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RELATIONSHIP BETWEEN YIELD, CROP DENSITY COEFFICIENT AND AVERAGE FRUIT WEIGHT OF 'GALA' APPLE

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A B S T R A C T

'Gala' apple (*Malus domestica* Borkh.) trees grafted on P 60 rootstock were planted at the space of 3.5 x 1.25 m. In order to achieve a high diversity of fruit quantity per tree, light (L), as well as, heavy (H) thinning were applied. The fruitless were not thinned in the control (Control) trees. The aim of the present study was to quantify the relationship between the number of fruits produced per unit of TCA (crop density coefficient CD), average fruit weight and the yield of 'Gala' apple trees. The yield and average fruit weight of investigated trees depended on the applied thinning. Correlation coefficients between CD and yield were positive, whereas between CD and average fruit weight negative. In order to describe precisely the influence of crop density level on the yield and average fruit weight, the multiple regression analysis involving the tree age was performed. The formula obtained can serve to determine a criterion for fruitlets thinning for the years to come.

Kay words: apple, crop density coefficient, 'Gala'

INTRODUCTION

High quality fruits have consistently higher prices and financial returns to growers are closely related to fruit size (Forshey, 1971; Dobbs and Rowling, 2006). Only optimal yield and high fruit quality guarantee profits. Therefore, to be competitive, growers should apply cultural practices, which increase the percentage of high quality fruit. The consistent production of fruit with optimum color and size can only be accomplished, when a proper balance between vegetative growth and fruiting is maintained (Rom, 1994).

Frequently, apple trees bloom abundantly and set too many fruits to optimize fruit size and return bloom. Therefore, most producers attempt to increase fruit weight by reducing the number of fruits on a tree. This increase the ratio of leaf area to fruit, resulting in an increased amount of available assimilates supporting fruit growth (Palmer et al., 1991). Early removal of fruitlets results in larger fruit size at harvest (Jones et al., 1992). Thus, fruit thinning is considered as one of the most important cultural practice affecting fruit quality and cropping consistency (Johnsen, 1987; Williams, 1994; Basak, 1999). However, the effects of thinning are hard to predict because one can not be certain whether the number of fruitlets left on a tree will be sufficient to produce a good quality crop. Too heavy fruit thinning reduces yield dramatically and increases fruit sensitivity to many physiological disorders during storage (Looney, 1986). According to Forshey (1971), thinning should be performed in a way that guarantees mature fruit to attain the desired size. Fruit from heavily thinned trees also have a short storage life and are likely to rot (Basak, 1999). For these reasons, it is important to know how many fruits should be retained to obtain optimum fruit quality and adequate storability. This is particularly important in high-density planting because in such orchards trees have tendency to bear small fruits with poor colour (Hugard, 1980). Fruit thinning also is necessary for some varieties having a natural inclination to produce small fruits. One of these cultivars is ‘Gala’ (McArtney et al., 1996; Wójcik et al., 2001). Despite this disadvantage, this cultivar enjoys growing popularity in Europe.

Very precise criteria are necessary to judge the effectiveness of thinning. Crop load is one of the orchard practices determining fruit quality (Francesconi et al., 1996; Wójcik et al., 2001; Treder and Mika, 2001). Crop load is generally defined as the number of fruits per tree (Francesconi et al., 1996; Wünsche et al., 2005). A number of researchers point out a negative correlation between fruit load and fruit size. Too heavy fruit loads reduce fruit size (Zhang et al., 1992; Rom, 1994; Czynczyk et al., 2001). The size of the tree is usually expressed as trunk cross-sectional area (TCA). It is the most common surrogate measurement to determine the tree size and, indirectly, the capacity of the tree to produce fruits (Wright et al., 2006). On the other hand, a certain minimal number of fruits per tree is needed to guarantee satisfactory yields (Silbereisen, 1983; Zhang et al., 1992; Treder and Mika, 2001). Thus, too excessive thinning may result in lower crops and profits. Crop load is often expressed in terms of number of fruit per trunk cross-sectional area (TCA) and named crop density (CD), (Lombard et al., 1988). The studies by Webb et al. (1980), Bergh (1990), Marini et al. (2002) indicate that the number of fruits per TCA may predict the proper crop load in the most satisfactory way.

