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Relationship between Basic Shoot Parameters and Shoot Spatial Position in the Canopies of Young Sweet Cherry Trees

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Summary

Spatial location of the reproductive organs within tree canopy is of a paramount importance in fruit cropping. This research was undertaken to determine the relationship between shoot location in tree canopies *vs.* shoot characteristics and flower formation potential. The experiment was carried out using 6-year-old 'Burlat' sweet cherry trees planted at the density 1000 trees ha^{-1}. Tree canopies were divided into three horizontal zones located at 50–150,150–250, and 250–350 cm above the soil line. Shoot samples were taken from all zones to measure shoot length (SL), shoot diameter (SD), and the number of flower clusters (NFC). There was a close relationship between SL and SD *vs.* NFC, respectively. Shoots from the bottom and center zones were shorter, and had significantly higher NFC than those from the upper zone. Regardless of zone location, the correlation SL × NFC was approx. 31 % stronger than that of SD × NFC. Regression analysis for the entire canopy showed an exponential function relationship between the SL and NFC. The responses were fitted by an exponential function model with $R^2 = 0.877$. The minimum and maximum NFC cm^{-1} of shoot length predicted by this model were 0.03 and 0.81 for the shoots 86 cm and 4 cm long, respectively. In order to stimulate formation of flower buds in the upper parts of young densely planted sweet cherry trees, it was suggested to replace invigorating dormant pruning by summer pruning.

Key words. flower formation – growth correlation – planting density – tree architecture

Introduction

The results of extensive research on sweet cherry contributed greatly to the implementation of new production methods, which significantly influenced tree growth and cropping patterns (Sansavini and Lugli 1998; Lang and Lang 2008). Simultaneously, worldwide research on tree architecture and virtual plant modelling (Prusinkiewicz et al. 1997; Lang and Lang 2008; Smith et al. 2008) prompted the investigation on tree canopies designed for dense sweet cherry plantings (Guimond et al. 1998; Lang and Lang 2008). Because field experiments on tree training and orchard design usually take up a long time, therefore the results of these investigations have been incorporated into virtual models, contributing greatly to the development of orchard management strategies (Godin et al. 1997; Prusinkiewicz et al. 1997; Allen et al. 2005).

Most of sweet cherry cultivars are characterized by a strong growth habit (Rejman 1994). Nowadays in Europe, sweet cherry trees are commonly grafted on semi- and/or vigorous rootstocks of *Prunus mahaleb* L. or *P. avium* L. type. In spite of robust growth habit of such rootstock/cultivar combinations, sweet cherry trees could be grown in dense plantings provided that appropriate training techniques are applied (Vogel 1994; Zahn 1996). However, such types of sweet cherry plantings can create serious management problems unless basic tree/orchard dimensions are strictly controlled, thus providing an undisrupted influx of sunlight into the orchard system (Jackson 1980; Wagenmakers 1995).

Flowers in young sweet cherry trees are born near the base of the previous-season shoots (Westwood 1978; Sitarek 2004). Therefore a large number of such shoots is needed for satisfactory fruit production of young trees. The number of flower clusters and their distribution on these shoots are mainly cultivar and rootstock dependent (Seliga 2008). The development of flower clusters depends largely on the length and thickness of the bearing branch segment (Kramer et al. 1984). The same authors (Kramer et al. 1984) found that the diameter of flower clusters in the 20–50 cm zone of short, vertical shoots increased more than that in horizontal longer shoots.

The results of our preliminary experiments suggested that in sweet cherry trees grown in dense plantings, the numbers of flower clusters calculated either per single shoot or per cm of shoot length, were associated with the position of the shoots in tree canopy [unpublished].

The objectives of this research were twofold: 1) to examine the correlations between shoot vegetative growth characteristics and the number of flower clusters, and 2) to determine the potential to formation of flower clusters relative to shoot position within a canopy of sweet cherry trees grown in dense planting.

