Optimizing Tree Density in Apple Orchards

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The optimization of orchard plantations is regarded as a key factor for successful orchard management. This implements a successful combination of natural, technical and financial resources. Besides fruit yield, other quality factors like the share of top color and fruit size are regarded as decisive economic factors. Fruit yields are limited to climatic conditions and cannot be increased continuously through higher planting densities. Increased tree density by 3.54 times with two spindle systems increased fruit yield only by a factor of 1.29. Therefore the optimum planting density has to be found.

The plant density development investigated on an area of 3,450 ha (8,525 acres) in the Bodensee area of southern Germany between 1990 and 1998 showed a tendency toward plant densities ranging from 2,600 to 3,600 trees/ha (1,052 to 1,457 trees/acre).

The economic success of an apple orchard depends to the largest extent on the price level for the fruit, then on the price to purchase plant material, higher picking output and fewer management hours for maintaining the system. Row distances less than 3 m (9.8 ft) have the risk of being too narrow for high picking outputs and easy management.

Negative influences on fruit size, color and soluble solids are expected only in plantings beyond 6,400 trees/ha (2,590 trees/acre). An increase in tree density from 3,000 to 6,400 trees/ha (1,214 to 2,590 trees/acre) showed a financial benefit in comparison to the lower density system. In year 5 the super spindle orchard achieved breakeven through rapidly increasing yields on a hectare basis due to a higher tree density. The slender spindle orchard achieved breakeven 1 year later in year 6. Putting all decisive factors together, the actual optimum tree density for the Bodensee region is about 4,000 trees/ha (1,619 trees/acre).

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INTRODUCTION

Modern fruit farming implements the right choice of orchard design, tree habit, tree training and rootstock to adapt on specific soil conditions. The objective is to improve early and high returns, but also to achieve regular yields, high fruit quality and finally to extend an orchard's lifespan.

The secret of managing physiologically balanced apple trees is to switch over from wood production into fruit production. Working with generative wood is the main benefit of high density plantings.

Restricted labor availability and the small size of apple orchards, sometimes not bigger than 1 to 2.5 ha (2.5 to 6.2 acres), were the reasons to develop high density plantings (HDP) in the Bodensee region. In the early 1980s 2- and 3-row bed systems were introduced from north Holland to raise tree density and yield potential by 25%. Too many formation and training hours, much vegetative growth and poor fruit color were the reasons to abandon bed systems.

In the early 1990s the super spindle system with 4,000 and more trees per ha (greater than 1,620 trees/acre) was introduced. With this system there was no more heading of the central axis after planting. Expected attributes were high and early yields, less manual work, less chemical input, high picking output resulting in low production cost per kg and a fast introduction of new valuable varieties into the market. In addition to that, a single row system allowed the possibility of machine planting, easier handling of pruning, harvesting and spraying and IFP compatibility.

MATERIALS AND METHODS

Influence of Plant Systems on Yield, Color and Fruit Weight

Three different plant systems with Jonagold on rootstock M.9 were planted in 1990 (=year 1). The slender spindle system was planted 3.0 x 1.2 m (9.8 x 3.9 ft) apart, the V-trellis 3.4 x 0.8 m (11.2 x 2.6 ft) and the super spindle 2.75 x 0.4 m (9.0 x 1.3 ft). Full tree volume of all plant systems was achieved in year 4. The annual yields per tree were recorded from year 4 to 7 and expressed as an annual mean value. In year 7 the share of top red color was measured by a color grader and turned into a color index, ranging from 0 as green color to 100 as red color. In addition to that, the average fruit weight was measured.

According to the plant density, the super spindle tree was trained differently in comparison to the slender spindle and V-trellis. In year 1 the super spindle tree was not headed. Steep and strong feathers, stronger in diameter than half the size of the central leader, were removed through ripping. In year 2 no significant manipulation through pruning took place. In year 3 weak shoots were cut into 2-year-old wood to promote shoot strength. Water sprouts were removed through ripping. In year 4 fruit wood cutting continued and tree height was limited by one single cut into 2-year-old generative (fruiting) wood.