The aim of is study was to quantify the relationship between the number of fruit produced per unit of TCA (crop density coefficient – CD) (Lamb, 1972; Lombard et al., 1988), average fruit weight and the yield of 'Gala' apple trees.

MATERIAL AND METHODS

The experiment was carried out in the years 1998-2004 at the Dąbrowice Experimental Station of the Research Institute of Pomology and Floriculture, Skierniewice. 'Gala' apple (*Malus domestica* Borkh.) trees grafted on P 60 rootstock were planted in the autumn of 1992 on sandy loam soil at a space of 3.5 x 1.25 m (2286 trees per ha). Before the experiment was started (in autumn 1997), the concentrations of available phosphorus (P), potassium (K), and magnesium (Mg) in the top layer (0-20 cm) of the soil were optimal: 65, 130, and 51 mg kg^{-1}, respectively. The level of organic matter and soil pH were 1.4% and 5.2%, respectively. Because of the adequate amount of P, K, and Mg in the soil, these elements were not applied during the experiment. Only nitrogen (N) was applied annually at a rate of 60 kg ha^{-1}, as ammonium nitrate (34:0:0) at bud break over the surface of herbicide strips (2 m-wide) along the rows. Trees were trained as a spindle by dormant and summer pruning, according to the principles recommended for intense apple planting. The trees were drip irrigated, when soil water potential at the depth of 20 cm fell below -0.03 MPa. To differentiate fruit load, hand-thinning of fruitlets was carried out each year, immediately after june drop. Both light (L) and heavy (H) thinning were applied. The light thinning let all the fruitlets develop from king flowers, while the heavy thinning let grow only the fruitless, which grew within a distance of at least 20 cm from each other. The fruitless were not thinned in the control (Control) trees. Each treatment was represented by 30 trees. The fruitlets remaining on the tree (L and H treatments) were evenly distributed within the canopy.

The fruit yield per tree was measured and mean fruit weight was calculated on the basis of a ca. 15 kg fruit sample from each plot, collected from entire tree canopies. Results were elaborated statistically by analysis of variance and differences between means were evaluated using Duncan's multiple range test at $p = 0.05$.

RESULTS AND DISCUSSION

The number of apples per tree and TCA measurements were used to calculate CD coefficient (fruit/cm^2 TCA) in all cropping years (Fig. 1). Coefficients differed considerably from year to year and between the treatments. Generally, CD values were lower in H treatment than in Control. The lowest CD values were observed in the years 2002 and 2004 due to spring frost damage. The fruit yield from investigated trees depended on the applied thinning (Fig. 2). The unthinned trees produced the highest

