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Augustyn Mika, Zbigniew Buler, Waldemar Treder, Cecylia Sopyła
Research Institute of Pomology and Floriculture
Pomologiczna 18, 96-100 Skierniewice, POLAND

RELATIONSHIP BETWEEN FRUIT DISTRIBUTION WITHIN 'JONAGOLD' APPLE CANOPY, FRUIT QUALITY AND ILLUMINATION

ABSTRACT. Canopies of 'Jonagold' apple trees grafted on M.9 rootstock, planted in 1996 at 3.5 × 2.0 m and trained as spindles, were subdivided in the spring of 2001 with bamboo canes into 120 measuring cubes (0.5 × 0.5 × 0.5 m) per tree. In each cube the number of fruits, fruit quality and leaf area were determined. In the summer of 2001, light levels in 6 horizontal layers were measured 5 times with a 'Sun Scan Probe' solarimeter (Delta-T Devices Ltd., Burwell, England). The results of these light measurements, expressed in watt/m^2, were converted to the percentage of light within the tree canopy in relation to that above the tree. The analysed parameters varied significantly between the layers for which the measurements were made. The greatest number of fruits was found in the upper part of the canopy in the layers from 1.5 to 2.5 m above the ground. The greatest leaf area was 0.5 m below, within the layers from 1.0 to 2.5 m. Both these parameters increased from the periphery towards the tree trunk. The percentage of light decreased rapidly from the tree top to the tree base and from the periphery towards the tree trunk. There was little difference from one tree to the next along the row. The best illuminated part of the canopy was more than 2.0 m above the ground. At the 1.5 m level, only the outer mantle of the tree canopy was well illuminated. Below 1.0 m, illumination was from 20 to 40% of that above the canopy and the apples were small and poorly coloured. In the middle part of the canopy, they were of a good size but still poorly coloured. Fruits of the best quality were obtained from the top part of the tree. Fruit colour showed a positive correlation with illumination ($r = 0.65$).

Key words: apple tree, orchard micro-climate, fruit and light distribution

INTRODUCTION. Cain (1971) and Palmer and Jackson (1974) found that fruit yield per unit area of an orchard showed a positive linear correlation with illumination by sunlight. The solar energy, which is not captured by tree canopies and penetrates to the ground level, is wasted without taking part in photosynthesis. Flower bud formation and fruit set depend on the supply of a specific amount of light energy, while the development of red colour on fruit requires direct sunlight. For that reason, planting trees too densely to maximize light interception can decrease yielding in the central parts of canopies or reduce fruit quality (Palmer and Jackson, 1974). Knowledge of the relationships between the light intensity and flower bud formation, fruit set, fruit size and colour enables the development of a beneficial orchard architecture and an adjustment of planting density, tree height and canopy size and shape.

When comparing canopies of various shapes, a positive correlation between the distribution of sunlight in the canopy and fruit quality is expected. However, this relationship is more complex than what is often assumed. In the leader-form of canopies, which is now common in orchards, the bulk of the crop grows only in the outer fruiting mantle – a layer 70 cm thick. Illumination in that mantle is the most important factor for crop quality. If the volume of the canopy is large, especially at its base, then a low percentage of fruit comes from the middle of the canopy, with a more significant percentage coming from the outer mantle. Despite very bad illumination in the centre of the canopy, the quality of the whole crop from the tree can be acceptable. Completely different light conditions can be created by inappropriate pruning, for example by cutting back the shoots on the periphery of the canopy.

Such pruning causes intense development of summer growth, which covers up the fruiting mantle and prevents apples from developing red colour even in a small volume canopy (Robinson et al., 1991).

Similar unfavourable light conditions are created by a high density planting of trees, especially in multi-row strips, where the leaf area index is very high, yield per unit area also high, but fruit quality is low (Mika et al., 2001).

The aim of this study was to determine the relationship between illumination, leaf area, fruit location within apple tree canopy and fruit quality.

