Relationships Between Yield, Crop Density Coefficient and Average Fruit Weight in 'Lobo' Apple Trees Under Various Planting Systems and Irrigation Treatments

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ADDITIONAL INDEX WORDS. crop density coefficient, planting systems, irrigation

SUMMARY. 'Lobo' apple (*Malus domestica*) trees grafted on Malling 26 (M.26) were planted on flat ground or on raised beds covered with black polyethylene. In both planting systems trees were drip irrigated to maintain soil water potential within the range of 0 to -0.02 MPa (0 to -0.3 lb/inch²) or were left without irrigation. Planting methods and irrigation influenced tree growth. Standard planted trees and irrigated trees grew stronger, whereas planted on beds less vigorously, irrespective to irrigation. The yield of all trees increased with time until the fourth year of production. Fruit size decreased as yield increased. Also lack of irrigation considerably reduced average fruit weight. Yield and trunk cross-sectional area (TCA) measurements were used to calculate crop density coefficient (CD). CD values varied considerably between the treatments showing their dependence on planting method, irrigation and tree age. In most cases, the correlation coefficient between CD and average fruit weight were negative, indicating

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that the weight of individual fruit decreased with increasing numbers of fruit per unit of TCA. We question whether CD coefficient may be universally used under wide range of environmental conditions and cultural practices.

Fruit growers must continuously improve their orchard cultural practices to meet the growing consumers demands for better quality fruit. Consumer perceptions of what constitutes optimal fruit size vary between cultivars. Marketing surveys in the Warsaw region of Poland by Zmarlicki (1996) showed that 64% of respondents preferred medium-sized apples [75 mm (3.0 inches) diameter], but 8.3% did not have any particular preferences regarding the size of apples. Results like these must be taken into account by fruit producers if they wish to remain competitive.

Consistent production of fruit with optimum color and size can be accomplished only when proper balance between vegetative growth and fruiting is maintained. Frequently, apple trees bloom abundantly and set too many fruit, to maximize fruit size and return bloom. That is why fruit thinning is considered the single, most important cultural practice affecting fruit quality and cropping consistency (Basak, 1993; Forshey, 1971; Johnsen, 1987; Williams, 1994). Currently, laborious hand thinning (Bergh, 1990;

Goffinet et al., 1995; McCartney et al., 1996), chemical (Byers and Carbaugh, 1991) and mechanical thinning are practiced (Stadler et al., 1996; Strimmer et al., 1997). 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. According to Forshey (1971), thinning should be performed in a way that guarantees mature fruit will attain the desired size. It is necessary that very precise criteria be used to judge the effectiveness of thinning. A number of researchers point out that there is a negative correlation between fruit load and fruit size. Heavy fruit loads reduce fruit size (Webb et al., 1980; Zhang et al., 1992; Rom, 1994; Osterreicher et al., 1998). However, a certain minimal number of fruit per tree are needed to assure satisfactory yields (Forshey and Elfing, 1977; Silbereisen, 1983; Zhang et al., 1992). Thus, excessive thinning may result in lower yields and profits. The studies by Webb et al. (1980), Bergh (1990), and Byers et al. (1991), indicate that the number of fruit per unit of trunk circumference or TCA may be the best predictor of proper crop load.

The aim of this study was to quantify the interrelationship between the CD (number of fruit produced per unit of TCA) (Lamb 1972, Lombard et al. 1988), average fruit weight, and yield of apple trees as affected by planting systems and irrigation.

