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Performance of 'Fuji' Apple on M.9 Rootstock in Different Tree Training Systems for the First Five Years

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ABSTRACT

The effects of five training systems on tree growth, yield, and some fruit characteristics were assessed for 'Fuji' apple grafted on M.9 rootstock for the first five years in Tokat, Turkey. The trees were trained in one of five ways: Slender Spindle (SS, 4762 trees ha^{-1}), Vertical Axis (VA, 2857 trees ha^{-1}), HyTec (HT, 1904 trees ha^{-1}) and two different tree densities of super spindle (L-Sup S with 5,000 trees ha^{-1}; H-Sup S with 10.000 trees ha^{-1}). Trunk Cross-sectional Area (TCA), canopy diameter and canopy volume were higher in low tree density systems (HT and VA) than in high tree density systems (SS, L-Sup S and H-Sup S). Annual and cumulative yields per tree over the first cropping years were higher in VA and HT than in SS, L-Sup S or H-Sup S. Yield per unit area was the highest in H-Sup S in every year due to the higher number of trees per hectare. Yield efficiency (yield cm^{-2} TCA) was higher in VA and HT than in SS, L Sup S or H-Sup S in every year. HT produced the largest fruit among the training systems in every year. VA had the second largest fruit in 2008, 2010, and 2011.

Keywords: HyTec, Fruit weight, Super spindle, Vertical axis, Yield.

INTRODUCTION

The most frequently applied method to increase apple orchard productivity and efficiency is high density tree planting, using an early ripening, size-controlling rootstock, and applying the appropriate management system (Ferree *et al.,* 1989; Robinson *et al.,* 1991; Ferree and Rhodus, 1993). High tree density allows greater early productivity, an earlier return of the invested capital, and sustainable high yields of good-quality fruit (Wertheim *et al.,* 2001). The greater early yield from high density plantings is due in part to their greater leaf area index and, therefore, greater interception of photosynthetically active radiation compared to young low density plantings (Jackson, 1989).

In addition to tree density, the tree training system influences total interception and distribution of light (Hampson *et al.,* 2002; Stephan *et al.,* 2008; Buler and Mika, 2009). A training system is the method of manipulating the arrangement of tree planting and canopy geometry to improve the interception and distribution of light, for the purpose of optimizing fruit quality and yield (Hampson *et al.,* 2002). Many comparisons of training systems have been reported in recent years (Hampson *et al*., 2004; Robinson, 2007; Stephan *et al*., 2008; Buler and Mika, 2009). In a study of the effects of training systems on yields of 'Elstar' on dwarf rootstock and of 'Šampion' apple on semi-dwarfing rootstock, both 'Elstar' and 'Šampion' trees trained as hytec had significantly lower yield

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than those trained as spindle (Buler *et al.,* 2001). Crassweller and Smith (2004) reported that, in the fourth year, little differences in cumulative yield per hectare were observed between slender spindle, hytec and vertical axis. Weber (2001) found that, although tree density was 3.5 times greater in super spindle than in slender spindle, average annual yield per hectare leaf 4 to 7- of super spindle was only 1.3 times higher than that of slender spindle. Robinson (2007) also reported that there was a curvilinear relationship between cumulative yield and tree density, and suggested that optimum planting density is dependent on the influence of economic factors and the law of diminishing returns.

During the past years, there has been an increasing interest in modern apple orchard establishment with high tree density systems on dwarf or semi-dwarfing rootstocks in Turkey. Nevertheless, there are only few studies about training in high tree density systems. Our objectives in the present study were to determine the effect of different training systems on the performance of 'Fuji' apple grafted on M.9 rootstock in terms of tree size, yield, and some fruit quality parameters for the first four cropping years.

MATERIALS AND METHODS

In December 2006, non-feathered trees of 'Fuji' on M.9 rootstock (original Malling 9) were planted in rows, in north-south orientation, into a light sandy loamy soil that was previously used for about 20 years to grow field crops, and then watered by hand. One week after planting, drip irrigation was installed. Trellis installation was completed before the planting.