Materials and Methods

Plant material and orchard design

The experiment was carried out in three consecutive years (2006–2008) in an orchard located near the Vistula River, 150 km south from Warsaw, Poland. Six-year-old 'Burlat' sweet cherry trees on *Prunus anium* L. rootstock were used. The planting density was 1000 trees ha^{-1} (4.5 × 2.2 m), and the trees were trained to a central leader canopy. The orchard floor consisted of herbicide strips maintained with glyphosate and mowed sod alleyways.

Data recording

For the experiment uniform trees planted in two adjacent rows were selected. Thirty one-single tree replications were used. The uniformity was decided based on trunk cross-sectional area measured below and above the graft union, the number and length of scaffold branches and tree height (data not shown). Tree canopies were divided in three horizontal zones located at: 50–150, 150–250, and 250–350 cm above the soil line. Every year, from each tree zone a random sample of five previous-season shoots (shoots) were collected (in total 450 shoots). On these shoots length, diameter and the number of flower clusters were measured.

Statistics

All data were subjected to analysis of variance, and for the mean separation a Duncan's multiple range test at $P < 0.05$ was applied. The strength of linear relationship between the investigated variables was evaluated by Pearson's product moment correlations (r). Responses in the number of flower clusters *vs.* the length of previous-season shoots were subjected to regression analysis, separately for each zone, and a whole canopy as well. The regression models were analyzed and their accuracy was assessed by the coefficient of determination (R^2). For all statistical computations a Statgraphics Plus software (Statistical Graphics Corp.) was used.

Results

Relationship between shoot length, shoot diameter and the number of flower clusters

Analysis of the basic characteristics of shoots indicated a close relationship existing between the values of tested characteristics and the location of zone where these shoots were collected from. In three consecutive years, there was a distinct order of significant differences between all canopy zones in the values of length and/or diameter of shoots, with one exception in 2008, when no difference in shoot length between the center (150–250 cm) and upper zone (250–350 cm) was found (Table 1). Comparison of the values of shoot length and diameter during the entire period of investigation indicated a significant trend to reduce these values in time, except for the shoot diameter in the zone 50–150 cm, where no difference between these values in 2006 and in 2007 were noted. We have not found any reasonable cause to explain a drastic reduction in shoot length and diameter in the third year of this study (Table 1). The number of flower clusters per cm of shoot length (NFC) in the bottom (50–150 cm) and center zone did not significantly differ from each other. The shoots from these zones induced significantly more flower clusters than the shoots from the upper zone. Regardless of zone location, the significance of differences in the NFC between par-

Table 1. Effects of the shoot location in 'Burlat' sweet cherry tree canopy on the values of their vegetative and reproductive growth characteristics

Position of tree zone (cm above the soil line)	Shoot length (cm)			Shoot diameter (cm)			No. flower clusters cm^{-1} shoot length		
	2006	2007	2008	2006	2007	2008	2006	2007	2008
50–150	41.1 a A	38.5 a B	13.1 a C	0.78 a A	0.76 a B	0.52 a C	0.18 b B	0.20 b B	0.63 b A
150–250	45.9 b A	43.0 b B	13.4 b C	0.89 b A	0.85 b B	0.62 b C	0.16 b B	0.18 b B	0.67 b A
250–350	61.0 c A	56.4 c B	15.0 b C	1.17 c A	1.11 c B	0.76 c C	0.08 a B	0.10 a B	0.59 a A

Mean values followed by the same letter are not significantly different according to Duncan's multiple range test at $P < 0.05$.
For each characteristic: to compare different canopy zones use values marked with a small letter (vertical); to compare the same canopy layers (horizontal; across the years) use values marked with a capital letter.

ticular years of this research was similar for all canopy zones (Table 1).

Linear correlation between vegetative and reproductive shoot growth characteristics

All examined correlations between either shoot length (SL) or shoot diameter (SD) *versus* the NFC were negatively related to each other at $P < 0.05$, except for one case in 2008 (Table 2). Regardless of the zone location and the year of observation, the strength of the linear correlation SL × NFC expressed by the coefficient of correlation (r), was approx. 31 % greater than that of the SD × NFC (Table 2). The r coefficient for both the SL × NFC, and the SD × NFC for the zones: 150–250 and 250–350 cm were similar in all years, except for the SD × NFC in 2008 (Table 2). Averaged for three years, the r-values for particular canopy zones, indicated strong positive correlations for the SL × SD and strong negative correlations for the SL × NFC. The strength of linear correlations SD × NFC in all zones was approx. 20 % weaker compared to the SL × NFC or the SL × SD (Table 3).

