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Effects of Different Pruning Systems on Fruit Yield and Quality in Plum (*Prunus salicina* Lindl.)

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ABSTRACT

This study was established at the experimental field of Horticulture Department of Çukurova University in Adana, Turkey during 2013-2015 harvest period two consecutive years. Two plum cultivars (‘Black Diamond’, ‘Angeleno’) and Friar as pollinizer grafted on Myrobolan rootstock were used as plant material. Trees produced commercially good yield in 2014, at the fourth growing season. The aim of this study was to compare four different pruning systems (spindle, 4 leader-Quad-V, central leader and open vase) and six different planting distances (0.8-1-1.2-1.6-2- 4 m and standard inter rows 4 m) for yield (ton ha^{-1}) on several fruit quality variables such as (fruit weight, firmness, fruit flesh/seed weight, TSS, TA). Morphological and phenological characters were observed and chilling accumulation of the study area was determined. Sufficient chilling accumulation was calculated in both years regarding fruit crop load. The best results for quality characteristics were obtained from Spindel (1.2x4 m) high density pruning system for both cultivars. Also, ‘‘Black Diamond’’ cultivar on Spindel (1.2 m) gave the highest fruit weight (110.4 g) and yield (62.27 ton ha^{-1}).

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Introduction

Recently, Japanese plum (*Prunus salicina* Lindl) is one of the most preferred plums by the consumers and fresh market. Also, plum is an important fruit in the world with about 6000 cultivars and 19-40 species (Riger, 2006; Blazek, 2007). A successful plum orchard depends on cultivars, growing conditions and training system. Especially, Mediterranean region of Turkey has suitable growing conditions for Japanese plums. In this region, ‘Santa Rosa’ and ‘Formosa’ have been the most preferred plum cultivars until 2000. In Turkey, among the stone fruits, the importance of plums is coming after cherry, peach and apricot. Total plum production of Turkey is 265490 tones (TÜİK, 2015). Due to important amount of carotenes, fibrous and anthocyanins content of plums, this fruit plays a crucial role in human diet (Sommano et al., 2013). Therefore, especially black plum cultivars are chosen by consumers. Recently, great confusion has been observed in pruning and planting density of plums at the Mediterranean region. Desired production has not been reached yet because of erroneous planting and pruning applications. Generally, classical pruning methods have been used in the orchards. Nowadays, together with the increase on the production of Japanese plum cultivars a necessity was observed to find out the suitable pruning methods for the ecological demands of those cultivars, which were newly introduced to the country and there was no sufficient information about pruning technics.

Pruning holds very crucial role for both decreasing juvenility period and increasing productivity and quality of fruit trees (Ashraf and Ashraf, 2014). It has been stated by a great number of researchers that pruning intensity directly affects offshoot developments (Hassani and Rezaee, 2007; Salem et al., 2008; Demirtas et al., 2010). It was stated that peach trees treated by hard pruning, offshoot development is ceased at the end of May but for other trees, it prolongs till to the end of June (Fukuda et al., 2002). It was observed that trees commence fruiting at late ages in case of nonpruning or hard pruning of peach trees (Miller and Byers, 2000).

An experiment was conducted to evaluate the phenological and pomological characteristics of 14 Japanese plum (*Prunus salicina*) cultivars in Mut-Mersin province of Turkey between 2008 and 2009 by Son (2010). The researcher reported that the highest fruit weight was obtained from 'Black Diamond' cultivar and the fruit ripening was the latest in 'Angeleno' than the others.

Mika et al. (2015) investigated the performance of four different planting density (4.0 m × 1.5 m, 4.0 m × 2.0 m, 5.0 m × 2.5 m ve 6.0 m × 3.0 m) with the application of Spindel, Selender Spindel and combined methods on four different varieties (*C. lepotitsa*, Stanley, Bluefre and President) grafted on Myrobalan rootstock. According to the results, 4.0 m × 2.0 m and 5.0 m × 2.5 m (800-1200 trees/hectare) were found to be the most efficient planting densities which were also diminishing the labor costs.