The trees were planted into one of five planting systems: Slender Spindle (SS), Vertical Axis (VA), HyTec (HT) and two different tree densities of super spindle (L-Sup S and H-Sup S). The spacing between tree rows and within rows for each system were 3.0×0.7 m for SS (4,762 trees ha^{-1}), 3.5×1.0 m for VA (2,857 trees ha^{-1}), 3.5×1.5 m for HT (1,904 trees ha^{-1}), 2.0×1.0 m for L-Sup S (5,000 trees ha^{-1}) and 2.0×0.5 m for H Sup S (10,000 trees ha^{-1}).

Slender Spindle (SS) trees were classically trained (Wertheim, 1978) with a final target height of 2.5 m. Plants were headed at 90 cm and planted 10 cm south of bamboo canes with the bud union facing the canes. Annually, vigorous upright leaders of SS were removed and replaced with a weaker branch to devigorate the leader.

Super spindle trees were developed without pruning at planting, and the leader was not headed until year 4. Acutely angled shoots and feathers that were more than half the diameter of the central leader were removed. In leaf 3, two year-old branches with weak annual shoots were cut back to promote shoot strength. Water sprouts were removed through ripping. In leaf 4, replacement of fruiting wood continued and tree height was limited by one single cut into two year-old generative wood (Weber, 2001; Robinson, 2007).

Vertical axis of trees was developed by heading the leader at 120 cm above the graft union at planting. Leaders were not headed from the second through the fourth year. At the beginning of the fourth year, large diameter limbs were removed back to the trunk with an angled cut to develop replacement limbs (Lespinasse and Delort, 1986).

Hytec trees were developed by heading the leader ~60 cm above the graft union at planting. A side shoot was directed upwards to form a new leader. Replacing the leading shoot by a side shoot was repeated for three years (Barritt, 1992).

The experiment was laid out in a randomized complete-block design with three replications, each consisting of three rows of trees. There were 25 trees in each row. Each experimental plot contained five trees in each of the three rows. Data were collected from the three central trees in the middle rows, using the remaining trees as guards.

The orchard was irrigated with drip irrigation each year from May to mid-October. Drip tubing was placed on both sides of the trunk, at a distance of 25 cm. Emitter spacing was 1 m, and emitter flow rate was 2 L h^{-1}. Trees were watered three times a week for 5 h each time in 2007 (1^{st} leaf). In subsequent years, the schedule was changed to daily watering for ~3 hours in order to accommodate the fast draining soil. Total water applied was about 800 L in 2007, and 1,400-1,450 L per emitter annually during 2008-2011. All trees were fertigated with 30 g of 20-20-20 N-P-K per tree per year from irrigation start up, followed by 15-0-0 at 75 g m^{-1} of row. All fertigations were completed by August 20 in each year. To control apple scab (caused by *Venturia inaequalis* (Cke) Wint), a fungicide (Flint 15 g 100 L^{-1}) was applied before bloom, at pink tip and at petal-fall. Foliar urea was applied at a rate of 3.5 kg ha^{-1} (1% w/v) after harvest. Fruits were hand-thinned after June drop to a spacing of 15 cm. Black textile mulch was used for weed control in the tree rows.

Trunk diameter was measured 15 cm above the bud union with digital calipers in mid-November each year. The average of two readings (north-south and east-west) was converted to Trunk Cross-sectional Area (TCA) for analysis. Canopy diameter was recorded as the average of across and along the row, and Canopy Volume (CV) was calculated in 2011 as $CV= (\pi r^2 h)/2$, where r= Canopy radius and h= Canopy High. Some trees flowered in the first year after planting (2007), but the trees were not allowed to fruit. Thus, yield values were not calculated for that year. Following the 2008 growing season, annual yields, Yield Efficiency (YE, yield TCA^{-1}), cumulative yield and, Cumulative Yield Efficiency (CYE, cumulative yield TCA^{-1} in 2011) were calculated. Calculations for average fruit weight and crop load (number of fruit cm^{-2} TCA) were made using the total number of fruit per tree. Soluble solids concentration (%) and titratable acidity (%) were determined using a randomly selected sample of 10 fruits per tree.

