Corvinus University of Budapest

FACTORS OF THE SPACING OPTIMIZATION IN INTENSIVE APPLE ORCHARD

Abstract of the doctoral thesis

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1. INTRODUCTION

Planting of high density apple orchards appeared in Hungary (10,000 or above tree/ha) an increasing tendency on international and west-European research. Apple growers are great disparity of opinion on the optimum density. Many grower plant with a number of 5000 tree/ha, while others with only 500 tree/ha (ROBINSON 2007b). It is a general opinion in fruit growing literature, that with an increased tree density, supposedly increase the useful cropping area of the orchard (CAIN 1970, GYÚRÓ et al. 1982), although there are no proved linear coherence between density and bearing surface and yield.

The main and the most critical part of the intensive cultivation method is an optimal row and tree spacing and canopy size. The small canopy comparing to traditional training systems, allows more efficient handwork and less costs, since pruning and harvesting can be done mostly from the ground. The small canopy results in efficient machine work and pest control. A high density orchard should start cropping early and give an annual production of high yields of high-quality fruit.

To calculate the optimal cropland for a given orchard, the best way is to consider rootstocks/ cultivars vigor, quality of planting material, site conditions, planed training system, harvesting technology and machinery (SOLTÉSZ 1997, HOYING AND ROBINSON 2000). PAR absorption is also very important to consider, before choosing the optimal cropland. Optimal light penetration is very important in high density orchards to result high productivity and quality (WAGENMAKERS AND CALLESEN 1995, WÜNSCHE et al. 1995).

Spacing recommendations for high density orchards in Hungary are usually based on Western-European fruit growing experiences, thus the necessity of inland researches are indispensable. In high density orchards the correlation between spacing, plant number and productivity can be different in each country, considering special light conditions, which can be measured with special equipment. Our research expectation is to find out more detailed results of the above mentioned coherence.

2. OBJECTIVES

1. The experimental design covered the followings:
2. To examine behavior of trees in different rootstock (M.9 Burgmer 984, M9 T.337, Jork 9) and different row and tree spacing.
3. To find answer for the coherence between single tree and orchard bearing surface and yielding in case of different spacing.
4. To examine effect of tree spacing on unit tree yield index and orchard cumulative yield.
5. To examine leaf area index (LAI) and photosynthetic active radiation (PAR) in two different orchards, where spacing and canopy size is different. We used two varieties Gala Must and Jonica.
6. To be able to give advice about optimal orchard spacing for Hungarian fruit growers.

3. MATERIALS AND METHODS

3.1. Experimental orchard

An experimental orchard was established in spring 2000 at the Corvinus University Budapest, Faculty of Horticultural Science, Department of Fruit Science.

Soil type in the orchard is light-sandy-loam. Attributes: pH = 7,8–8; K_A = 30–32; $CaCO_3$ = 11–15 %, mould content of soil 0,8 %. Szigetcsép is located on the edge of the Great Hungarian Plain, on the south part of Csepel Island, thus the climate of the orchard suits to this area’s main climate. Relatively high radiation, extreme changes in temperature and minimal rainfall. The climate of Szigetcsép is specially hot, with an average 10,4 ˚C yearly temperature, average temperature of bearing season is 18,3˚C. Hours of sunlight per year of which 71 % are during the bearing season. Average yearly rainfall is 545 mm, of which 309 mm falls during the bearing season. Although high degree uncertainty of precipitation can cause problem (TŐKEI 1997).

An experimental orchard was established Jonica and Gala Must on three dwarfing rootstock (M.9 T.337, M.9 Burgmer 984, Jork 9). Trees were planted on two row distance (3.6 m and 4.5 m) with four tree distance (0.75-1.75 m).Four trees are in the parcel and the tree distance variation is in five repeat.

Table 3.1. The analyzed spacing and planting density variation (Szigetcsép, 2002).

Row- and tree spacing (m)	*Spacing (m^2)*	*Planting density (piece/ha)*	*Canopy form*
4.5 x 1.75	7.9	1270	Vertical axis
4.5 x 1.50	6.8	1481	
4.5 x 1.25	5.6	1778	
4.5 x 1.00	4.5	2222	
3.6 x 1.50	5.4	1852	Slender spindle
3.6 x 1.25	4.5	2222	
3.6 x 1.00	3.6	2778	
3.6 x 0.75	2.7	3704	

The nowadays very common slender spindle system requires 3.6 m row distance, and 1.5 m basal diameter of the canopy, and the crown height was limited to 1.8 m (WERTHEIM 1978). We planted the trees to 4.5 m row distance in case of the Vertical axis system, where the canopy basal diameter was 2 m, and the crown height was limited to 2.8 m (LESPINASSE AND DELORT 1986).

For plantation we used one year old, 80 cm high whips, where the grafting height was at 20 cm. In the first two years weed control in the orchard was done mechanically, from 2003 the area between rows was turned, and in the rows chemical weed control was used. In the orchard wire-support was used. The tree trunk height was limited to 0.8 m.

3.2. Experimental methods

In the experimental orchard the combination of two varieties and three rootstocks were tested with different row spacing, all combinations were repeated five times. Our earlier statistic results showed no coherence between rootstock and plant-spacing. The effect of spacing had the same tendency in case of all rootstock, thus discussion of results became less complicated.

From the year of plantation we measured trunk circumference at 60 cm, canopy size (length, width, height). We calculated unit trunk cross sectional area (cm^2) and canopy size of trees (canopy projected area, canopy volume and canopy covered index).

<u>The following formulas were used to calculate different indexes:</u>

Trunk cross sectional area (cm^2) = (Trunk diameter/2)^2 x π

Canopy projected area (m^2) = [(Canopy width + Canopy length)/4)]^2 x π.

Canopy volume (m^3) = Canopy projected area x canopy height)/2 (SILBEREISEN AND SCHERR 1968)

Canopy covered index = Canopy projected area / spacing (CAIN, 1970)

Canopy covered land of orchard (m^2/ha) = [10000 m^2/row distance (m)]* Canopy width (m).

In 2005 we measured the basal diameter, length and number of thin, medium and thick productive shoots. From these results we calculated the number of thin, medium and thick shoots per 1 m^3 canopy volume. In these productive shoots we counted quantity of inflorescence and we measured fruit yield.

In 2002 and 2006 frost damage was more than 60-70 % in the orchard, which caused lower yielding in the already bearing orchard.

In 2001 and 2002 we counted number of fruit per tree (piece). From 2003 we measured fruit weight in each parcel, than we took out 50 sample piece from each parcel, and we measured average fruit weight.

