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Intensive plum orchard with summer training and pruning

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Abstract: An intensive plum orchard model was created for two types of fruit harvesting: by hand and with a self-propelled straddle harvester working in continuous motion. Six plum cultivars grafted on semi dwarfing rootstock 'Prune Wangenheim' (*Prunus domestica*) were planted at three densities (1000, 1250 and 1666 trees/ha). A new training system - central leader spindle - was applied. The leader was not headed after planting and summer training treatments were performed. From the third year onward renewal pruning was done after fruit harvesting. The new training and pruning system resulted in very rapid tree growth, much young wood, fruit bud formation on young wood and early bearing. Trees appeared to be suitable for hand and mechanical harvesting within four years from planting.

1. Introduction

In Western Europe plums are grafted on Myrobalan B, St. Julien A, Marianna and other vegetatively propagated rootstocks (Nicotra and Moser, 1995). In Eastern Europe it is difficult to propagate dwarfing and semi dwarfing rootstocks for plums and prunes because of long and hard winters. Stool beds are often damaged by winter frost and hard-wood cuttings are not properly rooted because of low temperatures in autumn and spring. Mother plants in stool beds are also threatened by plum pox. Very few nurseries produce trees grafted on St. Julien A and GF 655/2. Most plum and prune trees are grafted on seedlings of selected types of *Prunus divaricata*. Such trees are planted at 4x3 to 5x5 m and trained to open centre form. In Poland about 20% of trees are grafted on seedlings of 'Prune Wangenheim' (*Prunus domestica*). This cultivar is self-pollinated, so seed trees grown in isolation produce seedlings with uniform grow habit (Sitarek *et al*., 2001). 'Prune Wangenheim' is compatible with all European plums and prunes. Cultivars grafted on 'Prune Wangenheim' are semi dwarf, tolerant to arid soils common in Poland and very productive (Sitarek *et al*., 2001). Such trees should be suitable for dense plantings in intensive orchards. In Germany, Zahn (1986, 1994) and Brunner (1990) introduced central leader spindle and free spindle (without shoot bending) for dwarf and semi dwarf, densely planted plums and prunes. These systems were tested in Belgium (Wustenberghs and Keulemans, 1996) with 825 and 1250 trees per ha and appeared to be very economical in yielding and harvesting.

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The goal of the present work was to elaborate an intensive plum orchard suitable for both hand and mechanical fruit harvesting with combined self propelled straddle harvester working in continuous motion, as is used in Poland to harvest sour cherries. The harvester requires densely planted trees with central leader up to 3 m high and young flexible shoots coming out of the leader. For this purpose new methods of summer training and pruning were introduced to plum trees. Studies were also undertaken on the intensity of tree growth of six cultivars grafted on 'Prune Wangenheim', their growth habit, canopy structure, fruit bud formation in relation to wood age, quality of flower clusters, fruit set, sun irradiation and distribution and yield. These studies enabled to precise the pruning method of trees in full bearing age.

2. Materials and Methods

One-year-old feathered trees of 'Cacanska Rana', 'Cacanska Lepotica', 'Cacanska Najbolja', 'Diana', 'Katinka', and 'Silvia' grafted on semi dwarf seedling rootstock 'Prune Wangenheim' were planted in autumn 2004 on a 0.5 ha plot, on sandy-loam soil at the Research Institute of Pomology, Skierniewice, Poland. To estimate optimum planting density, trees were spaced 4 m between rows and at various densities in the row: 1.5; 2.0 and 2.5 m (1666; 1250 and 1000 trees/ha). Each cultivar was planted in two rows (each consisting of 36 trees): one for hand harvesting, the other for mechanical harvesting. In each row the trees were arranged in three randomized blocks with four trees per plot. In the second year after planting the interrows were grassed down with frequent grass mowing in

conjunction with the maintenance of 1.5-m-wide herbicide strips along the row. A drip irrigation system was installed from the first year. This was necessary because yearly precipitation at Skierniewice is around 500 mm whereas plums grown in central Poland require 700 mm of rainfall. Fertilizers were applied according to the standard recommendation for commercial plum orchards. Eight to ten sprayings were essential to control pests and diseases.