Statistical analyses were carried out with the SAS software package (SAS Institute, Cary NC) according to completely block design. *TCA*, canopy volume, canopy diameter, and yield data were analyzed by analysis of variance and the means were separated by using Duncan's multiple range test.

To adjust for the effect of crop load (expressed as fruit number cm^{-2} TCA) on fruit characteristics, crop load was included as a quantitative source of variation in the analysis of variance for fruit characteristics. Means separation was carried out using the Least Significant Difference (LSD) test.

RESULTS AND DISCUSSION

In the second leaf (2008), except for H-Sup S, the other four training systems did not differ in TCA. H-Sup S had lower TCA than VA and HT. In subsequent years, TCA of trees trained as VA and HT were higher than those of trees trained as SS, L-Sup S and H-Sup S. Similar results were observed for canopy width and volume measured at the end of the 5^{th} leaf in 2011 (Table 1). Low density systems (VA and HT) had greater canopy width and canopy volume than high density systems (SS, L-Sup S and H-Sup S). These results support the finding of Robinson (2007) that there was a strong effect of increasing tree density on limiting tree growth.

In 2008, HT, L-Sup S and VA training systems had higher yield per tree than the H-Sup S system. In subsequent years, the yield per tree was higher in HT and VA than in the other training systems. For the first four crops, Cumulative Yield (CY) per tree of HT was three-times greater than H-Sup S and about two-times greater than L-Sup S and SS (Table 2). VA was second most productive system in terms of *CY* per tree. H-Sup S was the lowest among systems for *CY* per tree. The high yield per tree for VA and HT (low density systems) could be due

Table 1. Trunk cross-sectional area, tree canopy diameter and canopy volume for 'Fuji'/M.9 apple trees in different training systems over five years. [a]

Training system	TCA (cm^2)				Spread diameter (m)	Volume (m^3)
	2008	2009	2010	2011	2011	2011
SS [b]	2.34 ab	6.35b	7.86b	12.22bc	1.12b	0.91c
VA [c]	2.61a	7.87a	10.00a	14.33ab	1.31a	1.93a
HT [d]	2.67a	7.94a	10.79a	16.58a	1.33a	1.64b
L-Sup S	2.56ab	6.41b	7.93b	10.54dc	0.71c	0.72d
H-Sup S	2.22b	4.80c	7.66b	8.21d	0.63c	0.53d

[a] Means in the same column followed by the same latter are not significant different according to *LSD* ($P< 0.05$). [b] Slender Spindle, [c] Vertical Axis, [d] HyTec.

to the larger canopy of the trees. This result was in accordance with Robinson (2007) who reported that tree density had a highly significant negative effect on cumulative yield per tree

Yield per hectare was about 50% higher for H-Sup S than SS, VA and HT in 2008 (Table 2). Despite lower tree density in SS and VA, the yields per hectare of SS and VA were similar to that of L-Sup S in 2009 and 2010, and greater than that of L-Sup S in 2011. Even though HT had the lowest tree density, it also exceeded L-Sup S in terms of yield per hectare in 2011. In H-Sup S, diminishing yield per tree was more than compensated for by tree number per hectare, so that yield per hectare was highest in this system every year. H-Sup S had the highest cumulative yield for the first four crops years. Cumulative yield per hectare of SS was higher than that of HT. Cumulative yield per hectare of L-Sup S with the second highest tree density was similar to lower tree density systems (VA and HT) because yield per tree was higher on the trees trained as VA and HT. This result is in contrast with the findings of some researchers who showed that increasing tree density resulted in increased cumulative yield per hectare (Hampson *et al.,* 2004; Robinson, 2007). This situation may be due to differences in training systems and cultivar used. Ferree (1994) reported that significant interactions occurred among rootstocks, cultivars, and training systems.