We also classified fruits by size (<65mm; 65-75mm; 75mm<), and by coloration (<50 %; 50-75 %; 75 %<), and considering the two above mentioned characteristic we made three groups (class I.; II.; III.). We measured the fruit-equivalence with using the following formula (**I. class fruits (pieces) + II. class fruits (pieces) x 0.6 + III. class fruits (pieces) x 0.3)/100.**

Than fruit-equivalence multiplied by yield/tree gave total crop quantity considering quality too, we named this as **fruit-equivalence-yielding**. From these we calculated the **index of yield/trunk cross section area** by dividing the quantity of yield with trunk cross section area measured in the previous year.

Between 2002-2006 we counted the number of flowers/ tree (pieces), and this number divided by the trunk cross section area gave the **quantity of inflorescence (piece/tree).**

Between 2004-2006 we measured the photosynthetic active radiation (PAR) in the orchard with AccuPar LP 80 (Decagon). This equipment measures the sunlight radiation between 400 and 700 nm wavelengths. We measured PAR above the orchard, than at each tree we measured again six times, under the canopy at 80 cm high, in the middle, 25 cm to the left and to the right. Than we calculated the average below canopy PAR in percentage.

Because PAR changes constantly it is hard to compare results in case of different trees, specially with different spacing. As a solution we used the average arriving light (1400 PAR μmol $^{-m^2\text{-sec}}$) and with proportion we calculated PAR. Leaf are index (LAI) was measured by the same equipment indirectly from the photosynthetic active radiation (PAR).

We calculated light efficiency index: value equivalent index (kg)/ light interception (PAR μmol $^{-m^2\text{-sec}}$).

Table 3.2. Yearly data

Measured data	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**
Trunk circumference (cm)	x	x	x	x	x	x	-	-
Canopy height (cm)	x	x	x	x	x	x	-	-
Canopy width(cm)	x	x	x	x	x	x	-	-
Canopy length (cm)	x	x	x	x	x	x	-	-
Canopy tip height (cm)	-	-	-	-	x	x	-	-
Canopy tip length (cm)	-	-	-	-	x	x	-	-
Weight of pruning wood (kg/parcel)	-	-	x	x	-	x	x	-
Quantity of inflorescence (piece/tree)	-	-	x	x	x	x	-	-
Quantity of yield (kg/tree)	-	x	x	x	x	x	x	x
Fruit coloration	-	-	-	x	x	x	-	x
Fruit size	-	-	-	x	x	x	-	x
50 fruit's weight (kg)	-	-	-	x	x	x	-	x
Light measuring	-	-	-	-	x	x	x	-
Quantity of productive shoots in floors of canopy (piece)	-	-	-	-	-	x	-	-
Basal diameter of productive shoots (cm)	-	-	-	-	-	x	-	-
Lenght of productive shoots (cm)	-	-	-	-	-	x	-	-
Quantity of inflorescence in productive shoots (piece)	-	-	-	-	-	x	-	-

4. RESULTS AND DISCUSSION

4.1. Effect of spacing on tree growth

The tree spacing affected the trunk growth of both cultivars (Fig. 4.1.). The trunk thickness (TCSA), which is an important parameter of tree growth (HROTKÓ 2002a,b), proportionally reduced as related to the decreased in-row distance of trees. This effect of in-row spacing on trunk growth of Gala in both row distance, and that of Jonica at 3.6 m row distance is prevailing in a way, well known from growth physiology and production biology (GYURÓ 1980), showing a connection characterized by a quadratic polynomial. This confirms the opinion of HROTKÓ (2002a) against MIKA AND KRAWIEC (1999), and STAMPAR et al. (2000) who found a linear connection. The quadratic connection of trunk growth at trees on dwarfing rootstocks (M.9 Burgmer 984, M.9 T.337 and Jork 9) indicates that the maximum growth potential of rootstock-scion composite tree is the upper limit of trunk growth. Consequently the trees beyond a limit cannot utilize the larger space.

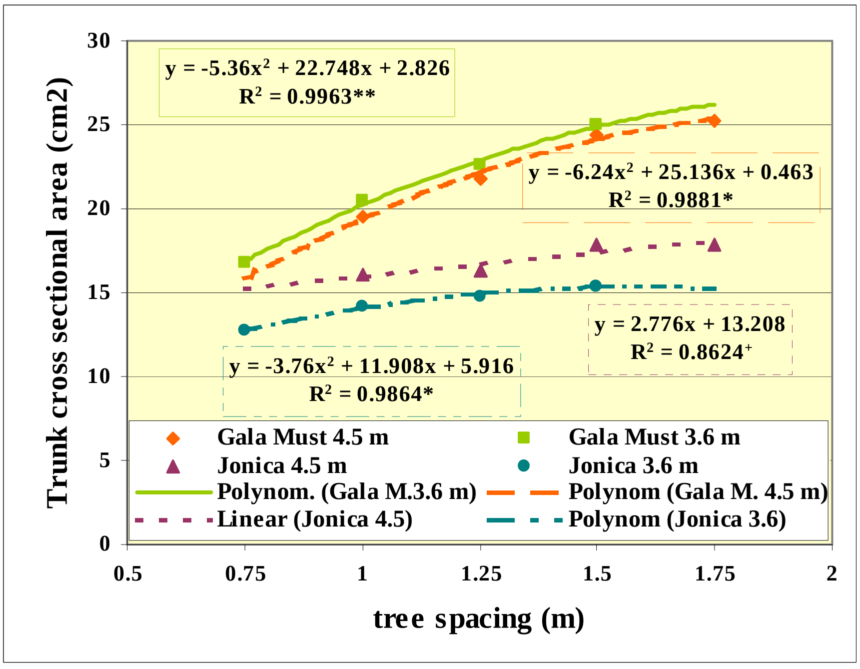

Fig. 4.1. Increase of trunk cross sectional area (cm^2) of Gala Must and Jonica trees planted at different row spacing as function of tree spacing within the row (2005).

Our results also imply that the row and tree spacing affect the growth of canopy volume of trees (Fig. 4.2.). On vigorous growing Gala Must– in case of both row distance – and on the less vigorous Jonica – in case of 3.6 m row distance- the canopy volume shows connection with tree distance. The connection can be expressed with a quadratic polynomial equation. In 4.5 m row distance the unit canopy volume growth of Jonica shows linear connection, which is not significant. These data also confirm the opinion of HROTKÓ (2002a) that the growth of canopy volume of trees determined by the growth potential of rootstock-scion combination is limited by the spacing.