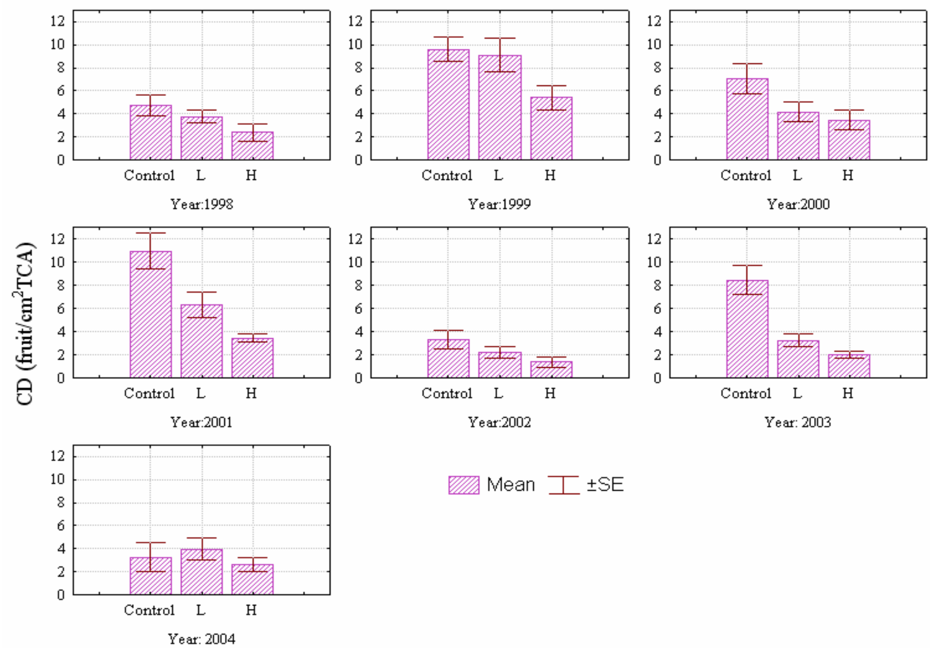

Figure 1. Crop density coefficient (CD) of 'Gala' apple trees as effected by different thinning levels CD = number of fruit per unit of trunk cross section area, L = light thinning, H = heavy thinning

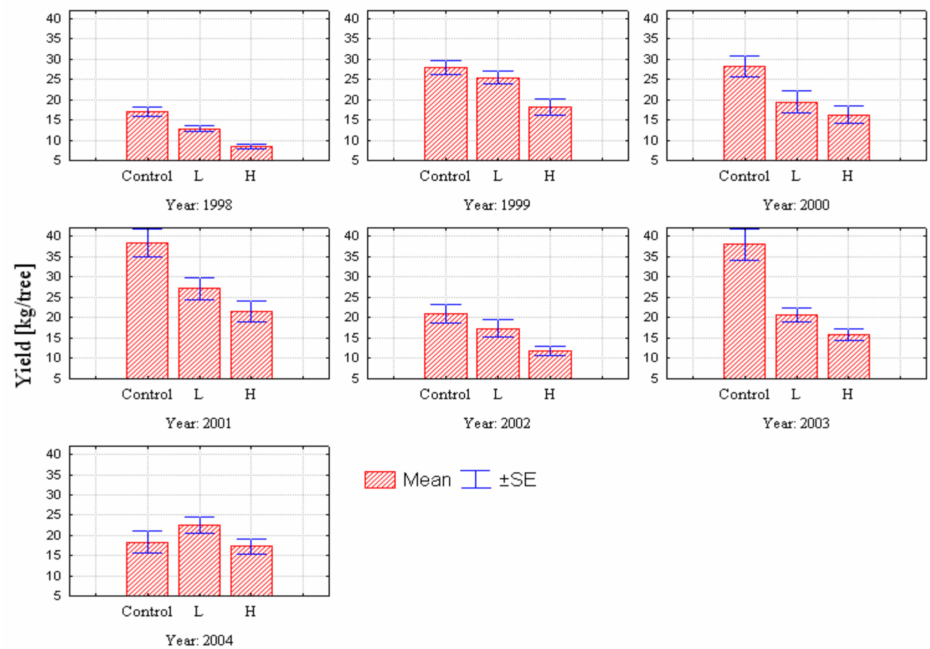

Figure 2. Yield of 'Gala' apple trees as effected by different thinning levels L = light thinning, H = heavy thinning