YE of HT in the second leaf (2008) was higher than *YE* of SS and H-Sup S, but not significantly higher than that of VA or L-Sup S. In the third leaf (2009), L-Sup S was characterized by a significantly lower *YE* than VA and HT. In subsequent years, HT and VA had the highest and second highest *YE*, respectively. When examining the four-year *CYE*, trees trained as HT and VA were found to have higher values than the other systems. L-Sup S and H-Sup S had similar *CYE* at the end of the fourth crop years. Although HT and VA had high *TCA*, these

Table 2. Annual and Cumulative Yields (CY) of 'Fuji'/M.9 apple trees in different training systems over five years.[a]

Training systems	Yield (kg $tree^{-1}$)					Yield (ton ha^{-1})				
	2008	2009	2010	2011	CY	2008	2009	2010	2011	CY
SS [b]	1.03bc	6.09b	7.32c	12.87c	27.31c	4.9b	29.0b	34.8b	61.3b	130.0b
VA [c]	1.68ab	8.48a	10.96b	20.63b	41.75b	4.8b	24.2b	31.3b	58.9b	119.3b
HT [d]	2.23a	8.62a	13.22a	29.73a	53.80a	4.3b	16.4c	25.2c	56.6b	102.5c
L-Sup S	1.76a	5.18bc	6.99c	9.39d	23.32d	8.7a	25.9b	35.0b	46.9c	116.6bc
H-Sup S	0.81c	4.21c	6.05c	7.57d	18.63e	8.1a	42.1a	60.5a	75.7a	186.3a

[a] Means in the same column followed by the same latter are not significant different according to *LSD* ($P< 0.05$). [b] Slender Spindle, [c] Vertical Axis, [d] HyTec.

Table 3. Yield efficiency of 'Fuji'/M.9 apple trees in different training systems over five years.[a]

Training system	Yield efficiency (kg cm⁻²)				
	2008	2009	2010	2011	Cumulative
SS [b]	0.45bc	0.96ab	0.93c	1.05c	2.24b
VA [c]	0.65abc	1.08a	1.09b	1.45b	2.93a
HT [d]	0.83a	1.09a	1.22a	1.81a	3.27a
L-Sup S	0.69ab	0.83b	0.88c	0.91c	2.26b
H-Sup S	0.36c	0.88ab	0.79d	0.92c	2.27b

[a] Means in the same column followed by the same latter are not significant different according to *LSD* (P< 0.05). [b] Slender Spindle, [c] Vertical Axis, [d] HyTec.

training systems produced higher *CYE* than the other systems due to higher yield per tree and greater canopy volume (Table 3).

In the first crop year (2008), fruit from the H-Sup S was characterized by a significantly lower average fruit weight than the other systems. HT produced the largest fruit among training systems every year. VA had second largest fruit in 2008, 2010, and 2011 (Table 4). The higher fruit weight in VA and HT may be related to low tree density. Fruit weight declined with increasing tree density in some previous studies (Corelli and Sansavini, 1989; Tustin *et al.,* 1993; Hampson *et al.,* 2002), but not others (Palmer *et al.,* 1989; Wagenmakers and Callesen, 1995).

HT had higher *SSC* than L-Sup S and H-Sup S in 2008. In the subsequent years, *SSC* did not differ among the training systems. The relative differences among training systems in titratable acidity changed from year to year (Table 5).

Table 4. Average fruit weight of 'Fuji' apple trees grown under different training systems over five years.[a]

Training system	Fruit weight (g)			
	2008	2009	2010	2011
SS [b]	188.3a	186.3c	187.7c	188.0a
VA [c]	199.0a	202.6abc	208.4ab	194.9a
HT [d]	206.8a	217.0a	222.1a	208.3a
L-Sup S	194.9a	208.3ab	206.5abc	153.8b
H-Sup S	146.2b	197.3bc	194.6bc	138.6b

[a] Means in the same column followed by the same latter are not significant different according to *LSD* (P< 0.05). [b] Slender Spindle, [c] Vertical Axis, [d] HyTec.