Many researchers stated that soil structure, rootstocks and cultivars altogether affects the planting density and should be considered altogether (Jackson et al., 1987; Mika et al., 1997; Morgas et al., 1998; Hrotkó et al., 2004; Gonda, 2006). Hrotkó et al. (2002) stated that plum orchards were increasing but there was lack information on pruning and other technical methods. Researchers emphasized on the necessity for the plantation of plum orchards in dwarf system to increase fruit quality, facilitate the harvest and decrease the labor costs. Constructed shape in pruning allows air entrance into the crown and increases the success percentage of disease and pest control (Simon et al., 2006, 2007). Similarly, there is a positive relation between the light entrance into the crown and coloring (Ferree and Schupp, 2003). Usage of pruning system in accordance with the ecological conditions, soil types and cultivar characteristics and giving correct information to the growers plays an important role in plum production of Turkey. Success in pruning systems may be changed according to cultivar, labor costs, fruit price and location (Lespinasse and Delort, 1986; Tustin et al., 1997; Lauri et al., 2008). Cultivars may response different in various pruning systems. However, it was observed that pruning systems might change biological characteristics of cultivars such as fertilization time, flowering density and fertilization percentage (Stephan et al., 2008).

This study was carried out for two years (2013-2015) with two plum cultivars at the experimental orchard of Horticulture Department of Çukurova University. The main objectives of this study was to establish a rapid canopy, high fruit quality and yield at early period by using most efficient pruning treatment and planting densities.

Materials and Methods

Plant Material

In this experiment, four pruning systems and four different planting densities were used. Tree spaces were arranged as 80-120-160-200 cm for Spindle and 4 leader Quad-V pruning system. Also, central leader and open vase pruning systems were established as 100-200-400 cm on two plum cultivars ('Black Diamond', 'Angeleno' and 'Friar' as pollinizers) grafted on Myrobolan rootstock. A total of 480 trees were used in the experiment. For the all pruning system, tree height were arranged about 2.5-3 m during the experiment.

Phenological Observations

Budbreak dates were recorded at 50% of budbreak, first bloom (min. 5% flowers were open) and full bloom date was recorded at the time as 90% of the flowers were open. Harvesting date (maturity) was detected by color change (from green to red and black) (Son, 2010).

Chilling Accumulation of the Experimental Area

The chilling accumulation of the experimental area was calculated by using chilling hours (Chill Unit) and standard method model (Linkosalo et al., 2008). The chilling accumulation of the area was calculated daily maximum and minimum temperatures of 24h by using a computer program according to the Richardson's chill unit, using asymcur curve model (Anderson and Richardson, 1987; Küden et al., 1997). In order to budbreak, trees need to fulfill their chilling requirement (Campoy et al., 2011).

Pomological Analysis

Fruit pomological analysis such as fruit weight (g) was carried out by using a digital scale (Shinko DJ-600E, Japan precision (0.1 g)) Total soluble solids (TSS) content was measured by digital hand refractometer (ATC-1. Atago, Tokyo, Japan). Fruit firmness (lb) was determined by a penetrometer (N.O.W. FHR-5. Tokyo Japan) equipped with an 8 mm cylindrical plunger on two opposite faces of the equatorial zone, after skin removal of the equatorial zone. Titratable acidity (TA) was determined by using an automatic titration apparatus (877 Titrino plus, Metrohm, Herisau, Switzerland) with 0.1 mol L^{-1} NaOH up to pH 8.1 and results were shown as g malic acid 100 ml^{-1} (Son, 2010). Flesh/seed ratios was calculated from fruit flesh weight/seed weight. Growth and vigour of the trees were measured yearly in October at the end of the growing season by calculating the cross-section area of the trunk (TCSA) 20 cm above the graft (Layne, 1994; Lepsis and Blanke, 2006).

Statistical Analysis

The experiment was carried out with three replications. Percentage data were arcsine-transformed before performing an analysis of variance (ANOVA). Means separation was determined by LSD test. Statistical analyses were carried out using JMP 5.0.1 version.

