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Characteristics of canopy and light transmittance in three types of apple orchards in Weibei areas of Shaanxi Province, China

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Abstract The effect of different modified tree shapes (MTS) on light reception was compared among three types of apple orchards: small-sized canopy, middle-sized canopy and large-sized canopy in Weibei areas of Shaanxi Province, China, by using WinsCanopy2004a (2002) for Hemispherical Image Analysis. The results showed that higher average values of photosynthetic photon flux density (PPFD) under canopy per day appeared in all tested orchards, and the number of branches per 667 m² was lower, indicating that the modified tree shapes were effective to improve the light conditions of canopy but the pruning amount seemed to be slightly more than the appropriate level in Weibei areas. The middle-sized canopy had the maximal light penetration and the small-sized canopy had the least and the leaf area index (LAI) and the ratio of one year-old shoots to scaffold limbs were maximal in large-sized canopy orchards.

Keywords apple orchard, canopy, light transmittance, modified tree shape, number of branches

1 Introduction

Light is the source of energy for fruit tree growth, which has an important influence on the buds, leaves, flowers, shoots and fruits as well as on root growth, flower bud differentiation, fruit setting, and fruit quality. As the internal photosynthetic active radiation (PAR) of the

canopy has a direct influence on apple quality, a reasonable canopy construction is therefore beneficial to the increase of yield, fruit quality and economic revenue (Hampson et al., 2002; Michael et al., 1998). The main apple-producing areas in China share the problem of poor light conditions, which cause lower biomass and reduce economic benefit. The key to resolving this problem is to reform the tree shape and enable it to meet the light and air requirements of different apple species, rootstocks and planting densities (Yuan et al., 2003).

The relationship between canopy structure and light reception has been studied widely in the past. Most research tends to be focused on the influence of the light in partial canopy on the yield and the fruit quality, but little research has been done on the overall solar radiation in the whole tree canopy circumstance (Hampson et al., 2002; Michael et al., 1998). The digital hemisphere picture analysis system (Model: WinsCanopy2004a, REGENT INSTRUMENTS INC Company, Canada) manufactured using bionic techniques based on the fish eye lens, can obtain hemispheric pictures through a digital camera and then analyze the picture using special software to determine the coefficient of sunlight which directly passes through the canopy. Finally, some optical characteristics of the whole canopy in plants can be determined by referring to a series of models (Regent instruments INC, 2002; Gordon et al., 2001; van Gardigen et al., 1999; Coops et al., 1998).

Since 2001, Shaanxi Province has used four key techniques to improve apple quality and one of these involves modifying the tree's shape. In practice, a 1.0 m wide passage was placed between adjacent rows and no overlapping branches between trees in a row was allowed. The tree height was controlled at less than the row spacing, and the ratio of the long shoot, the medium shoot and the spur was limited to 10:30:60, while the number of shoots was maintained at 60000–80000 per 667 m² etc. (Yuan et al., 2003; Fang and Zhang, 2003; Wang et al., 2000; Ruan et al., 2004).

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No standard for the appropriate indicator of light arriving at the bottom through the whole canopy has so far been proposed. In some cases, the reform seems to be somewhat heavier and the yield decreases. This experiment examined the relationship between the canopy structure and light transmittance in the canopy on three different apple orchards in the Weibei area using WinsCanopy2004a (2002) to provide some guidance for the popularization of the MTS in Shaanxi Province.

2 Materials and methods

2.1 Materials

The experiment was carried out in excellent apple-producing areas with deep soil, more than 1% soil organic matter and a proper irrigation system. Three typical types of orchards were selected for this experiment:

(1) Small-sized canopy orchard: 9-year-old Fuji trees were applied with a planting density of 2 m × 3 m, the row direction was N–S oriented with routine management and a slender spindle system was followed but the clogging of canopy was severe.

(2) Middle-sized canopy orchard: 8-year-old Fuji trees were applied with a planting density of 3 m × 4 m, the row direction was N–S oriented with routine management and a modified central leader system was followed. The MTS was adopted in 2003, and since then the canopy has become smaller with reduced vigor.

(3) Large-sized canopy orchard: 16-year-old Fuji trees on vigorous rootstocks were applied with a planting density of 4 m × 5 m, and row direction was N–S oriented. The dome-shaped systems were adopted with poor air and light conditions within the canopy. In 2003, the MTS was adopted by opening the top and removing the lower limbs up to 1.0 m above ground. In this way, light conditions in the orchard were improved significantly.

2.2 Methods

The experiment was carried out in October 2004 and 2005 after the apples were harvested. Before the leaves fell off, the three orchards had been randomly chosen. Eight to ten trees from each orchard were studied with WinsCanopy2004a (2002) from four directions of each tree. The collected pictures were studied using the analysis software. The Gap fraction, light transmittance through the canopy, leaf area index (LAI), average leaf angles (MLA), the PPFD direct under canopy per day (MJ or mol·m⁻²·day⁻¹), the photosynthetically active photon flux density below the canopy per day and the PPFD indirect under canopy per day (MJ or mol·m⁻²·day⁻¹), etc. were calculated. The average values obtained from each tree

were computed and the data was then analyzed. The number of the shoots for each tree was counted and the total number per 667 m² was reckoned, with yield data and fruit quality provided by the growers.