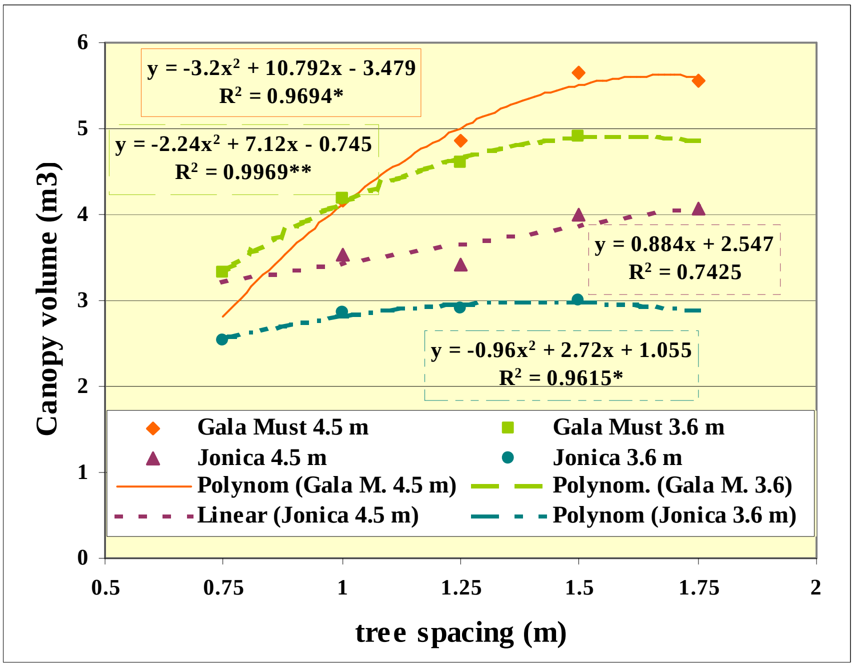

Fig. 4.2. Increase of canopy volume (m^3) of Gala Must and Jonica trees planted at different row spacing as function of tree spacing within the row (2005).

The canopy volume of Gala Must trees in 2005 reduced by 33.6 % at 4.5 row distance, while the canopy volume reduction at 3.6 m row distance was 47.9 within the 1.75 – 0.75 m in-row spacing range. The effect of decreased tree spacing on canopy volume of Jonica trees did not alter significantly, but the decreasing tendency is visible.

Our data definitely suggest that the canopy size of Gala at 4.5 m row distance doesn't increase at larger plant distance; consequently the rootstock/scion composite tree cannot utilize the larger space. This effect is based partly on pruning linked with tree architecture, which allows the spreading the canopy only in a limited space. The effect of row distance on canopy volume is more expressed at Jonica trees; the difference in canopy volume between trees planted in the same plant distance but at different row distance is significant.

Our results also imply that plant distance affect the number of productive shoots, although it can also be control by pruning (Fig. 4.3.). In case of both row distance and both cultivars we noticed significant differences, especially between the numbers of small productive shoots.

Increased plant distance shows linear connection with the number of productive shoots, thus the more trees we plant on 1 ha, the more productive shoot we will find. But it is also has the following disadvantage, too high density of branches, leaves and fruits in the crown.

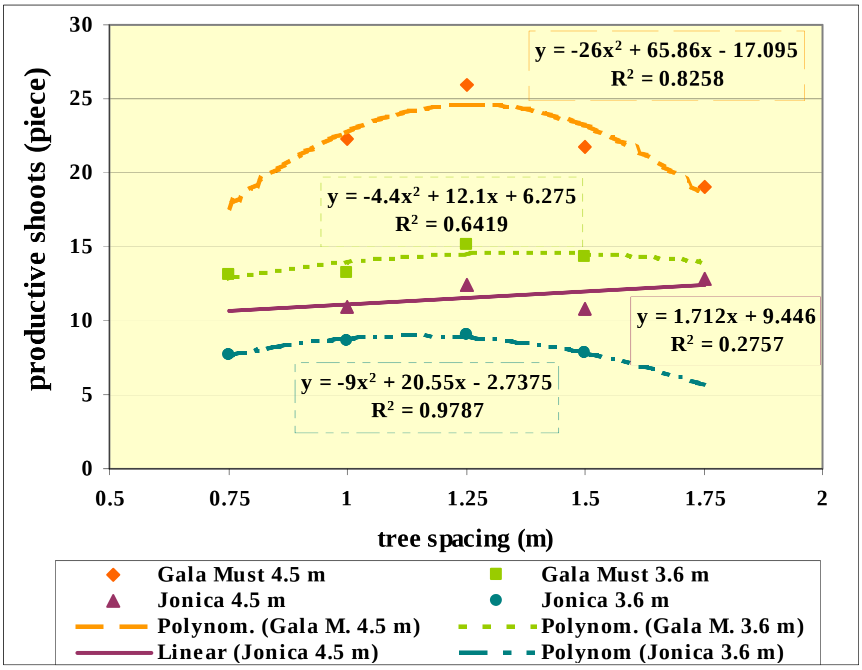

Fig. 4.3. Cumulative productive shoots in Gala Must and Jonica trees (piece /tree) planted at different row spacing as function of tree spacing within the row (2005).

In case of Gala Must the number of thin, medium, thick productive shoots was proportional in 3.6 m row distance, while in case of Jonica the number of thin productive shoots was decisive. In case of Gala Must and both row distance and in case of Jonica (3.6 m x 1.25 m row and tree distance) is observable in number of productive shoots. This connection wasn't significant in case of Gala Must in 3.6 m row distance (Fig. 4.3.).

4.2. Effect of row- and spacing distance and tree density on bearing surface of the orchard

The orchard bearing surface is measured and described differently in the literature. Authors from Northern-America prefer usage of cumulated trunk cross section area per hectare (WESTWOOD 1993). The term of orchard density (GYURÓ 1980) is replaced by the canopy covered area (HROTKÓ 2002a,b). In our work we added as comparison to the previous parameters the fruiting branch density and the leaf area index (LAI) which is more frequently used in characterization of orchard bearing surface.

On dwarfing rootstocks the cumulated TCSA (trunk cross section area)/ ha -in case of both cultivars- shows close connection with plant density (Fig. 4.4.). The connection can be expressed with a quadratic polynomial equation. HROTKÓ noted similar results (2002a,b) in case of trees on semi-dwarfing M.26, and with more vigorous rootstocks on bigger row distance (2-4m) the curve reaches it's maximum.

