July 2016. Horticultural Plant Journal, 2 (4): 181–187.

Horticultural Plant Journal

Available online at www.sciencedirect.com
The journal's homepage: http://www.journals.elsevier.com/horticultural-plant-journal

# Leaf Potential Productivity at Different Canopy Levels in Densely-planted and Intermediately-thinned Apple Orchards

SUN Ying [a,b], ZHANG Yin [c], JIANG Yuanmao [a], SONG Kai [a], GAO Juhong [a], ZHANG Dingyou [a], and ZHANG Jixiang [a,*]

[a] *State Key Laboratory of Crop Biology, National Research Center of Apple Engineering and Technology, College of Horticultural Science and Engineering, Shandong Agricultural University, Tai'an, Shandong 271018, China*

[b] *College of Science and Information, Qingdao Agricultural University, Qingdao, Shandong 266109, China*

[c] *Liaocheng Meteorological Administration, Liaocheng, Shandong 252000, China*

Received 25 March 2016; Received in revised form 20 June 2016; Accepted 2 July 2016

Available online

**Abstract**

Most apple orchards in the apple production districts in China were densely planted with vigorous rootstocks during the 1980s. These orchards have suffered micro-environmental deterioration and loss of fruit quality because of the closed canopy. Modification of the densely-planted orchards is a priority in current apple production. Intermediate thinning is a basic technique used to transform densely-planted apple orchards in China. Our goal was to provide theoretical basis for studying the effect of thinning on the efficiency of photosynthetically active radiation (*PAR*), fruit quality, and yield. We measured leaf area, solar radiation, and leaf air exchange at different tree canopy levels and by fitting relevant photosynthetic models, vertical distribution characteristics of leaf photosynthetic potentials and *PAR* were analyzed in various levels within canopies in densely-planted and intermediately-thinned orchards. Intermediate thinning significantly improved the radiant environment inside the canopies. *PAR* distribution within the canopies in the intermediately-thinned orchard was better distributed than in the densely-planted orchards. The invalid space under 30.0% of relative photosynthetically active radiation ($PAR_r$) was nearly zero in the intermediately-thinned orchard; but minimum $PAR_r$ was 17.0% and the space under 0.30 of the relative height of the canopy was invalid for photosynthesis in the densely-planted orchard. The leaf photosynthetic efficiency in the intermediately-thinned orchard was improved. Photosynthetic rates ($P_n$) at the middle and bottom levels of the canopy, respectively, were increased by 7.80% and 10.20% in the intermediately-thinned orchard. Leaf development, which influences photosynthetic potential, was closely related to the surrounding micro-environment, especially light. Leaf photosynthetic potentials were correlated with leaf nitrogen content ($N_l$) and specific leaf weight ($M_l$) at various levels of canopies. Compared with the densely-planted orchard, the photosynthetic capacity parameters, such as maximum carboxylation rate ($CE_{max}$) and maximum electron transfer rate ($J_{max}$), significantly increased in the intermediately-thinned orchard. Leaf photosynthetic potentials mainly depended on $N_l$ and $N_l$ was closely related to $PAR_r$. Leaf photosynthetic potentials and $PAR_r$ can be assessed using spatial distribution patterns of relative leaf nitrogen content ($N_{lr}$).

*Keywords*: photosynthetically active radiation (*PAR*); maximum carboxylation rate ($CE_{max}$); leaf nitrogen content ($N_l$); maximum electron transfer rate ($J_{max}$); specific leaf weight ($M_l$)

## 1. Introduction

Thinning is a common method used to promote tree growth in fruit tree or forest tree management (Smith, 1986; Han et al., 2003, 2006; Xu et al., 2014). Thinning increases the space for additional tree growth and canopy development, and photosynthetic area is increased (Lavigne, 1988; Medhurst and Beadle, 2001; Warren and Adams, 2001; Yu et al., 2003). Thinning increases availability of solar radiation, mineral nutrition, and water (Morikawa et al., 1986; Bréda et al., 1995; Kolb et al., 1998). Landsberg and Waring (1997) and Sabaté et al. (2002) simulated the utilization efficiency of $CO_2$ and solar irradiation energy

* Corresponding author. Tel.: +86 538 8249953.
*E-mail address*: zhangjx365@163.com

Peer review under responsibility of Chinese Society for Horticultural Science (CSHS) and Institute of Vegetables and Flowers (IVF), Chinese Academy of Agricultural Sciences (CAAS)

http://dx.doi.org/10.1016/j.hpj.2016.07.003

in relation to tree growth, and estimated $CO_2$ assimilation efficiency of canopy and tree productivity to determine the effects of thinning. However, thinning effects vary with environmental conditions, tree age, thinning technique, and thinning extent (Peterson et al., 1997; Tang et al., 1999, 2003; Johnsen et al., 2000).