Materials and methods

The experiment was conducted in the experimental orchard of the Research Institute of Pomology and Floriculture in Skierniewice from 1992 to 1997. 'Lobo' apple trees grafted on M.26 rootstock were planted in 1992 at 3.5 (XtimesX) 0.3 m (5 (XtimesX) 1 ft) spacing. Two methods were used to plant the trees: 1) standard planting on flat ground, or 2) planting on raised beds in order to speed up fruiting. Planting on beds consisted of placing the roots on the ground surface, covering them with peat to form a ridge and then covering the ridge, with a black plastic film (Fig. 1). The trees were either drip irrigated or received no supplemental irrigation. Polyethylene irrigation lines were equipped with emitters delivering 1.75 L·h⁻¹ (0.46 gal/h) and spaced at 0.5 m (1.5 ft) intervals. Irrigations were scheduled to maintain soil water potential within the range of 0 to -0.02 MPa as measured with tensiometers at 30 cm (11.8 inches) depth. Planting without irrigation was considered the control. The experiment was arranged into a 2 (XtimesX) 2 factorial split plot with planting method constituting main plots and irrigation constituting sub-plots. Each replication (experimental unit) consisted of one tree and each planting/irrigation treatment had 14 replications. Every year all fruit on each tree were counted and weighted. TCA was determined on each tree annually from two perpendicular trunk diameter measurements 30 cm above ground.

The rainfall distribution and air temperatures during the 1992-97 fruit growing seasons were recorded (Fig. 2). To mark drought periods, it was assumed after Walter and Lieth (1970) that 1 °C (1.8 °F) equals 4.5 mm (0.18 inches) of evaporation. The first 4 years of the experiment were dry but periods of excessive rainfall occurred in the last 2 years of study during which water supplies far surpassed plant water needs. In 1996, the precipitation was above average for the entire growing season, whereas in 1997 drought persisted in the second half of the summer.

Results and discussion

During 6 years of the experiment, irrigation significantly affected tree growth expressed as TCA (Table 1). Planting method also influenced

Fig. 1. Planting systems of 'Lobo' apple trees.

Fig. 2. Climatic graph of Skierniewice, Poland. To mark drought periods 1 °C (1.8 °F) equals 4.5 mm (0.18 inches) of evaporation; °F = 1.8(°C) + 32; 25.4 mm = 1.0 inch.

Table 1. Trunk cross-sectional area (TCA) of 'Lobo' apple trees planted on raised beds (P₁) and on flat ground (P₂) and drip irrigated (I₁) or grown without irrigation (I₂)

Factor	Year					
	1992	1993	1994	1995	1996	1997
Planting systems (P)						
On bed (P ₁)	1.16	1.95	2.40	3.66	4.33	5.15
Standard (P ₂)	1.20	2.11	2.81	4.37	5.12	6.05
Significance	NS	NS	**	**	*	*
Irrigation (I)						
Irrigation + (I ₁)	1.88	2.55	3.76	5.19	5.98	6.87
Control (I ₂)	0.87	1.50	1.85	2.91	3.47	4.35
Significance	***	***	***	***	***	***
P (XtimesX) I	NS	NS	NS	*	*	*

NS, **, ***, *** Nonsignificant or significant at P (XtimesX) 0.1, 0.05, or 0.001.

Table 2. Yield of 'Lobo' apple trees planted on raised beds (P₁) and on flat ground (P₂) and drip irrigated (I₁) or grown without irrigation (I₂).

Factor	Year				
	1993	1994	1995	1996	1997
Planting systems (P)					
On bed (P ₁)	8.63	17.38	23.25	36.58	17.11
Standard (P ₂)	7.18	18.91	20.59	41.56	17.38
Significance	NS	NS	NS	NS	NS
Irrigation (I)					
Irrigation + (I ₁)	10.06	23.74	27.17	43.17	21.13
Control (I ₂)	5.75	12.56	16.67	34.97	13.36
Significance	**	***	**	*	*
P (XtimesX) I	NS	NS	NS	NS	NS

NS, **, ***, *** Nonsignificant or significant at P (XtimesX) 0.1, 0.05, or 0.001.

growth of the trees, but significant differences were visible from third year after planting. Trees planted on bed showed less trunk increment. Dutch fruit growers growing dwarf apple trees

on very rich soil sometimes try to suppress additional growth by planting trees on beds covered with polyethylene. This planting method appeared to be effective in restricting

growth in this trial. It is also believed that shallow planting with bed forming may induce early bearing. This effect was not observed. According to Sako and Laurinen (1986), planting trees on low ridges covered with plastic film was a useful method under conditions in Finland. Such trees had better growth, productivity, and winter-hardiness than trees grown on flat ground. The better performance of trees on ridges was attribute to more favorable moisture conditions and higher soil temperature compared with trees on flat ground.