A new training system with summer pruning was introduced to obtain central leader trees suitable for mechanical harvesting and hand picking (Fig. 1). Trees having central leaders 1.7 m high at planting time were not headed after planting and side shoots were shortened lightly. Subordination of the side branches to the central leader was obtained by summer pruning. At the end of May or beginning of June (depending on the growing season) new shoots that appeared at the top of the central leader were thinned leaving only one to extend the leader. This treatment resulted in numerous short side shoots along the leader most of them setting flower buds in the first growing season. Any side shoots growing upright were bent to horizontal position by fixing (clips) pinches to the leader above shoots. These treatments were repeated in the second year. In spring of the third year, trees were nearly 3 m high with at least 1.5 m of canopy diameter and they were able to give the first crop. Further training was not necessary. From the fourth year onward, renewal pruning introduced in Poland by Czynczyk *et al*. (1976) was performed after fruit harvesting. Each branch over three years of age was cut off near the central leader leaving a 10-30 cm stub to ensure new shoot growth (Fig. 2). Light shoot thinning was carried out as necessary. Effect of cultivars and planting distance on tree growth, canopy structure, relation between shoot age and fruit bud formation, and fruit setting was stud-

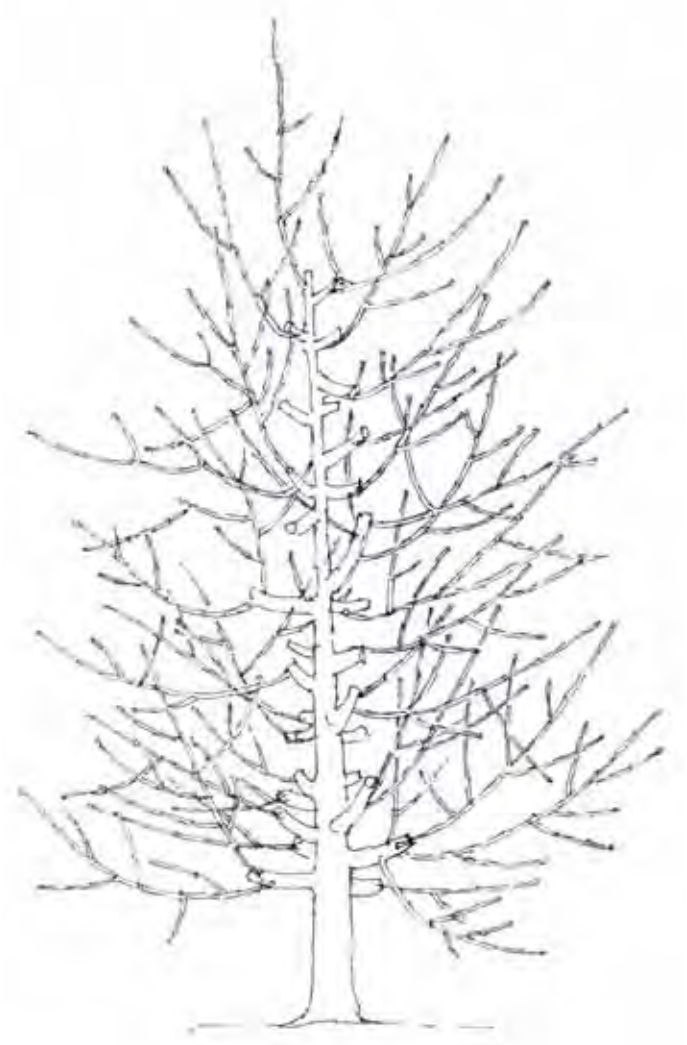

Fig. 2 - Plum tree pruning by renewal method done after harvesting. Old branches are removed to stumps and mainly one-, and two-year-old twigs are left.