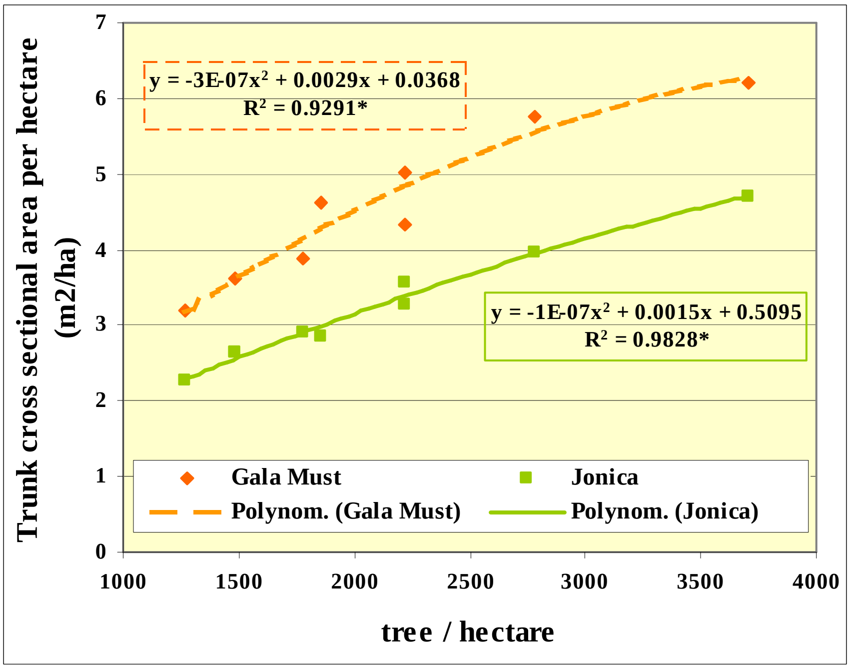

Fig. 4.4. Increase of trunk cross sectional area of Gala Must and Jonica orchards (m^2/ha) planted at different row spacing as function of tree spacing within the row (2005).

Trunk thickness is the index, which can not be change with fitotechnical interferences. More than 2778 tree/ha results in slower curve increase, specially in case of the more vigorous Gala Must, which means that higher plant density causes smaller trunk parameter. In consequence of rootstock-cultivar vigor and spacing limitation, the curve reaches its maximum point (MIKA AND KRAWIEC 1999; STAMPAR et al. 2000).

In case of Gala Must canopy volume/ha of orchard and increased plant density show close positive linear connection (Fig. 4.5). The orchard canopy volume of Gala showed 7056 and 12294 m^3 canopy volume, where the increase is larger within the range of 1270-2778 trees/ha but beyond 2778 tree/ha density the growth of canopy volume is not significant, nears the maximum.

In contrary the cumulated canopy volume of Jonica orchard showed linear growth within the examined in-row spacing range. A similar tendency is found by HROTKÓ (2002a,b) in orchard canopy volume on M.26 rootstocks. Our conclusion is that cultivars perform differently reaching the maximum typical to the rootstock-scion composite tree and site conditions at different tree density.

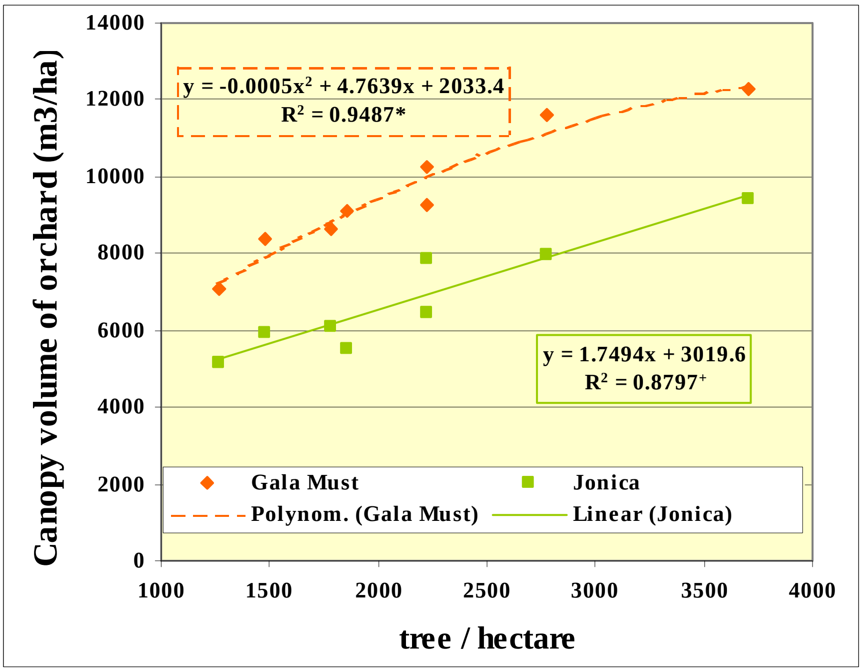

Fig. 4.5. Cumulated canopy volume (m^3/ha) of Gala and Jonica orchard planted at different spacing (2005).

Between 2700-3000 tree/ha plant density, the growth of cumulated canopy volume reduces. This index reaches it's maximum, which maximum determined by cultivar, rootstocks and spacing effects. Many other researcher experienced fruit size and colouring declaim, less productivity, thus unprofitable production within the above mentioned plant density (PALMER AND JACKSON 1973, WEBER 2001, WAGENMAKERS AND CALLESEN 1989, 1995).

We measured the number of productive shoots/ha and it's distribution in canopy. At both cultivars, we noted significant differences depending on plant distance, where tendency means that the total number of productive shoots/ha is higher in case of smaller plant distance (Fig. 4.6. and 4.7.). The connection is close, negative. Results imply that increasing plant density will issue in a linearly increasing number of productive shoots in crown. After the maximum point it results in too high density of branches.

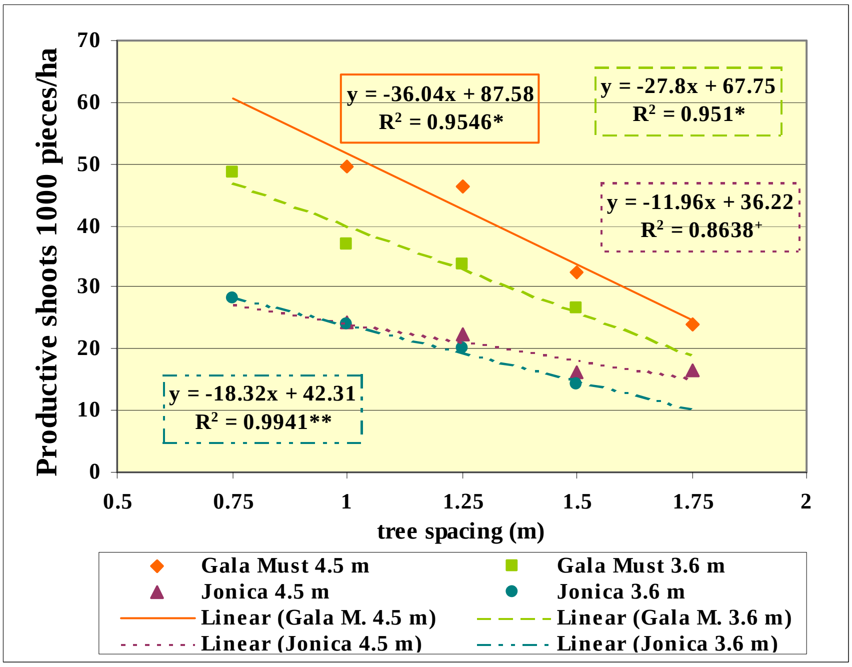

Fig. 4.6. Effect of spacing on cumulated fruiting branch number in one hectare of Gala Must and Jonica orchards (2005).