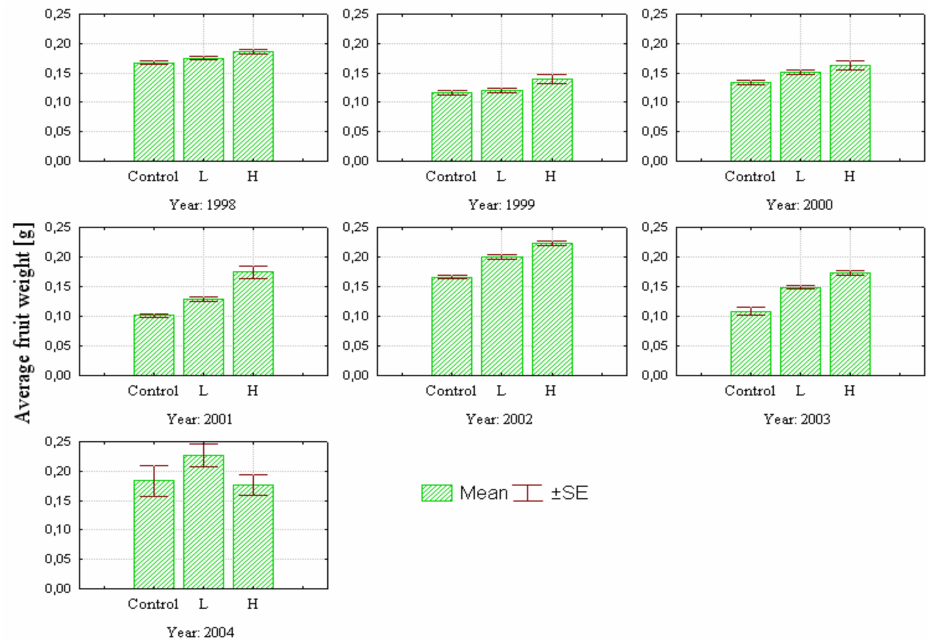

Figure 3. Average fruit weight of 'Gala' apple trees as effected by different thinning levels L = light thinning, H = heavy thinning

Table 1. Correlation coefficients and linear regression equations (Y = a + b*X) describing the relationship between yield (T/ha) and crop density (fruit no./cm^2 TCA) in 'Gala' apples under different thinning level treatments. Y = yield, X = crop density

Years	Correlation coefficient	Regression equation	
		a	b
1988	0.79 ***	4.70 **	2.20 ***
1999	0.56 **	12.45 ***	1.42 **
2000	0.74 ***	6.54 *	3.01 ***
2001	0.70 ***	13.71 ***	2.22 ***
2002	0.71 ***	7.44 ***	4.04 ***
2003	0.81 ***	10.08 ***	3.23 ***
2004	0.71 ***	9.13 ***	3.11 ***
1998-2004	0.71 ***	10.07 ***	2.3 ***

yield. The level of production affected fruit size significantly (r = -0.52***). The lowest average fruit weight was observed in control trees, whereas the highest one was obtained from the heavy thinned trees (Fig. 3). The relationship between yield and average fruit weight found in this study was reported previously by Zhang et al. (1992), Treder and Mika (2001).

The correlation coefficients between CD and yield were positive in all consecutive years, indicating that the higher CD level effects in the higher yield. (Tab. 1). The correlation coefficients between CD and average fruit

T a b l e 2 . Correlation coefficients and linear regression equations (Y = a + b*X) describing the relationship between mean fruit weight (g) and crop density (fruit no./cm^2 TCA) in 'Gala' apples under different thinning level treatments. Y = yield, X = crop density
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Years	Correlation coefficient	Regression equation	
		a	b
1988	-0.76 ***	201 ***	-6.79 ***
1999	-0.77 ***	169 ***	-5.46 ***
2000	-0.69 ***	180 ***	-6.34 ***
2001	-0.76 ***	188 ***	-7.70 ***
2002	-0.63 ***	228 ***	-1.35 ***
2003	-0.86 ***	183***	-8.68 ***
2004	0.40 *	154 ***	-6.32 *
1998-2004	-0.71 ***	191 ***	-8.17 ***

T a b l e 3 . Effect of level of hand thinning on fruiting index, crop density coefficient, total yield and mean fruit weight for the whole experimental period

