Both cultivar showed decreasing yield efficiency (related to TCSA) beyond 2500 tree/ha plant density, similarly to Stampar et al. (2000).
Summarizing our results on apple we confirmed that the correlation between tree density and bearing surface within the range of 1270-3704 trees ha^{-1} is not linear. The curve describing the correlation nears to a maximum typical to the rootstock-scion composite tree and to site conditions. Parameters of orchard bearing surface near an optimum around 3000 trees ha^{-1} density. Within the investigated spacing range the number of fruiting branches increased in linear correlation to the tree density; consequently in the limited canopy volume the branch-, leaf-, and fruit population is more and more crowded. Albeit the larger tree density slightly increases the ratio of intercepted PAR, so the efficiency of PAR utilization decreases. The cumulative yield efficiency index on TCSA basis reaches a maximum around the tree density of 3000 trees ha^{-1}. Based on our results in the investigated site conditions around 3.6 x 1 m spacing could be recommended for intensive orchards with slender spindle planted on dwarfing rootstocks.
High density orchard systems for stone fruits
There are numerous experiments all over the world to produce dwarf cherry trees for intensive orchards. One of the most promising training systems is described by F. G. Zahn, which needs well branched nursery trees for planting (Zahn 1990, 1996). Establishment of spindle trees by Zahn's method is realizable, but in the later years on the basal part of the canopy the renewal of fruiting wood may fail to come off due to lack of permanent basal branches (scaffolds). It seemed to be practical to combine the Zahn-spindle with permanent basal branches, and it isn't else but the well known slender spindle.
In northern countries the central leader versions are preferred while in South-Europe the open center canopy (spanish bush) is planted more. The main problem of these trainig systems was the lack of growth reducing roootstocks. The development in this field resulted in more series of dwarfing rootstocks which led to spreading of slender spindle. However, the growth reducing rootstocks allow planting of slender spindle trees in a density up to 1500 - 2000 trees/ha (Vogel 1994, 1995, Zahn 1990, 1996), growers in dry regions like in Hungary

prefer medium vigorous or vigorous rootstocks and train the trees to central leader (modified Brunner-spindle). While the growth control is managed in spanish bush orchard (Negueroles 2005) with summer pruning and water restriction, for modified Brunner-spindle in Hungary only summer pruning is recommended.

The yield in this orchard system two or three times higher compared to traditional plantations, 70% of the crop can be harvested from the ground and the fruit size and quality meets the requirements of world market. Our research and development project produced results in two stages of intensity, each stage is based on previous results, and now the complex system is spreading in Hungary and raised interest in abroad (Hrotkó et al. 2008, 2010). The Hungarian research in this field can be traced back to the early 70-es of last century when Brunner (1972) reported his invention, the so called sectorial double pruning. His spindle represented the first step forward with 660 trees ha^{-1}, which is followed by our semi-intensive modified Brunner-spindle in a density of 600-800 trees ha^{-1}. We targeted to collect and combine all the knowledge into our system, which fits well into our site conditions and can be based on vigorous or moderate vigorous mahaleb rootstocks. Working on this system and collecting experiences of other researchers led us to the recently recommended high density (1250 - 2000 trees ha^{-1}) orchard system, called Hungarian Cherry Spindle, which unifies the advantages of *Prunus mahaleb* rootstocks, as well as the advantages of training and pruning practices, developed by Brunner (1972), Zahn (1996) and the application of bioregulator BA on cherries (Hrotkó et al 1999, Magyar and Hrotkó 2005).

Importance of leaf canopy on example of high density sweet cherry orchard

The fruit size became an important parameter on the fresh cherry market. Although the importance of leaf/fruit ratio in fruit size and firmness is well known (Roper and Loescher 1987, Floree et al 1996, Cittadini et al 2006), little attention has been paid to the effect of rootstocks on leaf characteristics, distribution or canopy LAI of sweet cherry orchards. Cittadini et al (2006) developed an orchard-model, based on the ideal leaf/fruit ratio, where 1 m² leaf surface is required for the production of 0.8 kg of high quality and large sized fruit. Further on, considering that the cherry fruit consist of 80-85% water, the leaf canopy and its transpiration plays important role "pumping up" appropriate water supply for the fruits.