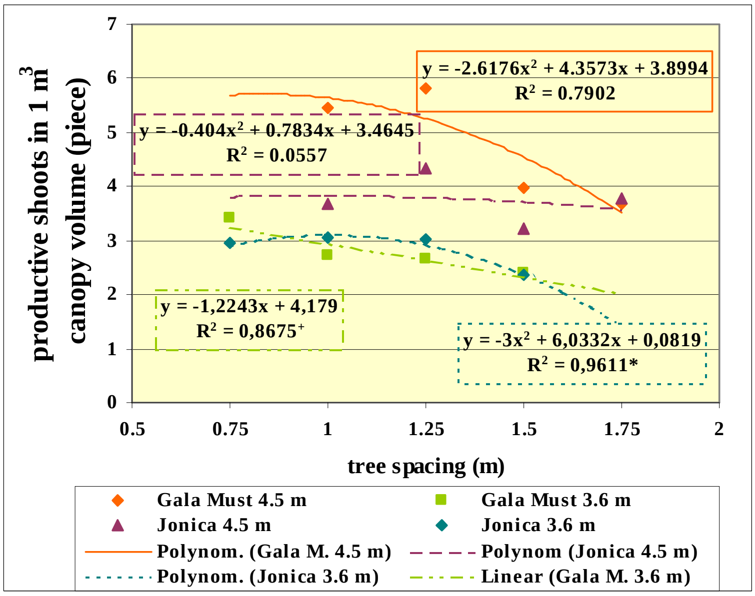

Fig. 4.7. Effect of tree spacing on fruiting branch number in m^3 canopy volume of Gala Must and Jonica orchard (2005)

The fruiting branch number in 1 m^3 canopy 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 polynomial function; at last cultivar the differences between the tree spacing are significant (Fig. 4.7.). 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 canopy volume slightly decreased.

Similar maximum at Gala Must planted at 4.5 m row distance occurred at 1.25 m tree distance. Gala Must at 3.6 m row distance showed in this in-row spacing range showed positive linear connection to tree distance. At both cultivars the fruiting branch number in 1 m^3 canopy volume was larger at 4.5 m row distance than that of at 3.6 m row distance.

4.3. Leaf area index of orchard and PAR absorption

The amount of absorbed photosynthetically active radiation (PAR) is slightly increasing when the tree distance is decreasing. Between the tree spacing and PAR absorption Gala Must showed negative linear connection at 3.6 m row distance, while the same connection at 4.5 m row distance was negative quadratic polynomial. At Jonica these connections were at 4.5 m negative linear, while at 3.6 m row distance quadratic polynomial (Fig. 4.8).

More than 2700-3000 tree/ha plant density reduces the efficiency of light absorption, and so PAR-absorption (CORELLI AND SANSAVINI 1989, ROBINSON AND LAKSO 1989, WÜNSCHE AND LAKSO 2000). Crown volume stops growing after a certain point, thus leaf-density increases, light penetration in crown decreases.

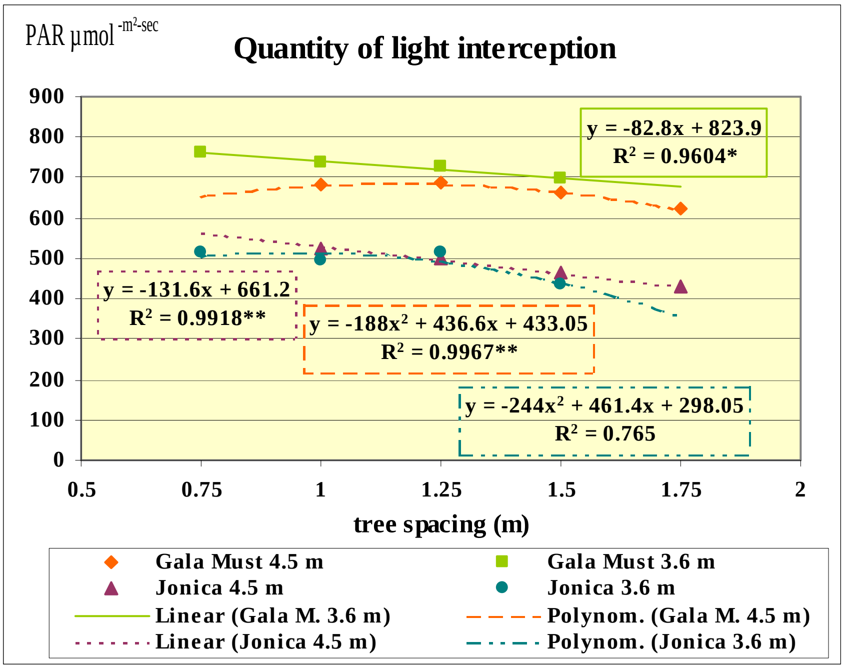

Fig. 4.8. PAR absorption of Gala Must and Jonica orchards planted at different tree spacing in average of 2004 - 2006) (PAR µmol$^{-m^2\text{-sec}}$).