Parameter	Thinning level		
	Control	L	H
Fruiting index [kg cm^{-2} TCA]	0.83 c	0.66 b	0.48 c
Crop density coefficient [fruit no. cm^{-2} TCA]	6.59 c	4.39 b	2.86 a
Total yield [kg tree^{-1}]	188.58 c	145.78 b	109.49 a
Total yield [T ha^{-1}]	431	333	250
Average yield [T year^{-1}]	61.6	47.6	35.7
Mean fruit weight [g]	139 a	164 b	177 c

weight were negative in all years that the weight of individual fruits decreased with an increasing number of fruits per unit of TCA. Both, the correlation coefficients and the parameters of linear regression were statistically significant for the consecutive years, (Tab. 2). The applied levels of thinning influenced significantly the average CD and fruiting index (FI) as well as, the total yield and average fruit weight during the investigation period (Tab. 3). The findings confirm the significant influence of thinning on the quality and quantity of yield. FI describes the productivity of a tree expressed as yield (in kg) on TCA (cm^2). This index can be calculated after finishing fruit harvest. However, the calculation of CD index is possible late in the spring, after fruit set, and it can be used as an important and valuable tool for considering accurate fruit thinning intensity and therefore to ensure high quality yield in the autumn. The negative correlation between CD and average fruit weight found in this study, as well as, the positive correlation between CD and yield, confirm the earlier findings of Webb et al. (1980), and Bergh (1990), Wertheim (1997) Lepsis and Blanke (2004). Since different cultivars, rootstocks and orchard systems were used in the above studies, one may assume that CD coefficients may be used universally under a wide range of environmental conditions and cultural practices. It is obvious that tree productivity does not depend solely on the trunk size or canopy dimensions. Photosynthesis depends on the total area of leaves on a tree, their condition and external conditions. Fruit thinning positively increase the ratio between leaf area and fruit number, resulting in increased availability of assimilates and potentially higher fruit quality at harvest (Palmer et al., 1991). In experiment with dry matter distribution in dwarf apples trees, subjected to various methods of thinning Giuliani et al (1997) showed that one fruit is fed by at least of $0.1m^2$ of leaf area. When the area of leaves is smaller, apples might not reach the required size. Too intensive thinning may reduce both yield and effectiveness of photosynthesis, which means that the productive potential of trees is not realized.

In the course of time, the average weight of fruit (at the same CD level) decreased (Fig. 4). This phenomenon results in the changeable proportion between the TCA and canopy volume. At the moment of tree planting, the distance between the trees is defined, what influences the canopy volume of an individual tree. To maintain the proper type and size of the crown, pruning is applied until the tree becomes mature, which in consequence, gives a constant volume of the crown with the growing trunk diameter (Fig. 5). In order to describe precisely the influence of the crop density level on the yield and average fruit weight, the multiple regression analysis involving the tree age was performed. The formula obtained can serve to determine a criterion for fruitlet thinning for the years to come. According to the formula 1, at the constant level of CD in the consecutive years (Y) of fruiting the average fruit weight (AFW) will diminish 5.1 g and the yield will increase at about 3.6 T/ha (2)

$$^{(1)}\ \mathbf{AFW\ (g) = 240{,}3 - 9{,}0^*\ CD - 5{,}1^*\ Y \quad (R = 0{,}71)}$$

$$^{(2)}\ \mathbf{Yield\ (T/ha) = -12{,}6 + 5{,}9\ CD + 3{,}6\ Y \quad (R = 0{,}77)}$$

On the basis of the formula, a nomograph was developed (Fig. 6) to determine the expected density of fruiting, which was necessary to obtain fruits with average weight of 150 or 160 g. For example, to get fruits with the average weight of 150 g in the thirteenth year of production, 2.8 fruitlets/cm^2 TCA is recommended; to get fruits of 160 g – the minimum CD should be 1.7 fruitlets/cm^2 TCA, respectively. The model indicates that in the sixteenth year of production it won't be possible to obtain yield with the average fruit weight 160 g.

CD can be useful for determining optimal number of fruits on a tree with an assumed size.