From the third year after planting the trees, an interaction between planting method and irrigation was observed. The irrigated trees planted in the traditional method had the greatest TCA. The annual yield of all the trees increased with the time, until the fourth year from planting (Table 2). In the following year, all trees produced less fruit due to weather conditions. Irrigation was the only factor that influenced the yield. The yield of the irrigated trees was significantly higher than nonirrigated trees.

The level of production significantly affected fruit size (Table 3). The largest fruit were produced in the first year of fruiting. Average fruit weight decreased in subsequent years. Lack of irrigation reduced average fruit weight considerably in the years of lowest rainfall, 1993, 1994, and 1995.

The number of apples per tree and TCA measurements were used to calculate CD in all cropping years (Fig. 3). CDs differed considerably from year to year and between the irrigated and nonirrigated treatments. The lowest CD values were observed in the first year of cropping when average fruit weight was the highest. Generally, CD values were lower in irrigated than nonirrigated trees. Correlation coefficients between CD and yield were positive in all the years (Table 4) indicating that the higher the level of yield, the higher CD. In most cases, correlation coefficients between CD and average fruit weight were negative, indicating that the weight of individual fruit decreased with an increasing number of fruit per unit of TCA. However, this was not true in the first production year for the trees that were irrigated and standard-planted as well as for the trees that were nonirrigated and planted on beds. This response was expected, as CD was very low in these two treat-

Fig. 3. Crop density coefficient (CD) of 'Lobo' apple trees planted on raised beds (P₁) and on flat ground (P₂) and drip irrigated (I₁) or grown without irrigation (I₂). CD = number of fruit per unit of trunk cross section area (TCA).

Table 3. Effect of planting 'Lobo' apple trees on raised beds (P₁) and on flat ground (P₂) and drip irrigated (I₁) or grown without irrigation (I₂) on mean fruit weight.

Factor	Year				
	1993	1994	1995	1996	1997
Planting systems (P)					
On bed (P ₁)	203	140	144	129	145
Standard (P ₂)	212	144	137	119	135
Significance	NS	NS	NS	NS	NS
Irrigation (I)					
Irrigation + (I ₁)	226	168	157	128	156
Control (I ₂)	189	117	124	119	129
Significance	***	***	***	NS	NS
P (XtimesX) I	NS	NS	NS	NS	NS

NS, Nonsignificant or significant at P (XtimesX) 0.1, 0.05, or 0.001.

ments; thus, there was little or no competition between fruit.

Optimal CD values required to produce fruit averaging 75 mm in diameters were calculated using fruit weight versus CD regression equations. These equations were developed for all the treatments and years of the study (Table 5). It was assumed that 75 mm was the most desirable fruit diameter from the standpoint of the consumer. Fruit of this diameter weighed approximately 148 g (5.2 oz) based on the previously established relationship between the weight and diameter of individual 'Lobo' apples [diameter in millimeters = $52.44 + 0.153x$ (weight in grams), $r = 0.96$]. Data for the first cropping year were

excluded from these calculations since the fruit produced that year were larger than 148 g.

The calculated optimal CD values varied among the treatments and years of study; thus, showing their dependence on planting method, irrigation, and tree age (Fig. 4). During the drought of 1994 and 1995, the trees that were nonirrigated and planted on beds were unable to produce apples averaging 148 g. However, under normal or excessive precipitation in 1996 and 1997, the same trees could produce such fruit when CD values were less than 3 fruit/cm² TCA.