Regression of the number of flower clusters on the shoot length

Regression analysis showed an exponential function relationship between the SL and NFC. This was true for all zones as well as the entire tree canopy that was significant at the 99 % of the confidence level ($P < 0.01$). The responses were fitted by exponential function models with the coefficients of determination (R^2) ranging from 0.783 (for the bottom zone) to 0.926 (for the upper zone), and the $R^2 = 0.877$ for the entire tree canopy (Table 4, Fig. 1). The R^2 indicated that the model explains 87.7 % of the variability in NFC after transforming to a logarithmic scale to linearize the model. The coefficient of correlation for transformed model equals to $r = -0.936$ indicating a strong relationship between the variables. The minimum and maximum NFC which have been predicted by these models were 0.03 and 0.68 (for the shoots 82 cm and 6 cm long), 0.04 and 0.82 (for the shoots 72 cm and 52 cm long), and 0.03 and 0.84 (for the shoots 86 cm and 4 cm long) in the bottom (50–150 cm), center (150–250 cm), and upper (250–350 cm) zone, respectively. For the entire canopy regarded as a unit (three zones together), the values of the NFC were 0.81 and 0.03 for the shoots 4 cm and 86 cm long, respectively.

Discussion

In young sweet cherry trees, the intensity of the growth of previous-season shoots, their spatial position within a canopy, and the number of shoots play an important role in flower bud formation, and consequently in establishing an adequate level of tree cropping (Flore and Kesner 1982; Kramer et al. 1984; Sitarek 2004; Mika 2011).

The results presented here suggest that in the upper part of densely planted trees an excessive shoot growth caused by abound influx of sunlight and related interaction of apical dominance and/or water/nutrient status (source – sink) may inhibit flower bud formation (Heinicke 1964; Mika 2011). This was particularly critical with young sweet cherry trees producing strong, upright shoots in the upper part of the canopy. As early as in 1961 Nasr and Wareing reported that actively growing shoot apex markedly inhibited bud setting and shoot branching in black currants. Inhibiting effect of intensively growing shoot acts only locally, and it is limited to either whole shoot or its part (Mika 2011). Therefore a great difference in flower bud formation among the shoots from different parts of tree canopy may be expected. We believe that sunlight interception and penetration into bottom and center zones of the canopies of tested trees were adequate to favour more flower bud formation than stimulate an excessive shoot elongation. It may be expected that by the application of lower planting density and different pruning regime than those used in our experiment, light penetration within tree canopies might be facilitated

Table 2. The relationship between shoot growth characteristics and the number of flower clusters dependent on the zone of shoot location within the canopy of 'Burlat' sweet cherry trees, expressed by Pearson's product moment correlations

Position of tree zone (cm above the soil line)	2006		2007		2008	
	Correlation coefficient (r)					
	SL[z] × NFC[y]	SD[x] × NFC	SL × NFC	SD × NFC	SL × NFC	SD × NFC
50–150	−0.70	−0.42	−0.74	−0.46	−0.49	−0.17 ns
150–250	−0.82	−0.64	−0.81	−0.66	−0.69	+0.01 ns
250–350	−0.80	−0.59	−0.82	−0.67	−0.79	−0.50

[z] SL – shoot length; [y] NFC – number of flower clusters cm^{-1} SL; [x] SD – shoot diameter.
All r are significant at $P < 0.05$ unless otherwise marked by ns (not significant). Sample size: 120–148 pairs.