The slender spindle and V-trellis were trained traditionally. In year 1 the central axis was headed at 1.60 m (5.2 ft) height, 40 cm (1.3 ft) above the basic scaffold. The anticipated feathers were bent into a horizontal angle position. In year 2 some 3 to 4 new emerging competitive shoots were taken out. The central leader was not headed again. Lateral shoots above the basic scaffold were bent 20˚ below horizontal. In year 3 no further bending of lateral shoots took place. Remaining laterals greater than one-third the diameter of the central axis were removed. In year 4 cutting into fruiting wood started and tree height was limited by one single cut into 2-year-old generative wood. The V-trellis tree was planted at a 70˚ angle, but tree training was the same as for the slender spindle.

Plant Density Development and Actual Planting Densities

A survey was carried out among 1,016 growers of the cooperative Marktgemeinschaft Bodenseeobst eG on an apple production area of 3,450 ha (8,525 acres) every 2 years from 1990 to June 1998. The figures (Table 2) reflect the real planting density of the orchards, respectively 90% of the total surface, depending on variety and influenced by the introduction of super spindle systems into practice at the end of the 1980s. The average plant density was carried out over all existing apple orchards in the area, regardless of age (Table 2).

The current planting density activities of growers in the Lake Constance area in 1999 reflect differences in soil conditions, tree habit and variety (Table 3).

COMPARISON OF ECONOMIC DATA BETWEEN TWO PLANT DENSITIES

Basic economic data originated from occasional notes and interviews with more than 20 farmers during the past 3 years. As spindle trees are the dominant planting system in the region, the economic comparison took place between a slender spindle system of 3,000 trees/ha (1,214 trees/acre) and a super spindle system of 6,429 trees/ha (2,602 trees/acre).

The investment cost for the establishment of the orchards is based on Euro/ha (1 Euro = 1 US $) and reflects the actual commercial environment. The annual yield development is expressed as a mean value of obtained yields depending on the different planting densities. The maximum yield per tree with the slender spindle was achieved in year 5 with 13.5 kg per tree and with the super spindle in year 4 with 7.7 kg per tree. Yield fluctuation of 35% in year 7 and a 20% loss in year 9 were due to influences like biennial bearing, pest or hail damage and occurred equally for both systems.

The economic comparison is calculated as a net present value (NPV) of future cash flows to the initial cash outflow attributable to the investment. An interest rate of 6% and a price level of 0.54 Euro per kg fruit was further assumed in this model.

RESULTS

Influence of Plant Systems on Yield and Quality

The highest yield was achieved by the super spindle system with 58.5 MT/ha (Table 1). From the V-trellis 47.8 MT/ha of apples and from the slender spindle system 45.5 MT/ha were harvested. Though tree density increased from the slender spindle to the super spindle system by 3.54 times, fruit yield increased only by a factor of 1.29.

The color index, ranging from 0 to 100, showed no significant difference between systems with Jonagold. Fruit from slender spindle trees achieved 59 points, fruit from V-trellis 55 points and from super spindle trees 52 points.

Fruit from super spindle trees averaged 194 g per fruit which was 14 g less than the V-trellis and 18 g less than the slender spindle. The average fruit weight of the V-trellis was slightly less than the slender spindle.

Development of Apple Plant Density

The plant density showed an increase with all varieties from 1990 to 1998 (Table 2). Jonagold started with 2,850 trees/ha in 1990 and increased to 3,490 trees/ha in 1996 but decreased to 2,930 trees/ha in 1998. Similar trends took

TABLE 1

Influence of different plant systems on average annual yield, fruit color and fruit weight of Jonagold on M.9 years 4 to 7 (Litz, 1997).

Plant system	Tree no. per ha	Tree no. per acre	Yield (tons/ha[Y])	Fruit color index[Z] (%)	Fruit weight (g)
Slender spindle	2778	1124	45.5	59	212
V-trellis	3676	1488	47.8	55	208
Super spindle	9090	3679	58.5	52	194

[Z]0 = green to 100 = red.

[Y]Approximately equal to bins/acre.