Results and Discussion

At the result of study, no significant difference on phenological observations was observed at different pruning and planting density systems in 2014-2015 season, except only 5-10 days earliness on blooming stages (Table 1). Harvest time for 'Black Diamond' cultivar was on 22-24 July and for 'Angeleno' was on 19-21 September (Table 1). These phenological observations are consistent with the other studies carried out in different ecological regions of Turkey (Balık, 2004; Çalışkan et al., 2006; Son, 2010). These researchers also found that 'Angeleno' and 'Black Diamond' ripen in September and in July, respectively. Cold accumulation of the region satisfied the requirements of the cultivars for both seasons (Table 2). The mean values of the pomological characters of the fruits in 2014-2015 season were given in Table 3, 4 and 5. The results showed that different pruning and tree spacing resulted with minor

differences on the pomological parameters such as fruit weights seed/flesh ratio, firmness, TSS, and total acidity (TA). No significant differences were found in both cultivars, except fruit weight of Black Diamond. The soluble solid ratio of the plums was generally high. The values ranged between 14.5-17.5 ('Angeleno') and 17.3-17.5 ('Black Diamond'). Similar results were measured in total acidity (TA). The highest fruit weight was determined in Black Diamond cultivar with spindel pruning system application (1.2×4 m) as 110.4 g. Moreover, fruit weight ranges of 'Black Diamond' and 'Angeleno' cultivars were 90.8-110.4 g and 69.42-72.85 g, respectively. This data was similar to the results of Son (2010) who indicated that fruit weight of 'Black Diamond' and 'Angeleno' was 91.26 g and 67.09 g, respectively. Also in another study carried out by Çalışkan et al. (2006), fruit weight of 'Black Diamond' was determined as 91.26 g. In terms of flesh/seed ratio, TSS and TA values did not show a significant difference and flesh/seed ratio (%) was determined between 34.1-34.7% ('Black Diamond') and 35.72-35.89 ('Angeleno'). The lowest fruit firmness ratio was obtained from 'Black Diamond' cultivar and the values ranged between 5.50-5.59 lb, while the highest ratio was observed in 'Angeleno' with 8.3-8.5 lb (Table 2). Also, TSS and TA values were ranged between 14.5-17.5% (TSS), 3.40-3.54% (TA) at 'Black Diamond' and 15.0-17.5% (TSS), 5.10-5.20% (TA) 'Angeleno' cultivar, respectively. These results are in accordance with the results of Balık (2004), Çalışkan et al. (2006) and Son (2010). All pomological analysis results were found to be similar with the results of Son (2010). Also, Çalışkan et al. (2006) examined 15 plum cultivars at Erdemli provice of Turkey. Different pruning systems, tree densities, climatic conditions and management practices could be the reason for differences.

The trunk cross-section area (TCA) was mainly affected by spacing and cultivar. For the spindle and 4 leader Quad V training systems, the TCA increased significantly depending on tree spacing ranged between 52.51-105.49 cm^2 ('Black Diamond') and 59.68-122.6cm^2 ('Angeleno'). According to our results, significant differences were found in cumulative yield, especially between pruning system and tree spacing combinations (Table 4). The highest cumulative yield (ton ha^{-1}) was obtained from Spindel system (1.2×4m) for both cultivars ['Black Daiamond' (62.27 ton ha^{-1}) and 'Angeleno' (53.04 ton ha^{-1})], while the lowest yield was recorded in Central Leader (4×4 m) pruning system for both cultivars with 30.34 and 27.77 ton ha^{-1}, respectively.

Table 1 Phenological observations

Cultivars	Bud Break Date		First Bloom Date		Full Bloom Date		Harvesting Date	
	2014	2015	2014	2015	2014	2015	2014	2015
B. Diamond	25.02	20.02	08.03	03.03	12.03	10.03	24.07	22.07
Angeleno	29.02	25.02	11.03	07.03	15.03	14.03	20.09	19.09
Friar	27.02	22.02	09.03	05.03	13.03	12.03	22.07	12.07

Table 2 Chilling accumulation of the experimental area in 2013-2015 winter periods