Table 3. Mean values for correlation coefficients (2006–2008) for the relationship between shoot growth characteristics and the number of flower clusters dependent on the location of shoot sampling in tree canopies of 'Burlat' sweet cherry

Correlation	Position of tree zone (cm above the soil line)		
	Coefficient of correlation r		
	50–150	150–250	250–350
SD[x] × SL[z]	+0.83	+0.84	+0.83
SL × NFC[y]	−0.80	−0.84	−0.85
SD × NFC	−0.67	−0.65	−0.69

[z] SL – shoot length; [y] NFC – number of flower clusters cm^{-1} SL; [x] SD – shoot diameter.
All r are significant at $P < 0.05$ unless otherwise marked by ns (not significant). Sample size: 416–441pairs.

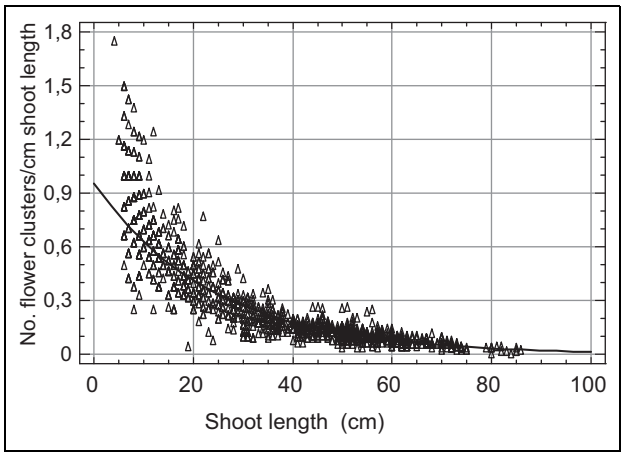


Fig. 1. The number of flower cluster responses on previous season shoots as influenced by shoot length in 'Burlat' sweet cherry trees (means for 2006–2008). Regression equation: $y = -0.0463 - 0.042^X$ with $R^2 = 0.877$.

thus improving the conditions for flower bud formation. It was possible that the high number of flower clusters on the shoots from bottom and center zones resulted from the reduction in shoot elongation since flower formation potential was inversely correlated with shoot growth. Regardless of shoot location, the NFC was more correlated with shoot length than with its diameter. Shoot length exerted an exponential curve effect on the number of flower clusters. Shorter shoots induced more flower buds than long, more vigorously growing shoots. It was suggested that moderately growing shoots of about 30 cm length are characterized by optimal flower bud formation potential (Sitarek 2004).

High quality fruit crop in young sweet cherry orchards is produced on moderately growing shoots that are well exposed to sunlight (Proebsting 1985; Sitarek 2004). In

Table 4. Coefficients for the regression of the number of flower clusters on the shoot length (with standard errors in parentheses) in horizontal zones of the canopy of 'Burlat' sweet cherry trees

Position of tree zone (cm above the soil line)	b_0 (SE)	b_1 (SE × 10^{-2})	R^2
50–150	−0.1299 (0.0378)[z]	−0.0408 (0.1057)	0.783
150–250	0.0189 (0.0338)[z]	−0.0434 (0.0857)	0.859
250–350	0.737×10^{-3} (0.0287)[z]	0.0425 (0.0575)	0.926
Whole tree canopy	−0.0463 (0.0186)[z]	−0.042 (0.0441)	0.877

[z] regression equation: $y = b_0 + b_1^X$ where X is the shoot length.
R^2 coefficient of determination

contrast with those shoots, the vigorous shoots from the upper part of tree canopy are characterized by a limited possibility to set flower buds. Therefore, it is essential to inhibit the growth of these shoots while increasing their flower formation potential. Replacement of invigorating dormant pruning by summer pruning with special emphasis on strongly growing shoots in the upper tree part seems to be an appropriate technique.

Summer pruning has been commonly regarded as a relatively efficient tool in increasing flower formation in sweet cherry trees (Webster and Shepard 1984; Morgaś and Mika 1996; Guimond et al. 1998; Sitarek 2004). However, a final outcome of performing pruning procedures depends upon many factors, among which rootstock, cultivar, timing and severity of pruning, or type of pruning cuts are of paramount importance (Kesner et al. 1981; Webster and Shepard 1984; Guimond et al. 1998).

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