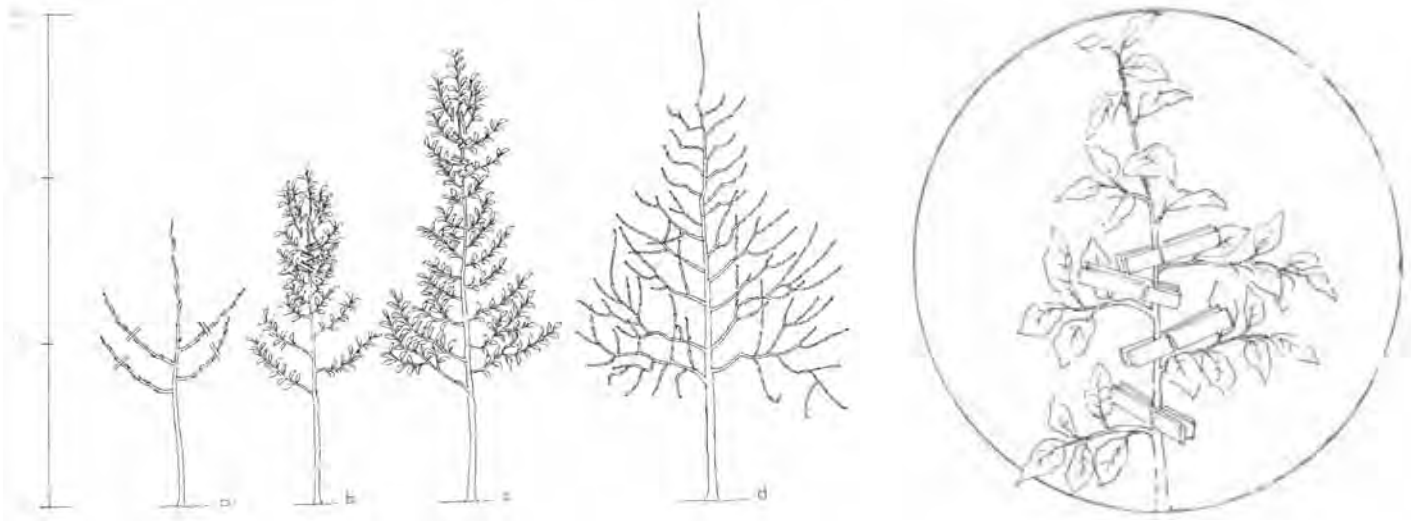

Fig. 1 - Plum tree training with summer pruning: a) planted feathered tree is left with unheaded central leader and lightly headed side shoots; b) in May side shoots appearing at top of the leader are cut off except for one left for leader prolongation, some lower shoots are bent with clips; c) treatments at top of the leader are repeated in May of the second year; d) tree with fruiting ability in spring of the third year; e) shoot bending with a clip.

ied. To estimate light interception, the irradiation intensity was measured at ground level in rows and interrows with a Delta T Tube Solarimeter TSL and with a light sensor mounted above trees (Anderson, 1964). Light interception was calculated by subtracting the light intensity at ground level from light intensity above trees and was expressed as percentage of light intercepted by the canopy. Light distribution was measured across tree rows on three levels: 0.8; 1.6 and 2.4 m with Sun Scan Probe type SS -1 (Delta-T Devices Ltd, Burwell, Cambridge, England). Harvesting efficiency with a combine harvester was recorded. Fruit quality of hand-picked fruit against mechanically harvested fruit was compared.

3. Results and Discussion

In the sixth year after planting (2010) the growth of trees, expressed by trunk cross sectional area (Table 1), showed significant differences between cultivars and also significant differences between the most dense tree spacing in the row compared to the two larger spacing treatments. The large differences in growth intensity among cultivars indicate that this factor should be considered in designing intensive plum orchards. Treatment in the most densely spaced rows resulted in a dwarfing effect on tree growth. When the orchard is managed over a long period, such dwarfing effect leads to a smaller crop from smaller trees, as is often observed in intensive apple orchards (Mika and Piskor, 1996). The new applied methods of tree training resulted in rapid vertical growth. All the trees (except for cv. 'Katinka') reached the required height (3.0-3.5 m) in the fourth year after planting (Table 2). In the subsequent years tree height had to be restricted by pruning to coincide with gap required by the harvester. For this reason strong shoots appearing on the top of trees were removed from the fourth year on trees for both machine and hand harvesting. Canopy spread (Table 3) increased until the sixth year from planting. Trees of cv. 'Silvia' created the most spread whereas 'Katinka' formed compact trees which were significantly smaller than the other cultivars. Some influence of planting density on canopy spread was evident but the differences were not significant. In renewal pruning method, old branches are cut out and replaced by young shoots. Due to that, trees are kept in a constant spread. Canopy structure is favourable for fruiting because most of new shoots are short, in range 5-10 cm. (Table 4). Such shoots are able to form fruit buds on one-year-old wood (Table 4). There were no significant differences between cultivars and planting density treatments. Spur number per tree was also estimated in the fourth year after planting. In spite of renewal pruning, which forced young wood to grow, numerous spurs were present in the tree