In the trees that were standard-planted and nonirrigated, the calculated optimal CD values varied from

2.64 to 4.25 fruit/cm² TCA depending on the year of study (Fig. 4). During the period 1994-96, the calculated optimal CD values in the trees that were irrigated and planted on bed, were higher than in the rest of the treatments; the highest value of 7.84 fruit/cm² TCA was recorded in 1995. In 1997, however, the same trees produced small fruit of poor quality and their optimal CD value dropped to 0.41 fruit/cm² TCA. In the trees that were standard-planted and irrigated, the calculated optimal CD values decreased over the course of study from 6.12 to 1.60 fruit/cm² TCA.

The calculated optimal CD values (Fig. 5) and yield versus CD regression equations (Table 5), were used to estimate trees' potential to produce apple crops whose individual fruit averaged 148 g (Fig. 5). In low precipitation years (1994 and 1995), the trees that were nonirrigated and planted on beds could not produce such crops. During the same period, however, nonirrigated and standard-planted trees could produce light crops of fruit in this size category. Using this model, we estimated that in 1994 and 1996, respectively, nonirrigated, standard-planted trees could maximally produce 9 and 26 t·ha⁻¹ (4.0 and 11.6 tons/acre) of apples in the 148 g size category. These 2 years were characterized by low and high precipitation amounts, respectively. The trees that were irrigated and planted on beds could maximally produce 30, 41, 36, and 8.5 t·ha⁻¹ (13.4, 18.3, 16.1, and 3.8 tons/acre) of apples in this size category in 1994, 1995, 1996, and 1997, respectively. Similar estimates for irrigated standard trees were 32.5, 32.5, 27.0, and 18 t·ha⁻¹ (14.5, 14.5, 12.0, and 8.0 tons/acre).

The present data confirm with the results obtained by Treder and Mika (1996), that showed that standard-planted 'Szampion' and 'Gala' apples trees grafted on M.9 rootstock responded positively to irrigation. The lack of irrigation had a restrictive effect on the growth of those trees. The effectiveness of drip irrigation in increasing apple productivity under climatic conditions in Poland was also reported by Pacholak and Wisniewski (1994), and Treder et al. (1992, 1993). Also, the present work underscores the positive influence of irrigation on fruit size.

The relationship between yield

Fig. 4. Determined levels of crop density coefficient (CD) to obtain fruit weighing 148 g (5.2 oz) each [75 mm (3 inches) diameter]; CD = number of fruit per unit of trunk cross section area (TCA).

Fig. 5. Determined levels of apple yield based on the assumed value of the crop density coefficient (CD) to obtain fruit weighing 148 g (5.2 oz) each [75 mm (3 inches) diameter]; CD = number of fruit per unit of trunk cross section area (TCA); 1 t·ha⁻¹ = 0.45 ton/acre.

and average fruit weight found in this study was previously reported by Webb et al. (1980), Zhang et al. (1992), and Osterreich et al. (1988). The range of CD values reported in this study overlap those given by Lombard et al. (1988). Since different cultivars, rootstocks, and orchard systems were used in the above studies, one may assume that CDs may be used universally under a wide range of environmental conditions and cultural practices. The negative correlation found in this study between CD and average fruit weight as well as the positive correlation between CD and yield, confirms the earlier findings by Webb et al. (1980), and Bergh (1990). In Holland,

Wertheim (1997) reported CD values to vary from 3 to 6 fruit/cm² TCA in 'Red Elstar' apple trees grown on dwarf rootstocks. The weight of individual fruit in this experiment varied from 140 to 210 g (4.9 to 7.4 oz). In a similar study in Norway, CD values less than 4 fruit/cm² TCA were reported for young 'Gravenstein' and 'Aroma' apple trees grafted on dwarf and semidwarf rootstocks (Ystaas et al., 1997). In Australia, James (1997) compared productivity of three apple cultivars, Royal Gala, Braeburn, and Red Fuji, grafted on dwarf and semidwarf rootstocks. CD for the young trees of the first two cultivars varied from 3 to 6 fruit/cm² TCA, whereas

the average fresh fruit weight was about 150 g (5.3 oz) for 'Royal Gala' and 250 g (8.8 oz) for 'Braeburn.' The data obtained in the present experiment, with the assumption that fresh fruit weight should be 148 g, are similar.