TABLE 2

Development of plant densities in apple orchards, depending on the variety, on a production area of 3,450 ha (1990-1998). The average values represent all existing orchards of all ages.

Variety	1990	1992	1994	1996	1998
Jonagold	2,850	2,990	3,180	3,490	2,930
Golden Delicious	2,510	3,240	3,160	3,080	2,580
Gala	3,780	4,850	4,900	3,350	2,850
Braeburn	3,690	5,660	5,560	4,270	3,530
Average	1,720	2,120	2,350	2,390	2,580

place with Golden Delicious. Gala and Braeburn started at a higher level. The plant density of Braeburn in 1990 was 3,690 trees/ha, increased to 5,660 trees/ha in 1992 and remained at that level in 1994. It decreased to 4,270 trees/ha in 1996 and finally to 3,530 trees/ha in 1998. The average plant density (of all old and new orchards) increased steadily from 1,730 trees/ha in 1990 to 2,580 trees/ha in 1998. The overall plant density also may be seen as an indicator of the innovative process of a region to replace old orchards.

The actual plant densities (Table 3) range from 2,343 trees/ha to 6,429 trees/ha. The range depends largely on soil conditions, choice of variety and training scheme of spindle, slender spindle or super spindle trees. The individual growth habit of each variety has an influence on the planting density as well.

Cash Flow Analysis

In year 1 the negative cash flow reached the maximum net present value with minus 23,898 Euro for the super spindle system and minus 17,984 Euro for the slender spindle system with no yields (Table 6). The difference of 5,914 Euro/ha is due to higher investment cost for the super spindle orchard, resulting from the higher plant density, though cheaper plant material by 0.63 Euro per tree (Table 4) was used. In year 5 the super spindle orchard achieved breakeven through rapidly growing yields due to a higher tree density. The slender spindle orchard achieved breakeven 1 year later in year 6.

The super spindle orchard stayed favorable for all consecutive years with a positive difference of 15,466 Euro/ha in year 10. This is due to a higher average annual yield of 9 MT once full yield has been obtained, a higher picking output of 30 kg per hour and lower tree management cost of 75 hours in 5 years for training and 14 hours less for hand thinning (Table 5).

DISCUSSION

Light interception management is very important to ensure yield productivity in high density orchards (Wagenmakers, 1995, Wünsche et al., 1994). Fruit quantity is limited and cannot be continuously increased through higher planting densities. Therefore the optimum has to be found. Higher plant densities are able to achieve higher yields especially during the first years. Yield capacity does not rise proportionally to the increase in tree density. Similar results have been obtained with Royal Gala in year 8 in South Tyrol, where tree density increased by a factor of 4.0, but yields only by a factor of 1.28 (Mantinger and Vigl, 1999).

Fruit size is also closely related to the number of fruit per tree and tree volume. Ultra high density orchards above 10,000 trees/ha (4,047 trees/acre) have a negative effect on fruit size. A loss of fruit weight with large fruited varieties like Jonagold may be tolerated or even can be an advantage. A loss in fruit weight with a medium-sized variety like Royal Gala cannot. In a similar trial Royal Gala lost on average after 8 years 6% in size due to an ultra high density planting (Mantinger and Vigl, 1999). A minimum leaf area per fruit is needed to obtain well-sized fruit which, under European conditions, is an optimum fruit size range from 70 mm to 80 mm in diameter.

Fruit color in this experiment showed only a slight difference between the low and high density system. According to Wagenmakers, the effect of tree density on fruit color was more evident for the lower than the upper part of the tree. The share of well-colored fruit decreased sharply by exceeding 10,000 tree/ha (4047 trees/acre) (Wagenmakers, 1995).

Regarding the influence of rootstocks on financial success, Jonagold on M.9 achieved the highest annual cash flow. Only M.9 as an interstem with a longer lifetime of 15 years compared to that of 9 years for M.9 had an annual cash flow slightly higher, but lower (minus 18%) with M.27 and P.22 (Groot, 1997).