Table 1 - Influence of cultivars and spacing on tree growth expressed by trunk cross sectional area in the sixth year from planting (2010)

Influence of cultivars	Trunk cross sectional area (TCSA) (cm^2)
'Cacanska Rana'	46.6 bc
'Cacanska Najbolja'	52.9 d
'Cacanska Lepotica'	35.0 a
'Diana'	42.8 b
'Katinka'	33.3 a
'Silvia'	51.7 cd
Influence of spacing (m)	
4 x 1.5	40.7 a
4 x 2.0	45.6 b
4 x 2.5	44.8 b

Different letters indicate significant differences separately for cultivars and spacing at P=0.05.

Table 2 - Influence of cultivars and spacing on tree growth expressed by tree height in the fourth year from planting (2008)

Influence of cultivars	Tree height (m)
'Cacanska Rana'	3.08 b
'Cacanska Najbolja'	3.26 b
'Cacanska Lepotica'	3.20 b
'Diana'	3.44 b
'Katinka'	2.50 a
'Silvia'	3.62 c
Influence of spacing (m)	
4 x 1.5	3.20 a
4 x 2.0	3.17 a
4 x 2.5	3.20 a

Different letters indicate significant differences separately for cultivars and spacing at P=0.05.

Table 3 - Influence of cultivars and spacing on tree growth expressed by tree spread in the fourth year from planting (2008)

Influence of cultivars	Tree spread (m)
'Cacanska Rana'	2.47 b
'Cacanska Najbolja'	2.33 b
'Cacanska Lepotica'	2.50 b
'Diana'	2.44 b
'Katinka'	1.74 a
'Silvia'	2.67 c
Influence of spacing (m)	
4 x 1.5	2.49 a
4 x 2.0	2.38 a
4 x 2.5	2.40 a

Different letters indicate significant differences separately for cultivars and spacing at P=0.05.

Table 4 - Influence of cultivars and spacing on canopy structure (% of shoots in three classes of length) in the fourth year from planting (2008)

Influence of cultivars	Class 5-50 cm	Class 51-90 cm	Class 91-150 cm
'Cacanska Rana'	73.5 ij	18.7 cde	6.6 ab
'Cacanska Najbolja'	62.1 hi	30.2 ef	4.8 a
'Cacanska Lepotica'	60.4 gh	13.8 bcd	24.7 def
'Diana'	48.3 g	34.2 f	14.0 bcd
'Katinka'	74.6 j	14.6 bcd	10.2 abc
'Silvia'	54.1 gh	22.7 def	21.7 def
Influence of spacing (m)			
4 x 1.5	61.1 c	21.2 b	15.0 ab
4 x 2.0	62.1 c	22.5 b	12.4 a
4 x 2.5	64.1 c	22.1 b	11.0 a

Different letters indicate significant differences separately for cultivars and spacing at P=0.05.

canopy (Table 5). Significant differences among cultivars suggests that some variation in pruning methods may be needed in future for cultivars producing a small number of spurs. Bare wood, typical for plums under traditional pruning, did not appear. The significant differences between cultivars show the variation in the growth habit of the chosen cultivars.