MATERIALS AND METHODS. Canopies of five-year-old apple trees, grafted on M 9 rootstock, spaced at 3.5 × 2.0 m (1429 trees/ha) in N-S oriented rows and trained as wide spindles, were subdivided in the spring of 2001 with bamboo canes into 0.5 × 0.5 × 0.5 m cubes. In each cube, of which there were 120 per tree, the number of fruit at harvest and fruit quality (size, mean weight, colour) were determined, as well as the leaf area by means of an AMS Delta-T Devices apparatus following the picking of leaves in the autumn. The levels of sunlight illumination were measured five times during the vegetative season with a 'Sun Scan Probe' portable solarimeter manufactured by Delta-T Devices Ltd., Burwell, England. 64 readings were obtained from each measurement, which meant that with two repeats for six trees at either end of the row and for one horizontal level of the canopy more than a few hundred results were obtained for each measurement level. The results of the measurements in watt/m^2 were converted to the percentage (%) of light reaching inside the canopy in relation to the amount of light above the canopy, assumed to be 100%. The measurements were made for 6 trees of similar growth vigour and canopy size, and growing side by side in the same row. Those trees were treated as replications. During the peak of vegetation, apple trees were slightly over 3 m high, had canopies 2.5 m wide at the base and branches touching the ground. The majority of the biometric measurements were put through a statistical analysis of variance and the significance of means was assessed using the Duncan`s t - test at P=0.05.

RESULTS. The intensity of sunlight within the canopies measured across the row at six measurement levels (from 0.5 to 3.0 m) decreased from the top of the canopy towards its base, particularly down to the 1.0-1.5 m level, and from the inter-row side towards the inside of the canopy (Fig. 1). Abundant illumination (from 40 to 100%) was found only in the top part of the tree, down to 2 m level. At 1.5 m, 1/3 of the canopy cross section received illumination below the value required for normal fruiting (i.e. less than 20%). At 1.0 and 0.5 m levels, beneficial illumination was found only in the outer mantle of the canopy and only on the inter-row side and not on the sides along the row. At the 0.5 m level, illumination along the row was the same both in the centre of the canopy and at the point of contact of two neighbouring trees in the row. The amount of sunlight there did not exceed 20% of the illumination above the canopies.

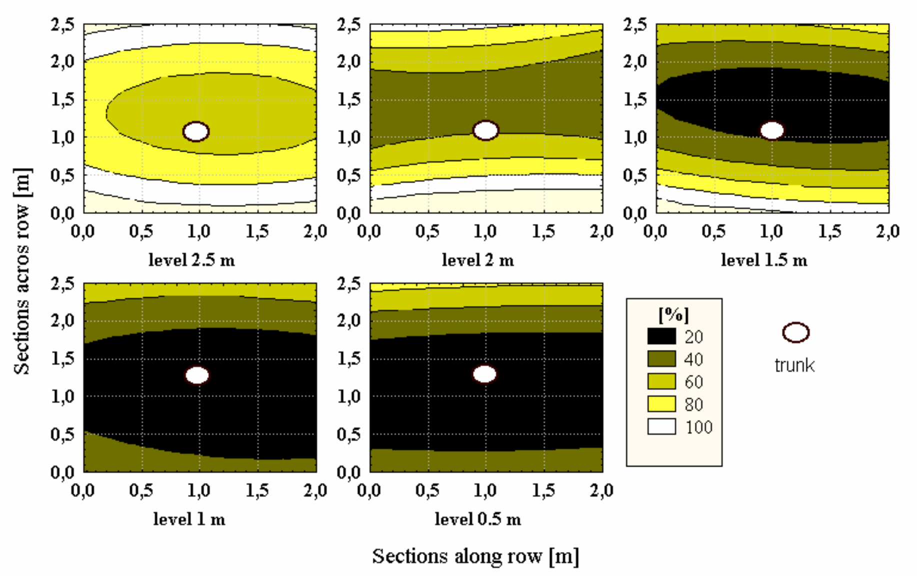

Figure 1. The percentage of light reaching the measurement levels from 2.5 m height down to the canopy base at 0.5 m

Leaf area is shown for horizontal canopy layers 0.5 m thick (Fig. 2). In the top layers of the canopy, the leaf area increased concentrically from the periphery towards the inside of the canopy. In its central layer (1.0-1.5 m), the leaf area in the measuring cubes was the largest and amounted to approx. 20 dm^2 per cube. The leaves in that region were most evenly distributed. In the lower layers, the leaf area decreased from the periphery towards the inside of the canopy. The leaf area per measuring cube in the lowest layer of the canopy was no more than 20% of that in the top part.