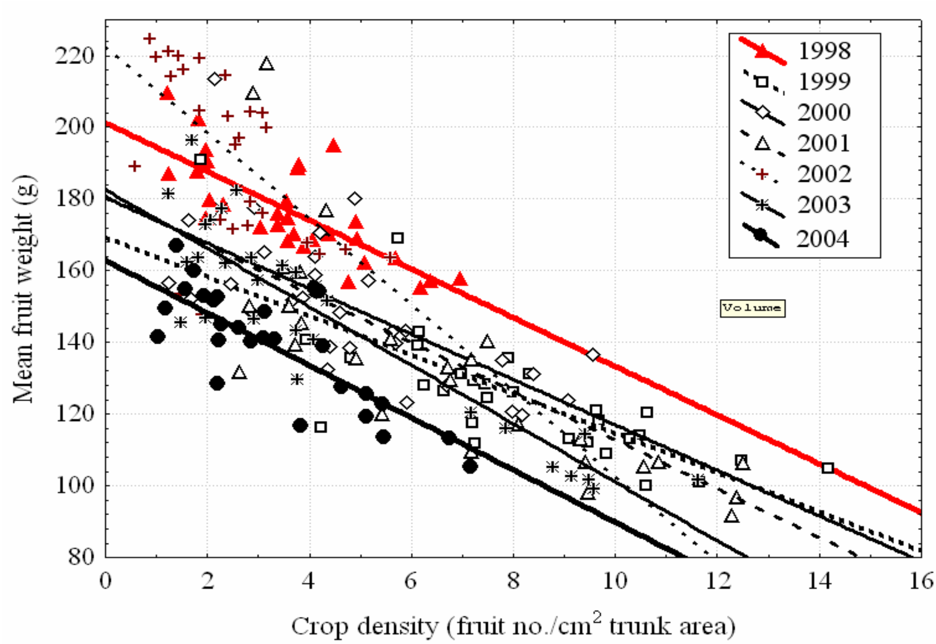

Figure 4. Effect of crop density on mean fruit weight

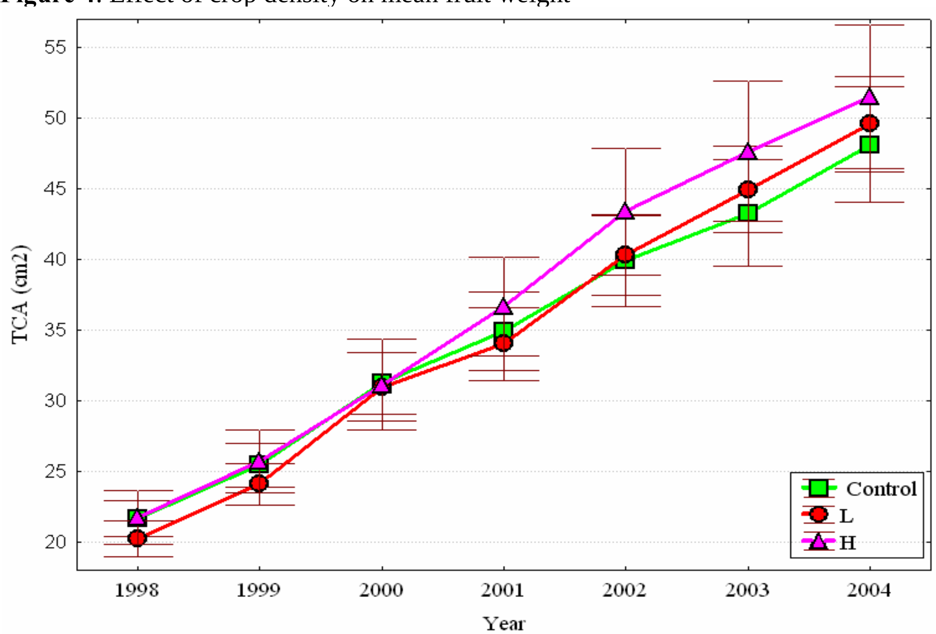

Figure 5. Trunk cross-section area of 'Gala' apple trees as affected by different thinning levels