Table 5 - Influence of cultivars and spacing on fruiting spurs per tree in the fourth year from planting (2008)

Influence of cultivars	Number of fruiting spurs
'Cacanska Rana'	238.8 b
'Cacanska Najbolja'	260.8 b
'Cacanska Lepotica'	136.6 a
'Diana'	285.7 c
'Katinka'	146.1 a
'Silvia'	265.8 b
Influence of spacing (m)	
4 x 1.5	216.8 a
4 x 2.0	-
4 x 2.5	219.6 a

Different letters indicate significant differences separately for cultivars and spacing at P=0.05.

In the fifth year from planting, trees of three cultivars planted at distances of 1.5 and 2.0 m created dense structures in the bottom part of the canopy; for this reason leaf area index (LAI), light interception and light distribution at three planting distances were estimated. This very laborious study was performed only on vigorously growing Silvia cultivar having the most regular canopy structure (Table 6). The results reveal that LAI, expressed as ratio of total canopy leaf area to ground area under tree (m^2/m^2), achieved a value of 2.5 at planting distance 4 x 1.5 m. This was close to the optimum value (2-3) suggested by Jackson (1996) for intensive apple orchards. Trees spaced 4 x 2.5 m were far from that value. Light interception (Table 7) was at an acceptable level at planting distance 4 x 1.5 and 4 x 2.0 m but still insufficient as required for an intensively planted orchard; according to Jackson (1996) the value should be 60-70%. Light interception at planting distance 4 x 2.5 m was very poor. In a number of studies it has been found that light interception is correlated with fruit production per ha (Jackson, 1980). In apple orchards, production increases with light interception up to about 70% available light. Light distribution within the fruit tree canopy was acceptable in the upper and middle parts of the trees. In the bottom part (0.7 m above ground) it was critical at the 1.5 x 4 m planting distance, low at 4 x 2 m and sufficient at 4 x 2.5 m planting distances. These results show that the most densely planted trees (1.5 m) require more heavy pruning in the fifth year from planting than trees spaced 2 and 2.5 m in the row.

The relationship between the age of wood and percent of cluster fruit bud setting was studied in three years

Table 6 - Influence of spacing on leaf area, leaf area index (LAI), and light interception of 'Silvia' cultivar in the fifth year from planting (2009)

Spacing (m)	Leaf area (m^2)	LAI	Insolation on ground level (Watt/m^2)*	% of light interception
4 x 1.5	15.16 a	2.52 c	168.0	44.6 b
4 x 2.0	14.20 a	1.78 b	176.3	46.8 b
4 x 2.5	14.75 a	1.48 a	105.5	28.0 a

Mean insolation above trees 376.7 Watt.

Table 7 - Influence of spacing on % light distribution in three canopy levels of 'Silvia' cultivar in the fifth year from planting (2009)

Spacing (m)	Canopy level from the ground		
	0.8 m	1.6 m	2.4 m
4 x 1.5	7.7 a	18.8 bc	48.0 d
4 x 2.0	19.5 bc	29.2 c	48.1 d
4 x 2.5	10.5 ab	32.4 c	49.5 d

(2008-2010). There were no significant differences between years. Table 8 shows the results in the sixth year from planting on fully-grown trees. Many differences were found in the ability of the cultivars to set fruit buds on young wood. In spite of this, most cultivars were able to set 60 to 80% of cluster fruit buds on one-year-old and two-year-old wood. The rest (20-40%) was set on three-year-old wood. These results indicate that trees treated with renewal pruning produce enough fruiting wood and the pruning method does not have adverse effects on tree yielding. Bare wood observed on trees with traditional regulated pruning was not observed in this experiment. Detailed studies on flower bud formation revealed that cluster fruit buds on one-year-old wood consist of, on average, fewer flowers than clusters on older wood (Table 9). For this reason one can expect that young wood may set less fruit than older wood. However this was not proven.