Months	2014 (2013-2014 Period)		2015 (2014-2015 Period)	
	Hours below (45°F)	Chill Unit (CU)	Hours below (45°F)	Chill Unit (CU)
November	71	2	6	36
December	62	83	233	39
January	187	74	159	137
February	118	41	134	104
March	73	15	44	30
Total	511	215	576	346

Table 3 Effect of different pruning system and tree space on pomological characters

Black Diamond	Fruit weight (g)	Seed /Flesh Ratio (%)	Firmness (lb)	TSS (%)	Total Acidity (%)
Spindel 0.8 × 4 m	100.40[a]	34.3	5.52	17.3	3.42
Spindel 1.2 × 4 m	110.40[a]	34.1	5.51	17.5	3.43
Spindel 1.6 × 4 m	98.20[b]	34.7	5.59	17.5	3.40
Spindel 2 × 4 m	94.68[b]	34.6	5.50	17.4	3.42
4 Leader Quad - V 0.8 × 4 m	97.20[b]	34.5	5.51	17.4	3.42
4 Leader Quad - V 1.2 × 4 m	105.60[a]	34.3	5.52	17.3	3.54
4 Leader Quad - V 1.6 × 4 m	108.50[a]	34.3	5.53	17.4	3.51
4 Leader Quad - V 2 × 4 m	106.50[a]	34.9	5.51	17.5	3.51
Goble 1 × 4m	96.20[b]	34.8	5.53	17.4	3.42
Goble 2 × 4 m	105.80[a]	34.2	5.54	17.3	3.43
Goble 4 × 4 m	104.60[a]	34.6	5.54	17.2	3.44
Central Leader 1 × 4 m	90.80[b]	34.5	5.52	17.3	3.54
Central Leader 2 × 4 m	106.20[a]	34.3	5.51	17.5	3.54
Central Leader 4 × 4 m	104.20[a]	31.6	5.52	17.5	3.52
$LSD_{0.05}$	6.20	3.42[ns]	0.12[ns]	0.95[ns]	0.18[ns]

ns: Non significant

Table 4 Effect of different pruning systems and tree spaces on pomological characters

Angeleno	Fruit weight (g)	Seed /Flesh Ratio (%)	Firmness (lb)	TSS (%)	Total Acidity (%)
Spindel 0.8 × 4 m	69.42	35.80	8.5	16.5	5.10
Spindel 1.2 × 4 m	70.27	35.72	8.9	17.5	5.15
Spindel 1.6 × 4 m	70.42	35.85	8.6	16.0	5.15
Spindel 2 × 4 m	71.48	35.82	8.6	16.0	5.20
4 Leader Quad - V 0.8 × 4 m	69.74	35.89	8.7	16.5	5.10
4 Leader Quad - V 1.2 × 4 m	69.32	35.78	8.5	15.5	5.12
4 Leader Quad - V 1.6 × 4 m	69.25	35.77	8.8	17.5	5.11
4 Leader Quad - V 2 × 4 m	72.45	35.86	8.4	15.0	5.14
Goble 1 × 4m	69.52	35.89	8.5	15.0	5.13
Goble 2 × 4 m	69.95	35.86	8.5	15.0	5.12
Goble 4 × 4 m	72.85	35.87	8.4	14.5	5.15
Central Leader 1 × 4 m	70.88	35.83	8.5	15.0	5.13
Central Leader 2 × 4 m	71.35	35.84	8.5	15.5	5.14
Central Leader 4 × 4 m	72.34	35.82	8.3	15.0	5.15
$LSD_{0.05}$	3.25ns	0.85ns	0.72ns	1.55ns	0.15ns