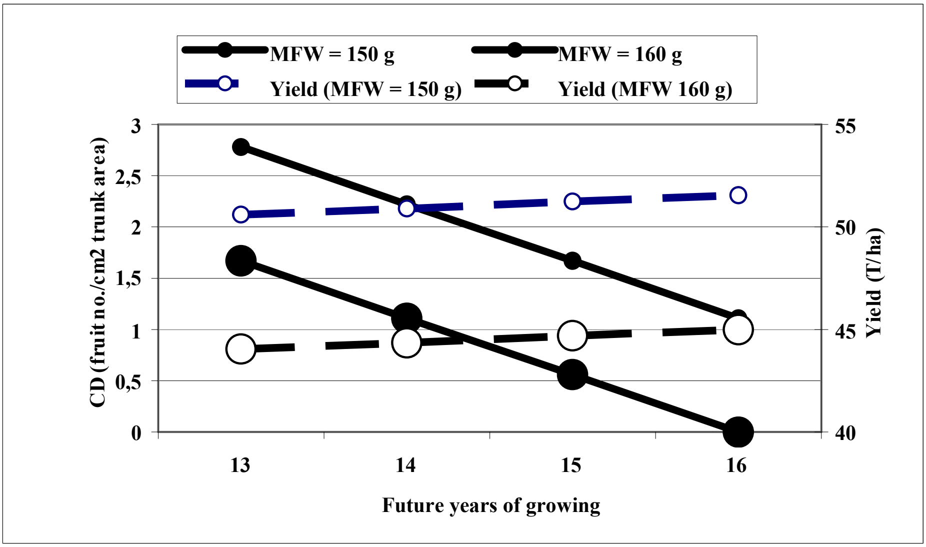

Figure 6. Simulated density of fruiting required to obtain fruit with mean weight (MFW) 150 or 160 g as dependent on tree age

Earlier thinning can result in a very large improvement in mean fruit weight at harvest (Johanson, 1994) and much greater return bloom (Byers, 2002). Jones et al. (1992) reported a linear decrease of 'Fuji' fruit size with delaying of hand thinning. The earlier thinning is performed, the bigger fruit can be obtained at the predetermined yield parameter (McArtney et al., 1996). Another important factor influencing the size of (Received/Accepted)fruit at the predetermined level of CD is the type of a rootstock used (White and Tustin, 2002; Marini et al., 2002).

In conclusion, further investigations should be carried out in order to introduce additional parameters to the above formula.. They should include, apart from CD and the tree age, the time of the thinning and rootstock used.

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ZALEŻNOŚĆ POMIĘDZY WSKAŹNIKIEM GĘSTOŚCI OWOCOWANIA A PLONOWANIEM I ŚREDNIĄ MASĄ OWOCÓW JABŁONI ODMIANY 'GALA'

Waldemar Treder

S T R E S Z C Z E N I E

Celem badań było określenie zależności pomiędzy wskaźnikiem gęstości owocowanie (WGO) wyrażonym liczbą owoców przypadających na cm^2 powierzchni przekroju poprzecznego pnia a plonowaniem oraz średnią masą owoców jabłoni odmiany 'Gala'. Drzewa w rozstawie 3,5 x 1,25 m posadzono w SZD Dąbrowice jesienią 1992 roku. Dla osiągnięcia dużego zróżnicowania zagęszczenia owocowania zastosowano dwa poziomy przerzedzania zawiązków oraz nieprzerzedzaną kontrolę. Otrzymane wyniki wykazują istotną dodatnią korelację pomiędzy poziomem WGO a plonowaniem drzew i ujemną korelację pomiędzy tym wskaźnikiem a średnią masą owoców. Dla szczegółowego opisania tych zależności wyznaczono parametry ich równań liniowych. Otrzymane formuły mogą być przyjęte jako wiarygodne kryterium przerzedzania zawiązków. Pozwalają one na wyznaczenie określonej liczby owoców na drzewie dla uzyskania zakładanej średniej masy owoców i wielkości plonu.

Słowa kluczowe: jabłoń, wskaźnik gęstości owocowania, 'Gala'