Table 8 - Influence of cultivars and spacing on % of spur fruit buds on young wood in the fourth year from planting (2008)

Influence of cultivars	1-year-old	2-year-old	3-year-old
'Cacanska Rana'	34.4 efg	42.4 ghi	21.4 bcd
'Cacanska Najbolja'	50.0 i	30.1 def	19.5 bc
'Cacanska Lepotica'	37.5 fgh	25.9 cde	39.4 fghi
'Diana'	11.9 a	48.2 hi	39.2 fghi
'Katinka'	40.8 fghi	37.5 fgh	20.6 k
'Silvia'	16.5 ab	44.5 ghi	38.2 fgh
Influence of spacing (m)			
4 x 1.5	28.2 ab	40.4 e	31.2 abcd
4 x 2.0	29.0 abc	36.7 de	32.0 bcd
4 x 2.5	35.6 cde	36.7 de	24.8 a

Different letters indicate significant differences separately for cultivars and spacing at P=0.05.

Table 9 - Influence of cultivars and shoot age on number of flowers in one spur fruit bud in the fourth year from planting (2008)

Influence of cultivars	Number of flowers in one spur fruit bud
'Cacanska Rana'	4.3 d
'Cacanska Najbolja'	1.9 b
'Cacanska Lepotica'	1.9 b
'Diana'	2.9 c
'Katinka'	1.3 a
'Silvia'	1.3 a
Influence of shoot age	
1-year-old	1.9 a
2-year-old	2.1 b
3-year-old	2.5 c

Different letters indicate significant differences separately for cultivars and shoot age at P=0.05.

Most of the cultivars set 5 to 10% fruit out of 100 flowers (Table 10). As the result, the percent of fruit on one- and two-year-old wood was similar to the percent of cluster flower buds (60-80).

Table 10 - Influence of cultivars and spacing on yield (kg/tree) in the fourth and sixth years from planting (2008 and 2010 [z])

Influence of cultivars	2008 kg/tree	2010 kg/tree
'Cacanska Rana'	9.7 a	16.5 c
'Cacanska Najbolja'	28.6 c	4.9 a
'Cacanska Lepotica'	11.4 ab	16.1 c
'Diana'	14.5 b	17.1 c
'Katinka'	15.0 b	11.7 b
'Silvia'	9.0 a	11.1 b
Influence of spacing (m)		
4 x 1.5	13.8 a	12.7 a
4 x 2.0	14.3 b	12.2 a
4 x 2.5	16.0 c	13.9 a

Different letters indicate significant differences separately for cultivars and spacing at P=0.05.
([z]) Yields in 2007 and 2009 were affected by spring frosts.

Trees came to blossom in the second year after planting and produced about 0.3 kg of plums per tree. In the third year, blooming was very abundant but spring frost in the first days of May killed all the flowers. For this reason the first yield was obtained in the fourth year after planting. Most of the trees produced from 8 to 30 kg per tree. The most productive was 'Cacanska Najbolja', the poorest was 'Katinka'. There were many differences within cultivar and little differences within planting distances. Only 'Cacanska Najbolja' and 'Diana' gave a greater crop when planted at the greater distance. In the fifth year again spring frost in May reduced the crop to less than one kg per tree. Acceptable yield was obtained in the sixth year after planting (2010) (Table 11) when most trees yielded 15-18 kg per tree. There were again very large differences in tree productivity among cultivars but none in terms of planting distance. This suggests that when renewal pruning is performed trees can be spaced at even 1.5 m in the row. The good yield, calculated per hectare, varied from 13.9 tons at the largest planting distance to 23 tons at the closest spacing.

In the fourth and sixth years after planting fruits were harvested by hand and by self-propelled straddle harvester. Harvesting was begun when the forces between fruit and stem were 6-8 N, fruit firmness 5 kg/cm, and TSS 12-14%.

Table 11 - Calculated yield in 2008 and 2010 (t/ha)

Influence of spacing (m)	2008	2010
4 x 1.5	23.0	21.2
4 x 2.0	17.9	15.3
4 x 2.5	16.0	13.9

The effectiveness of mechanical harvesting was about 95%, with 5% fruit left on the tree or lost on the ground. Labour efficiency was 150 kg/8-hour-day at hand picking and 15 ton/day with mechanical harvesting. After grading fruit harvested by machine did not differ visually from that picked by hand. When put in cold storage at temperatures close to 0°C the fruit remained in good condition for five to seven days. The fruits were excellent for processing, but rather poor quality as dessert fruit.

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