ns: Non significant

Table 5 Effect of different pruning systems and tree spaces on TCSA and yield

Pruninig System and Tree Spacing	TCSA (cm^2)		Yield (kg $tree^{-1}$)		Yield (ton ha^{-1})	
	B.D	A	B.D	A	B.D	A
Spindel 0.8 × 4 m	54.23^{cd}	59.68^{d}	16.90^{e}	15.8^{g}	52.72^{b}	49.29^{b}
Spindel 1.2 × 4 m	57.18^{cd}	64.12^{cd}	31.15^{b}	25.5^{e}	62.27^{a}	53.04^{a}
Spindel 1.6 × 4 m	57.45^{cd}	63.69^{cd}	35.40^{b}	26.5^{d}	55.22^{b}	41.34^{c}
Spindel 2 × 4 m	71.45^{c}	74.25^{c}	41.30^{a}	28.4^{d}	51.62^{b}	35.50^{e}
4 Leader Quad - V 0.8 × 4 m	52.15^{cd}	58.85^{d}	15.30^{e}	13.7^{h}	47.73^{b}	42.74^{c}
4 Leader Quad - V 1.2 × 4 m	56.15^{cd}	62.38^{cd}	24.85^{c}	21.3^{f}	51.68^{b}	44.30^{c}
4 Leader Quad - V 1.6 × 4 m	57.38^{cd}	68.45^{c}	30.23^{b}	21.5^{f}	47.15^{b}	33.54^{e}
4 Leader Quad - V 2 × 4 m	70.12^{c}	73.38^{c}	40.81^{a}	27.6^{d}	51.01^{b}	34.50^{e}
Goble 1 × 4m	64.12^{c}	65.12^{c}	17.60^{e}	15.5^{g}	44.00^{b}	38.75^{d}
Goble 2 × 4 m	72.24^{c}	76.23^{c}	36.75^{b}	31.3^{c}	45.93^{b}	39.12^{d}
Goble 4 × 4 m	78.12^{c}	86.74^{b}	48.95^{a}	42.5^{a}	31.90^{c}	27.20^{f}
Central Leader 1 × 4 m	73.93^{c}	78.3^{c}	20.15^{d}	17.5^{g}	50.37^{b}	43.75^{c}
Central Leader 2 × 4 m	89.45^{b}	95.24^{b}	39.45^{b}	35.4^{b}	49.31^{b}	44.25^{c}
Central Leader 4 × 4 m	105.49^{a}	122.26^{a}	49.85^{a}	44.8^{a}	30.34^{c}	27.77^{f}
$LSD_{0.05}$	15.50	16.18	9.04	2.30	9.52	3.55

B.D: 'Black Diamond' , A: Angeleno, TCSA: Trunk sectional area

Generally the yield was found to be 30.34-62.27 ton ha^{-1} in 'Black Diamond' and 27.77-53.04 ton ha^{-1} in'Angeleno'. In terms of tree spacing, the highest yield was obtained from Spindel system with 1.2×4 m, 4 leader quad -V 1.6×4 m, Goble 2×4 m and Central Leader 2×4 m for both cultivars. The mean yield (kg ha^{-1}) was found to be higher in 'Black Diamond' cultivar than 'Angeleno' cultivar in all pruning systems and densities. All results were congruent with the results of Mika et al. (2015), who studied on the suitability of plum and prune cultivars grown in a high density planting system for mechanical harvesting with 4 plum cultivars at Skierniewice, Poland. Mika et al. (2015) indicated that the maximum cumulative yield was obtained from the highest planting density. Also, they noticed that there was no significant difference on fruit quality related to planting distance. Mika et al. (2015) suggested that high density plantation of plum tree spaced at 4 m to 1.5-2.0 m with the renewal pruning were very successful with the mechanical pruning. Concerning the increase of intensive planting orchards, mechanical harvesting would take an important role (Peppelman et al., 2007).

Conclusion

In this study, there was no significant effect of different pruning applications and tree spacing on the phenological data and fruit quality parameters. However, trunk cross-sectional area (TCSA) and cumulative yield gave significant differences. Concerning the yield per hectare, 1.2×4 m planting density in Spindel system can be suggested. The Spindel and 4 Quad V systems with 0.8×4 m planting density created excessive density, also high yield per unit could not be obtained with 1.6×4 m and 2×4 m planting density. Similarly, 1×4 m planting density was evaluated as intensively dense in Goble and Central Leader systems, while 4×4 m was found as sparsely dense. The results of this study will contribute to create plum orchards with limited tree height (2.5-3 m) and suitable to mechanical harvest.

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