Table 5. Soluble Solid (SSC) and Titratable Acidity (TA) content of 'Fuji' apple trees grown under different training systems over five years.[a]

Training System	SSC 2008	SSC 2009	SSC 2010	SSC 2011	TA 2008	TA 2009	TA 2010	TA 2011
SS [b]	12.65ab	12.60a	13.67a	13.40a	0.31bc	0.28abc	0.31a	0.30b
VA [c]	12.37ab	12.22a	13.89a	13.26a	0.38a	0.25c	0.20b	0.38a
HT [d]	13.90a	13.40a	13.68a	13.18a	0.29c	0.26bc	0.23b	0.32ab
L-Sup S	11.13b	12.87a	13.61a	13.01a	0.34abc	0.33a	0.30a	0.34ab
H-Sup S	11.77b	12.90a	13.57a	12.80a	0.36ab	0.32ab	0.32a	0.37a

[a] Means in the same column followed by the same latter are not significant different according to *LSD* (P< 0.05). [b] Slender Spindle, [c] Vertical Axis, [d] HyTec.

CONCLUSIONS

In terms of yield per hectare in the first four cropping years, H-Sup S appeared superior to other training systems for 'Fuji' apple, however, this system had lower *YE* and fruit weight than VA and HT. On the other hand, it is not clear if this system will maintain its superiority in subsequent years. It has been documented that initially cumulative yield per hectare was a linear function of density, but later, the relationship became curvilinear (Robinson, 2000; Hampson *et al.,* 2004). When yield efficiency and fruit weight were evaluated, VA and HT training systems for 'Fuji' apple seemed superior to the other systems used in this study for the first five years.

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عملکرد سیب رقم فوجی 'Fuji' روی پایه M.9 در سامانه های پیرایشی مختلف در پنج سال اول

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چکیده

در این پژوهش، اثر پنج سامانه پیرایشی روی پنج سال اول رشد درخت، عملکرد، و بعضی ویژگی های میوه سیب فوجی پیوند شده روی پایه M.9 در منطقه Tokat در ترکیه ارزیابی شد. درختان این آزمایش به یکی از روش های زیر پیرایش شد: به شکل دوک نخ ریسی(با نماد SS و به تعداد ۴۷۶۲ درخت در هکتار)، به شکل محور عمودی (با نماد VA و به تعداد 2857 درخت در هکتار) و به روش Hytec(با نماد HTو به تعداد 1904 درخت در هکتار) و با دو تراکم مختلف (یکی با نماد L-Sup Sو تراکم ۵۰۰۰ درخت در هکتار و دیگری با نماد H-Sup S با تراکم ۱۰۰۰۰درخت در هکتار). نتایج نشان داد که سطح مقطع تنه درخت (TCA)،قطر سایه سار(canopy) و حجم سایه سار در سامانه های با تراکم کم (HTو VA) بیشتر از سامانه های با تراکم زیاد (SS و L-Sup S و H-Sup S)بود. عملکرد های سالانه و تجمعی به ا زای هر درخت در طول سال های اولیه کاشت در روش های VA وHTبیشتر از روش های SS و L-Sup S و H-Sup Sبود. بیشترین عملکرد در واحد مساحت در هر سال به تیمارH-Sup S مربوط می شد و این به خاطر تعداد بیشتر درخت در هکتار در این تیمار بود. کار آیی عملکرد(به معنای عملکرد به ازای هر سانتی متر مربع TCA) در تیمار VA **و** HT در هرسال بیشتر از تیمار های SS، L-Sup S ، وH-Sup S بود. همچنین، سامانه HT در هر سال درشت ترین میوه را در بین سامانه های آزمایش شده تولید کرد. ازنظر درشتی میوه، سامانه VA در سال های ۲۰۰۸، ۲۰۱۰، و ۲۰۱۱ در مقام دوم قرار داشت.