In a modern orchard system it is important to maximize the amount of light interception and to optimize the light distribution within the canopy; these are two very important factors for productivity. The orchard leaf area index (LAI) is frequently applied in orchard evaluation. It has been shown that the productivity is correlated with LAI (Robinson and Lakso 1991).

Recently in high density sweet cherry orchards several new rootstocks in wide range of vigor has been planted; their effect on vigour, tree size and precocity is intensely investigated (Lang et al. 2004, Hrotkó 2008, Franken-Bembenek 2005). While the tree vigor, shoot growth and canopy density are strongly influenced by the rootstock, these rootstock effects are not separable from the effects of light environment within the canopy.

As a conclusion we can summarize our results that leaf population characteristics of sweet cherry trees on different rootstocks are strongly influenced by actual rootstock vigor. Total leaf area correlates to the actual tree vigor, which perform under a complex influence of rootstocks and site conditions. The leaf area index (LAI) and the different parameters of leaf density showed significant differences between cultivars and between trees on different rootstocks, however this rootstock effect is not completely separable from the actual tree vigor. This complex influence of rootstock vigor and site conditions is manifested in leaf size both on spurs and extension shoots. Leaf size is larger on vigorous trees and on vigorous extension shoots compared to spur leaves, albeit in both leaf type group considerable rootstock vigor effects are found. The rootstock vigor and site condition both strongly influence the light environment in the orchard and within the tree canopy; thus they influence the LAI and the leaf density within the canopy. These conditions cause differences in the spur leaf area. Our investigation showed large differences in proportion of spur leaf area compared to the total. Precocious cultivar

'Rita' and trees on precocious rootstocks of both cultivars showed higher spur leaf area ratio, albeit extremely high ratio on dwarfing rootstocks may lead to reduced shoot growth and in the first half of the season to low leaf/fruit ratio.

Open centre canopies for stone fruits

In the southern part of Europe, through Balkan peninsula, Turkey, Iran to China several stone fruit species is trained to the so called open-centre canopy, with certain special modifications. Peach, apricot and cherry trees are trained to this form. As one modification the compact vase is spreading nowadays in Hungary, while the "spanish bush" for cherries is based on the same tree architecture. When applied for cherry, the several summer pruning allows keeping the growth in the appropriate shape, combined with the lack of precipitation during the summer. For extremely dry and hot conditions vigorous rootstocks only are applicable to this system.

Orchard systems for mechanical harvest

The processing industry requires cheap raw material produced by fruit growers. Hand picking in sour cherry orchards trained to the traditional way to central leader or modified central leader is very expensive and inefficient. The small sized stone fruits (sour and sweet cherry, plums and apricots) are to be collected by hand from a huge space (50-130 m³ canopy volume) in a height of 2 to 5 m above soil level. Since the labour costs are increasing the picking costs are so high that hand picked sour cherry is less and less competitive for processing industry. On the other hand climbing on ladders or tree limbs is dangerous, picking people are exposed to serious injuries. As the labor costs are increasing all over the world, the mechanical harvest could provide the tool for reducing costs.

In the 60-70s of last century shakers were developed for mechanical harvest. In USA and many East-European countries during the 80-90-es the sour cherry was harvested by limb or trunk shakers. This generation of harvesters require special tree shape (vase or other open centre canopy), space for the machine (large row and plant distance) and robust tree capable to stand the shaking process. In these orchards the trees were planted on vigorous rootstocks which resulted in a late yield start and limited yield efficiency (10-15 t/ha max). Harvesting sour cherry by limb or trunk shakers involved a relative high loss on yield due to the harvesting process and diminished fruit quality due to fruit injury. On the other hand the nature of vase canopy shape developed for limb or trunk shakers involves the danger of larger loss on bearing surface when the tree looses one or two of its three limbs. This is extremely important for those cultivars sensitive to limb breakage. Spacing of trees in such mechanical harvested orchards are large (6-8 x 5-7 m) and the tree density is low (200-300 trees ha^{-1}). The main requirements of mechanical harvest should be considered. The relief of the orchard should be suitable for mechanical harvesting. To develop an appropriate field, orchard and tree design for mechanical harvesting. Training systems and spacing of the fruit orchard should be developed accordingly the method of mechanical harvesting and the size of the mechanical harvester machine. The open centre vase training system is the most preferred in those stone fruit (cherry, plum and peach) orchards where mechanical harvesting is applied. In generally the height of trunk is about 100-120 cm, and the optimal spacing is about 7 x 5 m. Application of regular pruning is needed to keep the canopy in shakable form and status. Fruits from too long limbs can not be removed because their wavering movement. One of the most important requirements and task is to reduce the fruit damage during the tree shaking, removal of the fruit from the canopy, and falling the fruit onto the catching surface. The plant and fruit health are one of the most important grower's task the point of the fruit and the product quality. Bark damages on the trunk should be treated and painted. Infected fruits should be removed during the grading process otherwise they become the transmitters of diseases and infect healthy fruits.