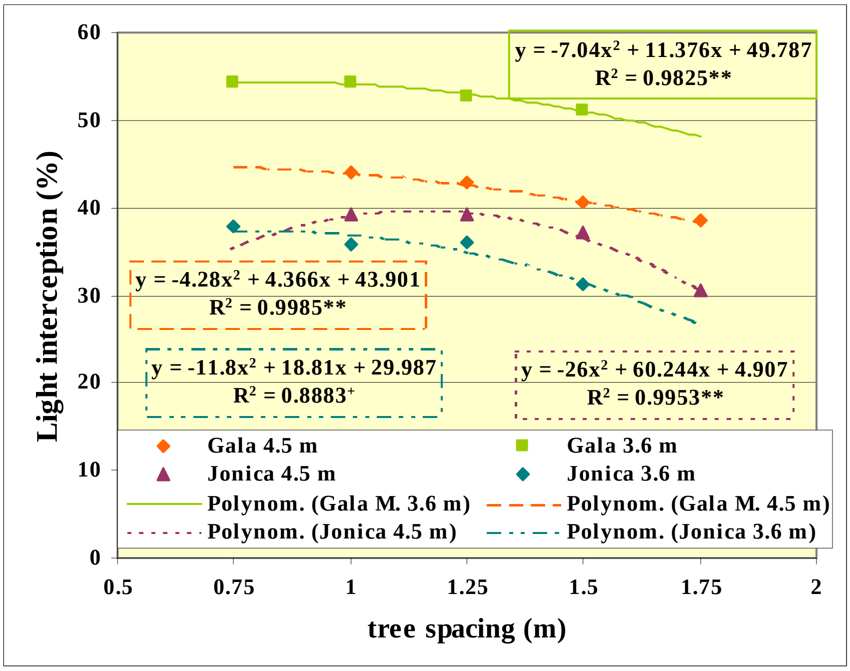

Fig. 4.9. Ratio (%) of intercepted PAR in Gala Must and Jonica orchards planted at different tree spacing. (2005).

In the ratio of intercepted PAR there are differences between the two cultivars. The vigorous Gala Must intercepted 39-56% of the PAR, while the cultivar Jonica showed only 26-40% PAR interception. At both cultivars there was a negative connection characterized by quadratic polynomial between the in-row spacing and PAR absorption (Fig. 4.9.). 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.

Leaf area index and increased planting density shows positive connection in case of both cultivar. This connection can be expressed with a quadratic polynomial equation (Fig. 4.10). Beyond 3000 trees ha^{-1} the growth of LAI is slight or not significant. Cultivar Jonica shows a maximum at 2222 trees ha^{-1} density; beyond this density the LAI doesn't increase, which is in contradiction to STAMPAR et al. (2000) results, who found that the increasing tree density results in larger LAI.

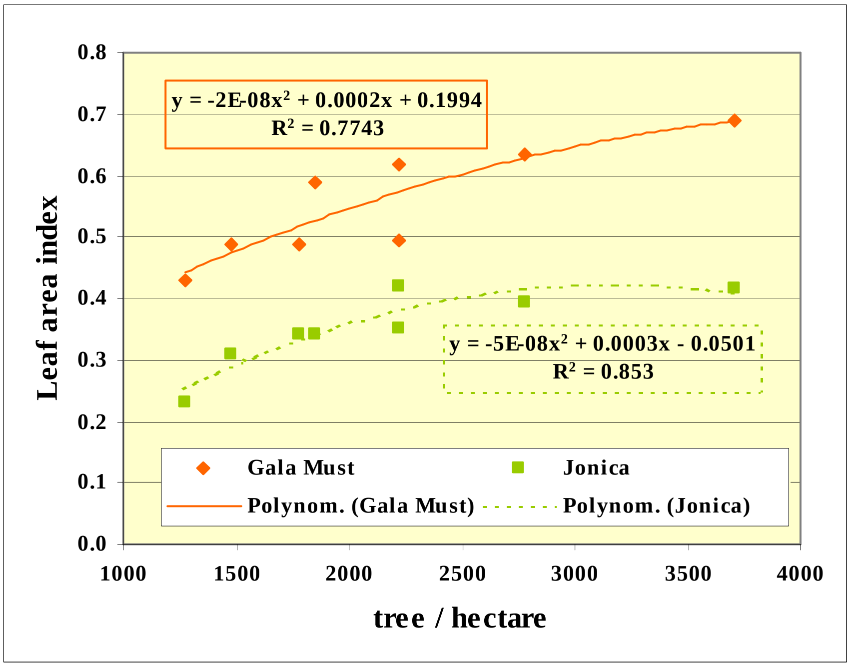

Fig. 4.10. Effect of tree density (trees ha^{-1}) on LAI of Gala Must and Jonica orchards (average of 2004-2006).

Leaf area index (LAI) showed values 0.23-0.42 at Jonica and 0.43-0.69 for Gala Must. These results differ from the data published by other authors (JACKSON 1980b; JAMES ÉS MIDDLETON 2001). The reason could be the methodology: we measured the whole orchard surface from row middle to next row middle. Our data show certain correspondence to index of canopy covered area (HROTKÓ 2002a).

4.4. Yielding characteristics of trees

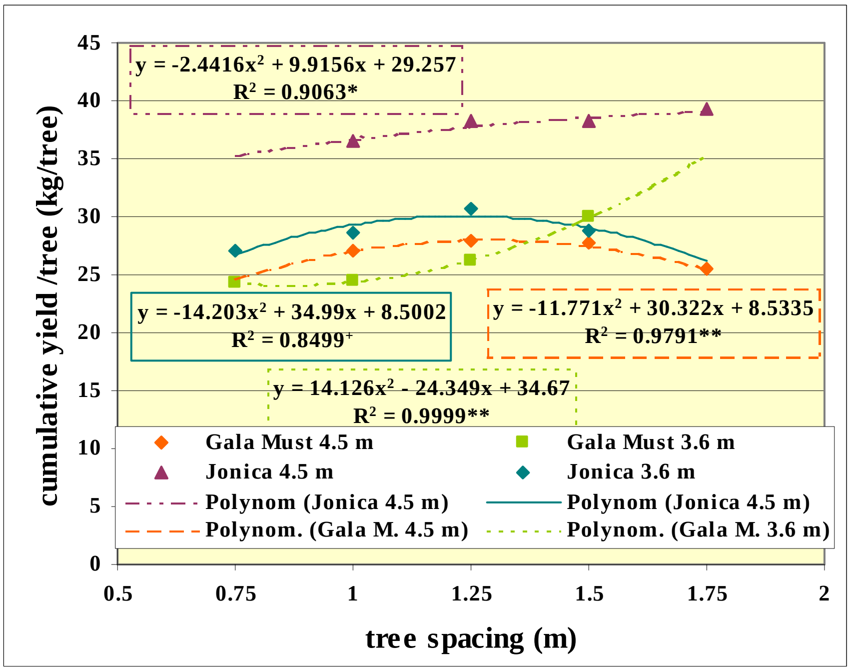

Fig. 4.11. Effect of tree spacing on cumulative yield (kg tree^{-1}) of Jonica and Gala Must planted at different row distance (2001-2007).

The cumulative yield (kg tree^{-1}) showed a tight connection to tree spacing (Fig 4.11.), but concerned this characteristic the cultivars perform differently. These differences could be explained partly by the different vigor and different spacing requirements.