With reliable data, CD might be a useful instrument for evaluating optimal density of fruit in the crown of a tree during thinning. It is obvious that tree productivity does not depend solely on trunk size or canopy dimensions. Photosynthesis depends on the total area of leaves on a tree, their condition, and external conditions. Giuliani et al. (1997) investigating the distribution of dry matter in dwarf apples subjected to various methods of thinning. They stated that 5-year-old apple trees might reach CD of about 9 fruit/cm² TCA at average fresh fruit weight of about 200 g (7.1 oz), provided that one fruit is fed by at least 0.1 m² (1.1 ft²) of leaf area. When the area of leaves is smaller, apples might not reach the required size. Fewer than three fruit per 1.0 m² (10.8 ft²) of leaves, results in reduced rates of photosynthesis caused by insufficient metabolism of its products. Too intensive thinning may reduce both yield and effectiveness of photosynthesis, which means that the productive potential of trees is not realized.

Observing different models of orchards indicated the dependence of the total area of leaves of a tree on the capacity of its canopy and diameter of its trunk. Due to the difficulties in the practical determination of the leaf area on a tree, the cross section area of its trunk can be an indirect parameter determining its yield potential. CD can be useful for determining optimal number of fruit on a tree for an assumed size.

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Table 4. Linear correlation coefficients between crop density and yield or crop density and average weight of individual fruit in 'Lobo' apples as influenced by two planting systems and two irrigation treatments

Treatment	Year				
	1993	1994	1995	1996	1997
Standard planting					
Yield	0.96	0.60	0.76	0.54	0.89
Fruit weight	NS	-0.58	-0.76	-0.87	-0.65
Standard planting + irrigation					
Yield	0.86	0.86	0.92	0.77	0.87
Fruit weight	-0.46	-0.62	-0.63	-0.69	0.37
Planting on bed					
Yield	0.97	0.57	0.84	0.84	0.82
Fruit weight	-0.79	-0.31	-0.73	0.83	-0.81
Planting on bed + irrigation					
Yield	0.95	0.76	0.84	0.9	0.89
Fruit weight	NS	-0.52	-0.6	-0.79	-0.71

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Table 5. Linear regression equations ($Y = a + bX$) describing the relationship between average fruit weight and crop density or yield and crop density in 'Lobo' apples under various planting and irrigation treatments. Y denotes average fruit weight or yield; X denotes crop density.

Year	Treatment	Avg fruit wt		Yield	
		a	b	a	b
1993	Standard planting	0.18	0.0016	0.25	2.66
	Planting on bed	0.23	-0.0116	1.92	1.79
	Standard planting + irrigation	0.23	-0.0045	1.79	3.88
	Planting on bed + irrigation	0.26	-0.0116	3.81	3.01
1994	Standard planting	0.17	-0.0053	5.77	0.94
	Planting on bed	0.13	0.0018	2.03	1
	Standard planting + irrigation	0.23	-0.0138	6.5	3.82
	Planting on bed + irrigation	0.2	-0.0084	7.92	3.94
1995	Standard planting	0.16	-0.0048	8.51	1.9
	Planting on bed	0.15	-0.0033	6.11	2.04
	Standard planting + irrigation	0.21	-0.0073	8.45	4.19
	Planting on bed + irrigation	0.18	-0.007	3.38	6.07
1996	Standard planting	0.17	-0.0045	18.39	1.95
	Planting on bed	0.16	-0.004	5.74	3.00
	Standard planting + irrigation	0.21	-0.0084	9.14	3.94
	Planting on bed + irrigation	0.16	-0.0062	15.18	4.96
1997	Standard planting	0.18	-0.01	2.09	3.40
	Planting on bed	0.17	-0.009	7.31	2.48
	Standard planting + irrigation	0.23	-0.200	6.72	4.57
	Planting on bed + irrigation	0.15	-0.0038	9.10	5.70

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