3 Result and analysis

3.1 Gap fraction

It can be seen in Table 1 that the middle-sized canopy orchard has the biggest gap, while the small-sized and large-sized canopy orchards have lower gaps, which means that the middle-sized canopy orchard has the best light transmittance. The different gaps among the three orchard types achieve a significant level. The large-sized canopy orchard has the biggest LAI, followed by the small-sized canopy orchard, while the middle-sized canopy orchard has the minimum LAI with the differences between the orchards reaching a significant level. The MLA of the three types shows no remarkable difference.

Table 1 Comparison of canopy characteristics and light transmittance in three types of orchards

canopy size	Gap fraction	LAI	MLA	PPFD direct under canopy per day/MJ or mol·m ⁻² ·day ⁻¹	PPFD indirect under canopy per day/MJ or mol·m ⁻² ·day ⁻¹
small	37.13b	1.46a	15.30a	15.09b	2.45b
middle	44.02a	1.12b	15.12a	19.97a	3.00a
large	30.54c	1.61a	14.76a	13.89b	1.99c

Note: Different small letters in each column represent a 5% significant level by *t*-test.

3.2 PPFD

Table 1 also shows that the large-sized canopy orchards have the biggest effective PPFD, which means better light transmittance, and this trend matches the results of the gap and the LAI. The small-sized canopy orchards have more effective PPFD under canopy per day than the large-sized canopy orchards, and the difference in PPFD indirect under canopy per day between the two types is bigger than that in PPFD direct under canopy per day, indicating that the large-sized canopy orchards can intercept more indirect radiation than the small-sized canopy orchards, and that the large-sized canopy orchards have more scaffold limbs and leaves.

3.3 Shoots

Tables 2 and 3 show that a significant difference in the total number of shoots per 667 m² exists among the three types of orchards, with about 60000 shoots in the small-sized canopy orchard and only 40000 in the others. The

large-sized canopy orchard has more secondary scaffold limbs and two-year-old branches but fewer scaffold limbs. The number of one-year-old shoots and spurs is close to that of the middle-sized canopy orchard. From the results of Gap, LAI and PPFD, it can be concluded that the secondary scaffold limbs and two-year-old branches of the three orchards have an apparent influence on light interception or transmittance.

Table 2 Comparison of tree canopy structure in three types of orchards (shoots·667 m⁻²)

canopy size	scaffold limbs	secondary limbs	two-year-old branches	shoots and spurs
small	916	2498	12071	59607
middle	500	1554	6549	34577
large	433	3463	13986	38428

Table 3 Comparison of branches, yields and fruit qualities among three types of orchards

canopy size	ratios of one-year-old shoots and scaffold limbs	ratio of one-year-old shoots and secondary limbs	PPFD direct under canopy per day/MJ or mol·m ⁻² ·day ⁻¹	average yield/kg·667 m ⁻²	top-quality fruit/%
small	70	26	17.54	2500	60
middle	69	21	22.97	2000	70
large	91	11	15.88	3000	75

3.4 Yield and fruit quality

It can be seen in Table 3 that the large-sized canopy orchard has a higher yield and better fruit quality than the two other orchards when compared with the trees before applying the MTS. The results show that the MTS is helpful in boosting the benefits. The middle-sized canopy orchard has the lowest yield, while the small-sized canopy orchard has the lowest rate of high-quality fruit. Low yield and poor quality were obtained from both small-sized canopy and middle-sized canopy orchards.

4 Discussion

(1) In this experiment, the canopy transmittance of apple trees was measured and analyzed with WinsCanopy2004a (2002). The result suggests that the LAI (2000)-Log series methods can be used to evaluate the canopy structure of apple trees, which is identical to the findings of Wu et al. (2006).

(2) PPFD of the canopy in growing season is an important index in evaluating the performance of the canopy to intercept sunlight. It is given that the difference of PPFD above and below the canopy is the light interception. Therefore, the average PPFD under the

canopy can reflect the capability of light interception of the canopy, which means that when the value of PPFD below the canopy is low, then the canopy can intercept more sunlight (Regent instruments INC, 2002).

The characteristic index of three types of apple orchards in the Weibei area shows that the middle-sized canopy has the biggest gap fraction and PPFD under the canopy, but it has the lowest LAI, which means that the middle-sized canopy has the best light transmittance. The large-sized canopy and the small-sized canopy both have lower light transmittance than the middle-sized canopy, but the large-sized canopy has better light transmittance than expected, and probably the MTS has shown a good effect.

The MLA has no marked changes, which may be related to the testing period, because the MLA of mature leaves may show small changes as a result of a stable inheritance (Campbell, 1986).

(3) The average transmittance in the orchards is 37%, which is greater than the general criterion of 25%–35% (van Gardigen, 1999). The number of the shoots is 40000 per 667 m², which is also lower than the conventional criterion. These results show that the MTS has been somewhat overdone in this area. Hence, we suggest that reforming the tree shape should be done progressively. Since the measurement was conducted after fruit harvest, the transmittance during this period should be better than that before the harvest.

5 Conclusion

The average PPFD under canopy per day of three types of orchards is higher, while the number of branches per 667 m² is lower, so that the tree shape modification is useful for adapting the tree canopy to suitable light interception, but some severe pruning seems to have been done in the Weibei area. The middle-sized canopy has the maximum light transmittance and the small-sized canopy has the least. The LAI and the ratio of annual shoots to the scaffold limbs in large-sized canopy are maximal. When WinsCanopy2004a (2002) is used for the apple tree canopy analysis, the LAI2000 methods should be selected simultaneously.

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