The cumulative yield of Jonica trees at 4.5 m row distance show positive linear connection to the tree spacing, while at 3.6 m row distance the cumulative yield beyond 1.25 m tree distance did not increased any more. In contrary, the cumulative yield of Gala Must trees at 3.6 m row distance increases proportionally to tree distance, but at 4.5 m row distance this increase stops at 1.5 m. In this last case could be supposed that the space of trees reached that maximum that in the given site and with the applied tree shape the rootstock-scion composite tree cannot utilize any more in increasing the yield (Fig. 4.11.).

Productivity of rootstock-cultivar combinations (measured in trunk cross-sectional productivity index) (Fig 4.12.) in case of both cultivars showed it's maximum level around 2500-3000 tree/ha, and the correlation can be describe with a quadratic polynomial.

Both cultivar showed decreasing productivity (TCSA productivity index) above 2500 tree/ha plant density (similar to STAMPAR et al. (2000)'s results).

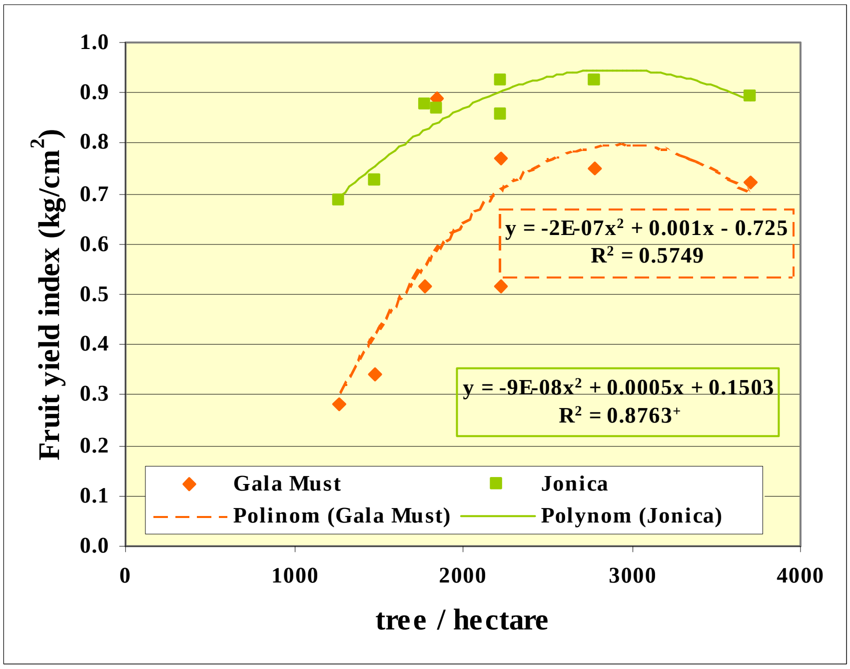

Fig. 4.12. Effect of tree density on cumulative yield efficiency index (kg/cm^2 by TCSA) of Jonica and Gala Must trees (2004)

4.5. Cropping characteristics of the orchard

Cumulative yield and tree density show close positive linear connection, similarly to the results of BALKHOVEN-BAART et al. (2000) and ROBINSON (2003).

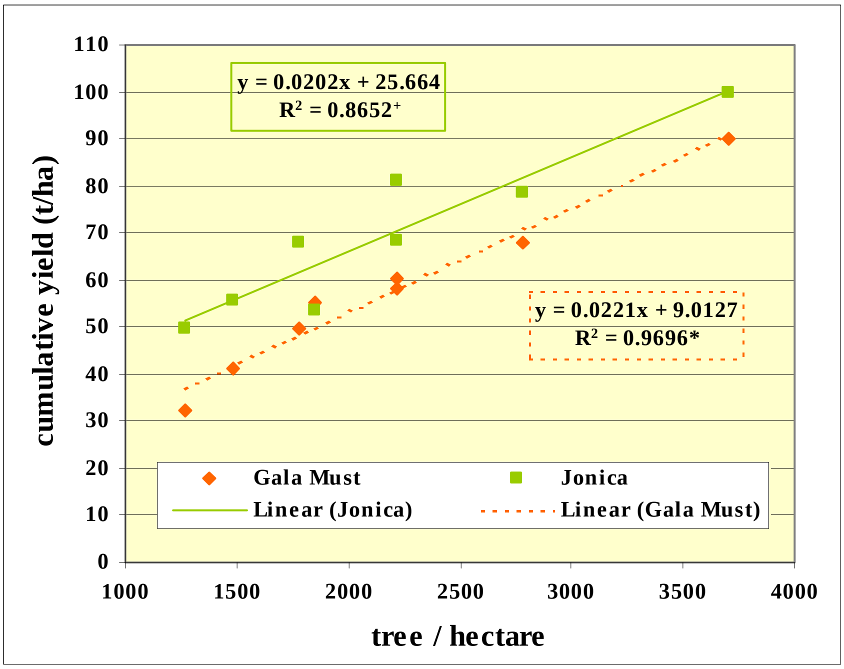

Fig. 4.13. Relation of tree density (tree ha^{-1}) and cropping index (t ha^{-1}) of Jonica and Gala Must apple orchard (2001-2007).

Tree density has stronger effect on productivity/ha than decreasing productivity index and maximalised PAR-absorption, specially in case of young orchards after turning to be productive, where crop/ha linearly increases with plant density. Further researches are necessary to see correlations in case of aged trees (CAIN 1970, ROBINSON AND LAKSO 1989, MIDDLETON et al. 2002, ROBINSON 2007b).

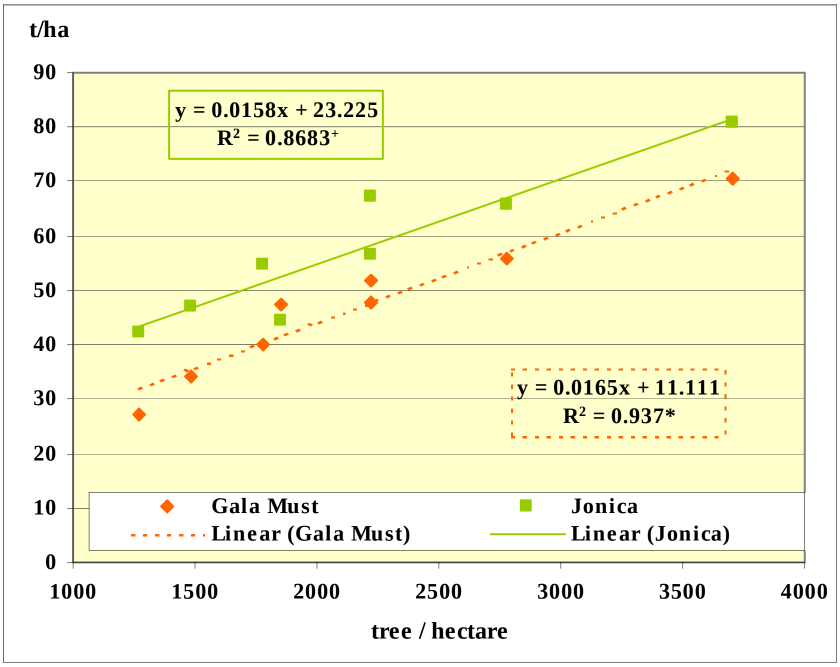

Fig. 4.14. Relation of tree density (tree ha^{-1}) and value-equivalent crop (t ha^{-1}) of Jonica (2004, 2005, 2007. year) and gala Must (2003, 2004, 2007) apple orchard

Fruit quality and cropping index/ha shows similar positive linear correlation with increasing plant density, which means that with a plant density of 1270-3704 trees/ha, the fruit quality will not decline till the orchard reaches it's 7th year.