The plant density development between 1990 and 1998 showed a tendency toward plant densities ranging on average from 2,600 to 3,600 trees/ha (1,052 to 1,457 trees/acre). The reason for the reductions since 1996 may be the rising prices to purchase plant material and smaller returns for the fruit. Other reasons for more moderate plant densities are now the availability of virus-free plant material with additional vegetative growth of relatively new varieties like Gala and Braeburn.

Today's recommended planting activities take into account parameters like soil condition and tree habit and fruiting pattern of each individual variety.

The economic success of an apple orchard depends primarily on the price level for the fruit, then on the price of trees from the nursery, higher picking output and fewer

TABLE 3

Plant systems and tree densities in new apple plantings in 1999 in the Lake Constance region.

Strong growth sites	Super spindle	Slender spindle	Spindle
Plant distance (m)	3.0 x 0.6	3.0 x 1.0	3.2 x 1.2
Trees per ha (x 0.9)	5,000	3,000	2,343
Weak growth sites	Super spindle	Slender spindle	Spindle
Plant distance (m)	2.8 x 0.5	3.0 x 0.8	3.0 x 1.0
Trees per ha (x 0.9)	6,429	3,750	3,000
Variety	Jonagold Idared	Jonagold Golden Delicious, Gala, Braeburn	Cox's Orange Elstar Boskoop

TABLE 4

Calculating cost in Euro/ha for the establishment of an apple orchard depending on different plant densities and tree quality used in the cash flow analysis shown in Table 6.

Training system	Slender spindle	Super spindle
Tree distance (m)	3.0 x 1.0	2.8 x 0.5
Trees (/ha)	3,000	6,429
Price per tree	3.17	2.54
Plant material	9,518	16,316
Frame & planting	5,023	4,428
Total	14,541	20,744

management hours for maintaining the system. Row distances less than 3 m (9.8 ft) take the risk of being too narrow for high picking outputs and easy management. Economic results improved with increasing tree density between 2,000 and 4,000 trees/ha (809 and 1,619 trees/acre) (Goedegebure, 1991). The optimum of average annual cash flow of Jonagold on M.9 was obtained with a tree density of 6,000 trees/ha (2,428 trees/acre) (Groot, 1997).

A tree density with 6,000 trees/ha is generally able to produce more fruit with high quality than a tree density of 3,000 trees/ha (Wagenmakers et al., 1994). Negative influences on fruit size, color and soluble solids are expected only in ultra density plantings above 8,000 trees/ha (3,238 trees/acre). An increase in tree density up to 6,400 trees/ha (2,590 trees/acre) showed a financial benefit in comparison to the lower density system. Putting all decisive factors together, the actual optimum tree density for the Bodensee region is about 4,000 trees/ha (1,619 trees/acre).

TABLE 5

Comparison of basic economic data between two different plant densities of Jonagold and training methods used in the cash flow analysis shown in Table 6.

Orchard system	Slender spindle	Super spindle
Trees (/ha)	3,000	6,429
Leaf of full yield	5	4
Yield in tons/ha	40.5	49.5
Picking output kg/h	130	160
Harvest hours/ha	312	309
Training (leaf 1-5) h/ha	186	111
Hand thinning h/ha	50	36
Labor wage in Euro/h	6.2	6.2

TABLE 6

Cash flow analysis in Euro/ha, comparing average annual yield and net present value (NPV) development between two Jonagold orchards of different plant densities. Price level of class I fruit 0.54 Euro per kg. Interest rate of investment 6%.

Year	**Spindle**		**Super spindle**		**Difference**
	kg/tree	**NPV**	**kg/tree**	**NPV**	**NPV in Euro**
1	0	-17,984	0	-23,898	-5,914
2	4.1	-16,814	3.1	-20,774	-3,960
3	7.4	-13,372	5.4	-14,262	-890
4	10.8	-8,057	7.7	-4,822	+3,235
5	13.5	-1,574	7.7	+4,307	+5,881
6	13.5	+8,975	7.7	+12,831	+3,856
7	8.8	+7,715	5.0	+17,529	+9,814
8	13.5	+13,201	7.7	+25,135	+11,934
9	10.8	+17,009	6.2	+30,588	+13,579
10	13.5	+21,891	7.7	+37,357	+15,466

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