In East-European countries, farmers are headed to renewal of their machines, which are now 20-30 years old, many of them doesn't work at all. That is the reason why around 70 percent of sour cherry is picked by hand. Medium sized or large farms producing sour cherry are thinking of buying new machines. For this renewal of technology this industry should be provided by an advanced new harvester technology which is represented by the continuously working chain harvester (Perry et al. 2008).

Chain harvester system was developed in Poland too (Holownicki 2013). Besides the advantages in the low fruit and yield loss and better fruit quality using this technology provides advantages for the orchard and bearing surface too. The tree shape is a spindle with one central leader, there are no limbs in the tree, which means that the loss on bearing surface due to limb breakage is eliminated. The technology requires small trees so it is possible to use growth reducing or dwarfing rootstocks for sour cherries also. Using low vigour rootstocks will contribute to larger tree density and increase the yield efficiency per ha. Of course there is little information how the sour cherry performs on dwarfing rootstocks in high density conditions, that is why this project needs investigation in this field too.

Recommendations in rootstock usage

The tree size control is an important factor for growers in reduction of fuel, agrochemical input and labour. The recent development in the rootstock research produced for each important temperate zone fruit crop a wide range of rootstocks in different vigour. On the other hand, in certain conditions, especially on stone fruit, high density plantations perform well even on vigorous rootstocks. In the complex approach besides the basic element, which is the rootstock vigour, attention should be paid to such indirect effects as water supply, soil fertility, precocity, tree architecture, training and pruning, leaf area index (LAI), relative light intensity, sunshine hours and length of growing season. Considering the competition of ground-cover plants and some weed, reduced fertilizer programs and irrigation supply, rootstock vigour larger than dwarf also may have increased importance (Hrotkó 2007).

The rootstock selection for the sustainable fruit growing is an important opportunity to improve the orchard resistance to diseases and tolerance for abiotic stress conditions. Also the healthy and well developed planting material is essential for the orchard establishment and early turning to bearing.

Rootstock breeder should regularly update their targets considering the changes in growers' requirements. Orchards producing for fresh market: high density orchards, appropriate for hand picking. Low vigour rootstocks are predominant in many rootstock breeding projects of different fruit species, although the vigour range should not be narrowed. Semi dwarf and moderate vigorous rootstocks also may find space for application in sustainable systems, where the all year round grass cover and weed competition should be considered. On the other hand high density stone fruit orchards are sustainable even on moderate or vigorous but precocious rootstocks depending on soil fertility (Zahn 1996, Mika et al. 1998, Hrotkó 2005, 2007, Long 2005, Negueroles 2005).

Increasing fruit growing in new regions, increasing growing in southern hemisphere, Asian countries, temperate zone fruit species in subtropical conditions etc. requires a more differentiated approach from rootstock research. The climate changes increase the importance of rootstock adaptability to temperature extremities, cold tolerance, winter hardiness, drought tolerance, water-logging, efficient water utilization and adaptability to suboptimal soil conditions. Also the importance of pest and disease resistance or tolerance of rootstocks as an essential tool for integrated fruit production or sustainable systems is increasing.

CONCLUSIONS

The discussed development emphasized the importance of some research topics for the future that could contribute to the sustainability of fruit orchards:

- optimized light interception and light penetration into the leaf canopy,
- estimate the water requirements, optimized water use efficiency,
- nutrient uptake and nutrient use efficiency,
- integrated plant protection, reduced emission of chemicals,
- optimized technical efforts (labor, fuel, other industrial products).

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