Relation between PAR-absorption and cumulative yield shows results similar to PALMER et al 1992, LAKSO AND ROBINSON 1997, ROBINSON 1997, WÜNSCHE et al. 1996, close linear correlation in case of both cultivars. Cumulative yield increases linearly with absorbed PAR at both cultivars, however a tight correlation exists only at Gala Must (Fig. 4.15). There is difference in the slope of the correlation between the two cultivars (Fig. 4. 15, 4. 16).

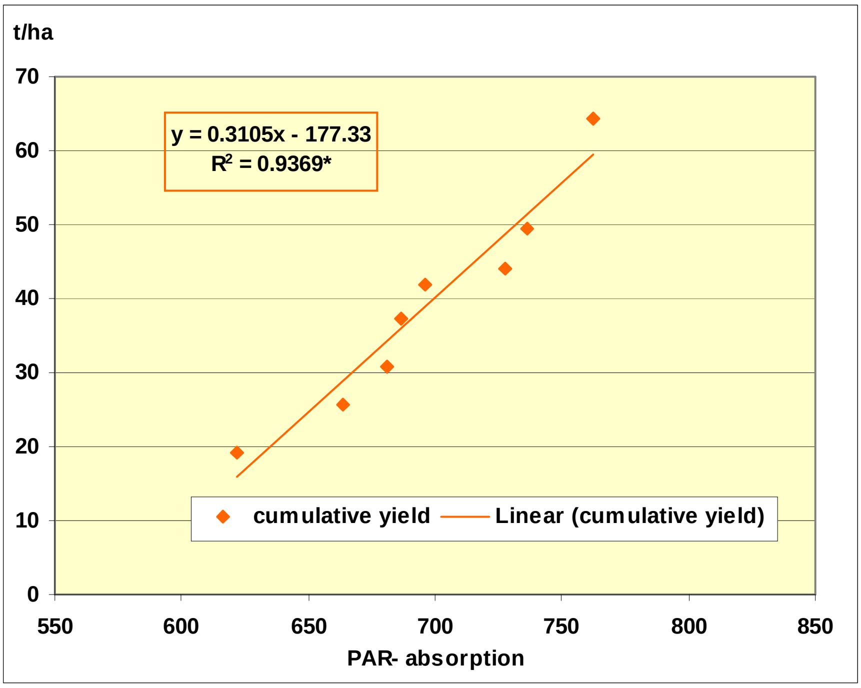

Fig. 4.15. Correlation between PAR absorption (PAR µmol $^{-m^2\text{-}sec}$) (average of 2004-2006) and the cumulative cropping index (t/ha) (average of 2001-2006) of Gala Must orchard.

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.

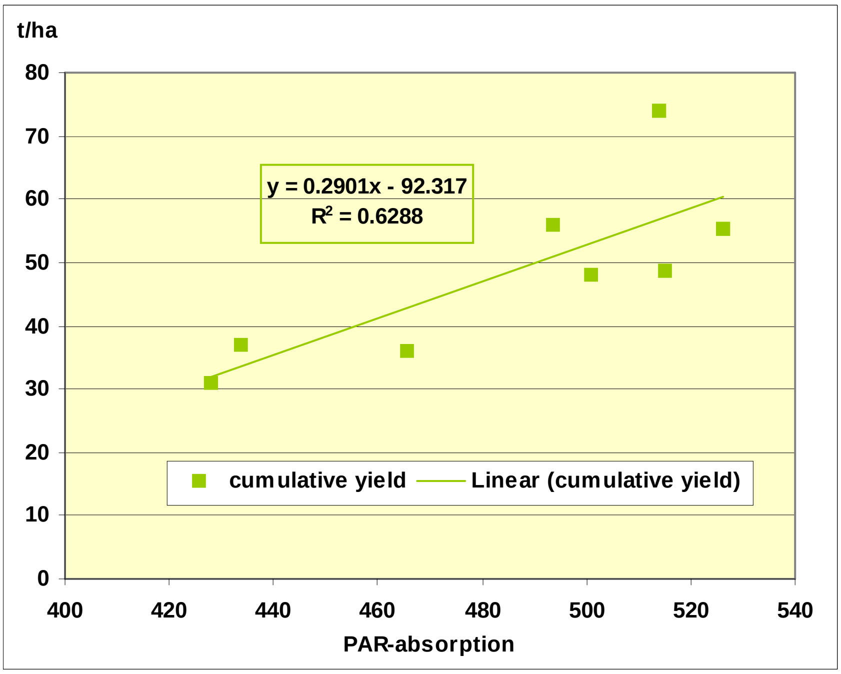

Fig. 4.16. Correlation between PAR absorption (PAR µmol $^{-m^2\text{-}sec}$) (average of 2004-2006) and the cumulative cropping index (t/ha) (average of 2001-2006) of Jonica orchard.

5. NEW SCIENTIFIC RESULTS

1. Our investigations confirmed the opinion concerning the specific connections of bearing surface and spacing of apple orchard: the correlation between tree density and bearing surface within the range of 1270-3704 trees ha^{-1} the TCSA and CA canopy volume 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 a maximum around 3000 trees ha^{-1} density.

2. Within the investigated spacing range the number of fruiting branches increases in linear correlation to the tree density; consequently in the limited canopy volume the branch-, leaf-, and fruit population is more and more crowded. The larger tree density slightly increases the ratio of intercepted PAR, so the efficiency of PAR utilization decreases.

3. The cropping index (t ha^{-1}) and the value-equivalent fruit cropping index shows a positive linear correlation to the tree number within the investigated range, which is typical to the cultivar. The cumulative yield efficiency index on TCSA basis reaches a maximum around the tree density of 3000 trees ha^{-1}.

4. 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.

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