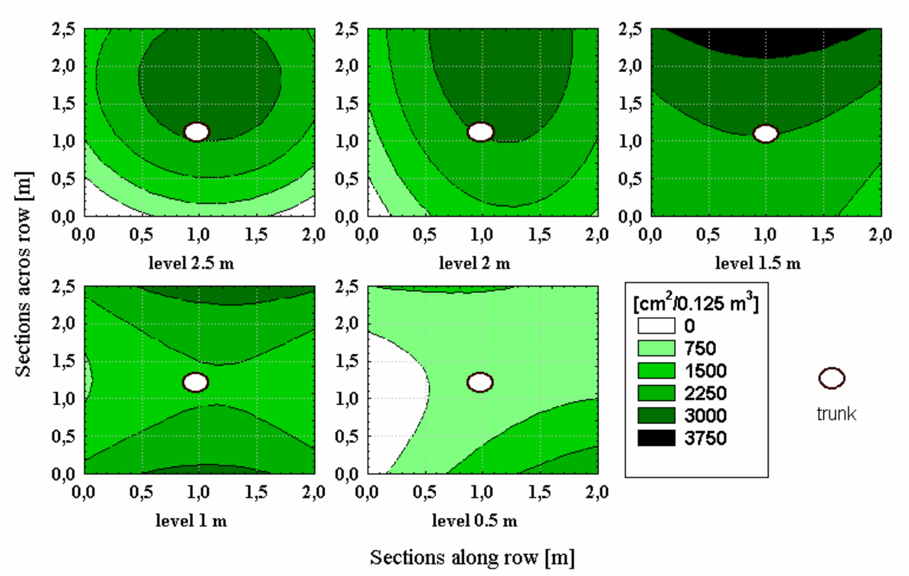

Figure 2. Leaf area in measuring cubes (0.125 m^3) in 0.5 m thick horizontal layers of the canopy, from the base of the canopy at 0.5 m up to the height of 2.5 m

Fruit distribution within the canopy, referred to in this paper as fruiting density (Fig. 3), was similar to leaf distribution, although the bulk of the fruits in the canopy was located higher (1.5-2.5 m) than the bulk of leaves (1.0-2.0 m). The highest fruiting density was found in the top part of the canopy and just below. The density increased concentrically from the periphery towards the centre of the canopy. At the base, in the 0.5 to 1.5 m layer, the fruiting density was quite uniform along the row, but increased from the inter-row side towards the centre of the row. In the lowest part of the canopy, the fruiting density showed distribution opposite to that at the top. It was the lowest in the centre of the canopy. The total yield per tree was very high (57.4 kg) for an orchard with 1429 trees/ha.

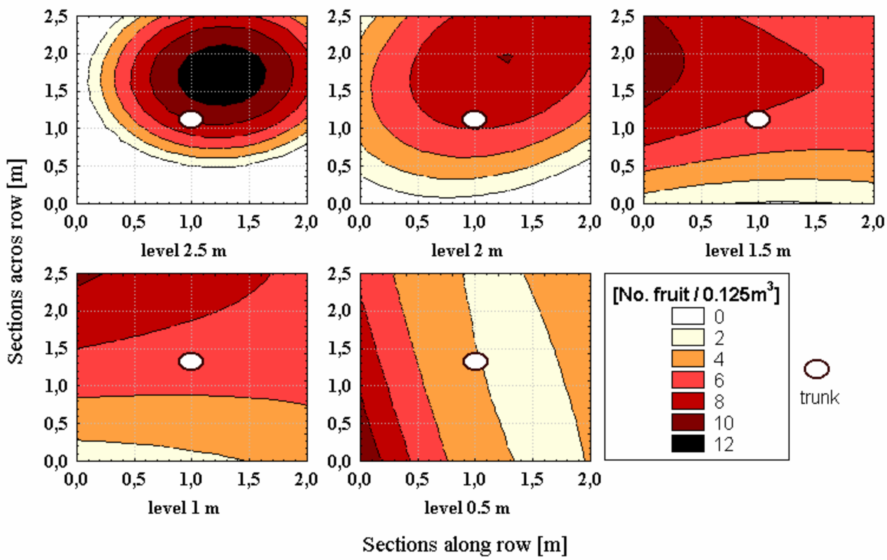

Figure 3. The number of fruits in measuring cubes (0.125 m^3) in 0.5 m thick horizontal layers of the canopy, from the base of the canopy at 0.5 m up to the height of 2.5 m

The results of the statistical analysis of the data related to illumination, leaf area and fruiting are shown in Table 1. The number of fruits per measuring cube, yield in kg per cube and mean weight of fruit were the highest in the top layer of the canopy (from 2.0 to 2.5 m). In the uppermost layer (above 2.5 m), those values decreased. The largest leaf area per measuring cube was found in the 1.0 to 2.5 m layers. At the crest of the canopy, in its centre and at its base, fruiting density was lower than in the top layer (2.0-2.5 m). Leaf area in the measuring cubes rapidly decreased towards the base of the canopy.