Solar radiation affects the N content of leaves located at different levels within canopy in order to acclimate environmental change and to optimize the photosynthetic capacity of the total canopy (Evans, 1989; Schoettle and Smith, 1999; Genard et al., 2000; Wilson et al., 2000; Meir et al., 2002; Han et al., 2003; Zhang et al., 2009). Leaf photosynthetic potential within the canopy is related to the N distribution pattern inside leaves. *PAR* inside the canopy can alter N reallocation inside mature leaves within the canopy, and this represents another response to radiation changes (Brooks et al., 1996). However, the acclimation mechanisms of the photosynthetic processes of the canopy and changes of leaf N content are not well studied in relation to changes of the environment following tree thinning (Medhurst and Beadle, 2005).

Since the 1980s, close tree planting with vigorous rootstocks has been used to provide early season fruit production, increased yields, and greater profits (Liu and Pu, 1987; Yang et al., 1998; Sun et al., 2000; Wei et al., 2003, 2004; Gao et al., 2006; Zhang et al., 2009; Zhai, 2012). However, close tree planting has created several problems including canopy closure, tree structure disorder, accelerated tree aging, micro-environment deterioration, increased production costs, increased pest and disease damage, decreased fruit quality, and decreased production efficiency (Wei et al., 2003, 2004; Zhang et al., 2009). Thinning techniques used in densely-planted apple orchards are keys to generate high quality, yield, efficiency, and sustainable development.

Thinning is a basic technique used in densely-planted apple orchards in China (Wei et al., 1997). Thinning can have positive effects on fruit quality and yield (Liu and Pu, 1987; Yu et al., 1999; Wei et al., 2004; Zhang et al., 2009). It is poorly known, however, how the leaves at different positions within the tree canopy adapt themselves to different micro-environments. The objectives of this study were to (1) quantify *PAR* availability following thinning; (2) study the relationship between leaf photosynthetic potential and *PAR*, using comparative analysis of leaf adaptation to micro-environments within the tree canopy; (3) determine if thinning leads to N reallocation between and/or inside leaves; and (4) provide data supporting modification of apple orchard planting density.

## 2. Materials and methods

### 2.1. Test orchards and thinning methods

The study was conducted in Sunjia Village (N 37°25′, E 120°30′), Zhaoyuan City, Shandong Province of China, from June to September in 2012. The apple cultivar was 'Red Fuji' (*Malus pumila* Mill. 'Red Fuji') grafted onto *Malus hupehensis* Rehd. The trees were 15 years old with a hierarchical-scattered tree structure. The orchard area was 4.0 $hm^2$ and the trees were planted at plant spacing and row spacing of 3.0 m × 4.0 m with north-south row direction. Management (fertilization, irrigation, pesticide applications, pruning, etc.) was done using local apple orchard administration methods. One half of the orchard (about 2.0 $hm^2$) was modified by intermediate thinning of every other row in December 2011. The intermediately-thinned and densely-planted orchards were similarly managed. During the test period, the tree canopy width and canopy height averaged (3.1 ± 0.2) m and (2.4 ± 0.2) m in the densely-planted orchard and (3.2 ± 0.2) m and (2.5 ± 0.2) m in the intermediately-thinned orchard.

### 2.2. Measurements of spatial distribution of PAR

Three trees were selected with similar shape, structure, and size in the densely-planted and intermediately-thinned orchards, respectively. With the trunk as the center and perpendicular to the row direction, part of the selected tree canopy was divided into several sets of cubic cells in 50 cm × 50 cm × 50 cm using frames made of steel tubes. A line quantum sensor (1 m long) with Li-1400 data logger (LI-COR, USA) was used to measure *PAR* at the bottom of each cubic unit. In order that the length of the line sensor fitted the length or width of the unit, half a length of sensor (0.5 m) was wrapped with a piece of black paper. So the actual *PAR* should be double the measured values. Every 10 d from June to September, a clear day was selected to measure the *PAR* at each unit every 2 h from sunrise to sunset. At each sample time, measurements were taken from the bottom to the top of the tree canopy and then from the top to the bottom. This provided two measured values at every unit for each sample time. Means for each time, daily means, and total means during the test of $PAR_r$ (the ratio of *PAR* at the unit within the canopy to that at the top of the canopy) were calculated.

### 2.3. Measurements of leaf area

In early June (at the test beginning) and late September 2012 (at the test end), the leaf numbers in every cubic unit were counted. Approximately 5% of the leaves were sampled and the leaf area was measured with a leaf area meter (Li-3100C, USA). The leaf area of every unit and the entire canopy and leaf area index (*LAI*) of the orchards were estimated.

### 2.4. Measurements of leaf gas exchange

Three fully expanded and non-senescing leaves on the middle of shoots within each cubic unit were selected to measure gas exchange using portable infra-red gas analyzers (CIRAS-2, PP Systems, Hitchin, UK). A clear day about every 15 d during the test was used to conduct the measurements from 6:00 to 18:00. On the sample day, leaf net photosynthetic rate ($P_n$) and *PAR* in each cubic unit were logged every 2 h from the top to the bottom of the canopy, respectively, in the intermediately-thinned and densely-planted orchards. The response curves of $P_n$ to *PAR* at the top, middle, and bottom of the canopy were fitted using hyperbolic and parabolic models provided by Software Origin 6.0 (Barritt, 1989; Sun et al., 2000; Buler et al., 2001; Costes et al., 2002; Gao et al., 2006).