Table 1. Fruit and leaf distribution, fruit quality and illumination levels in 'Jonagold' apple canopy measured across tree rows in 0.5 m thick horizontal layers (means from 6 trees)

Parameter	Horizontal layers in m above ground						
	0-0.5	0.5-1.0	1.0-1.5	1.5-2.0	2.0-2.5	2.5-3.0	>3.0
% of sunlight in the layer	23 a*	20 a	34 a	60 b	71 c	80 d	—
Leaf area per measuring cube [$dm^{2)}$]	5.7 a	16.1 b	24.6 d	21.8 cd	22.3 cd	16.6 b	18.8 bc
Number of fruits per measuring cube	2.7 a	5.2 bc	5.5 bcd	5.9 cd	7.4 d	5.0 bc	3.9 ab
Yield [kg] per measuring cube	0.42 a	0.86 bc	0.96 bc	1.08 cd	1.39 d	0.98 bc	0.74 ab
Mean fruit weight [g] in the layer	154 a	164 a	175 b	184 bc	196 d	193 cd	187 cd
% of fruit with red blush in the layer	23.6 a	36.2 ba	50.3 c	67.6 d	77.9 ef	89.5 f	90 f

Mean yield per tree 57.4 kg
*Means followed by the same letter do not differ significantly (Duncan's multiple range t - test at P=0.05)

The quality of fruit expressed as their mean weight and the proportion of skin surface coloured red was significantly higher in all the upper measuring cubes located at and above the 1.5-2.0 m layer. From that layer up towards the top, fruit quality did not change significantly, decreasing however, towards the base of the canopy. In the layer between the ground and the 1.0 m level, apples were poorly developed, with only a 1/4 of skin surface showing red colour. Half-way up the canopy, apples were adequately developed, but the red colour was present only on one half of the fruit surface. The best developed apples were at the top of the canopy. They were extensively, even completely coloured red. There was a significant correlation between the colour of fruits and the amount of sunlight reaching them (r = 0.65).

DISCUSSION. Determination of the relationships between the distribution of fruit within tree canopy, fruit quality and the amount of sunlight illumination should form the basis for optimizing the size and shape of tree canopies in an orchard. The findings of the present work – a rapid decrease in illumination from the top of the tree downwards and from the outer layer towards the centre of the canopy, confirm the results of some earlier studies published in the 1970's (Cain, 1971; Jackson and Palmer, 1971). Those studies were carried out in relation to the leader forms of canopies, which predominate in European orchards. The canopy shape with a vertical leader (spindle, super-spindle, axial) has become common because it enables a high density planting of trees, even at distances less than a metre apart along the row. Unfortunately, as Mika et al. (2000) have shown, the leader forms of canopies are not as well illuminated as the canopies with open centres (e.g. vase-shaped), which were used in the past. Considerably better illuminated than the leader form is a canopy with two leaders trained at an angle – the V system (Chalmers et al., 1978), or with four leaders – the Mikado system, developed by Widmer and Krebs (1996). That system makes trees resemble the vase form.

In intensive orchards even the most slender spindle, super-spindle and axial canopies create a poorly penetrable by light type of a hedge if trees are densely planted. Already at the beginning of summer, in the upper parts of such canopies a lot of new shoots and leaves develop (thanks to good illumination), which limit the amount of light reaching the centre and base of the canopy (Rom and Ferree, 1984). The results of the present study show that one half of the canopy volume receives illumination from 20 to 34%, which is considered inadequate (Jackson and Palmer 1971). For that reason, the bulk of fruit weight is located in the upper peripheral layers of the canopy compared with the location of the largest leaf surface. Under a dense canopy of leaves there are fewer fruits than above it, which can be seen by comparing the data in Table 1. This study and those of other authors (Sansavini et al., 1981; Wagenmakers, 1995) show that about 2/3 of the apple crop comes from the upper, penetrable parts of the canopy, while only 1/3 from that exposed to inadequate illumination. Poor illumination restricts first of all not only the extent of the red coloured area on apples, but also, although to a lesser degree, the development of apples to the required size.

Despite the very high yield (on average 57 kg per tree), the apples were relatively well developed (above 150 g). Polish consumers, however, prefer very large apples (180-200 g), so in that case it would be justified to increase fruit size at the cost of yield to the benefit of regular fruiting.

The obtained results indicate that there is a need for more severe (than in the past) pruning of apple trees on M.9 spaced at 3.5 × 2.0 m. It would be necessary to break up the canopy by removing whole branches at the leader, so the sunlight could reach the inside of the canopy from the sides, between branches. The structure of the compact row of trees, resembling a hedgerow, would also have to be broken up by pruning to enable light penetration between trees. The suggested way of pruning will improve the illumination, fruit distribution within the canopy and fruit quality at the cost of yield.

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