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THE IMPACT OF LIGHT PENETRATION INTO CANOPY AND SEASONALITY ON PHOTOSYNTHETIC INDICES IN APPLE TREE LEAVES

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ABSTRACT

The aim of this study was to analyse the impact of light penetration into canopy and the effect of distances between technological tools and seasonality on photosynthetic behaviour. Apple tree cultivar 'Auksis' was grafted onto super-dwarfing rootstock P22 and planted at different distances (from 0,25 m to 1 m in rows, while space between rows was 3 m). Photochemical reflectance and plant senescence reflectance indices were measured at two heights: 1.0 – 1.2 m above ground and 1.8 – 2.0 m above ground; specific leaf area, fresh and dry weight were evaluated from all the canopy. Strong positive correlations were determined between photochemical reflectance index and plant senescence reflectance index in higher and lower levels of the canopy. Strong negative correlations were determined between photochemical reflectance index and plant senescence reflectance index and between specific leaf area and dry and fresh mass ratio. Increasing density between apple trees from 1 m to 0.5 m led to increase in photochemical reflectance index and specific leaf area, but plant senescence reflectance index decreased. Meanwhile, seasonality had significant impact on specific leaf area formation and dry to fresh weight ratio. Dry and fresh weight ratio increased by 5% in autumn compared to summer. Our results indicated that with decreased light penetration into canopy photochemical reflectance index decreased, but plant senescence reflectance index increased. Moreover, in autumn, trees prepare for winter by storing more nutrients and leaves accumulate more dry mass.

Key words: *apple tree, seasonality, light penetration, planting density.*

INTRODUCTION

In regard to increasing global food demand, horticulture poses new challenges to grow large quantities of good quality fruits in small areas. Fruit yield depends on photosynthetic processes ant it is important to optimize photosynthetic productivity. The main part of the biomass quantity is dependent on the optimal photosynthesis system work (Long et al., 2006, Hüner et al., 2016). Photosynthesis is close not only to individual leaf but also on the light penetration through the canopy (Song et al., 2013). Young trees cover little with each other, but as the canopy is formed, the amount of light penetration into the canopy on the tree decreases (Cherbiy-Hoffmann et al., 2012). However, high density planting principle is to make the best use of space and light by planting of a greater number of plants through manipulation of tree size to get optimal return from tree (Choudhary et al., 2015). High – density planting can enhance the productivity of apple fruits, however, there must be right tree architecture for higher light interception, water and nutrition accumulation (Sharma and Jaipaul, 2014, Liu et al., 2016; Zhang et al., 2017). Variance of carotenoids content and their proportion to chlorophylls are therefore commonly used for the analysis of plant physiological state. Photochemical reflectance index (PRI) and plant senescing reflectance index (PSRI) are based on carotenoids and chlorophylls and are typically used to characterize the changes of physiological status of vegetation. Thus PRI characterizes the photosynthetic efficiency, the plant senescing reflectance index (PSRI) was found to be sensitive to the carotenoids and chlorophyll ratio and was used as a quantitative measure of leaf senescence (Merzlyak et al. 1999, Sims and Gamon 2002, Garbulsky et al. 2011). Specific leaf area (SLA) is calculated as leaf area per unit mass. Konopka et al. (2016) found that SLA was the smallest at the top of the canopy in full light conditions and increases with shading. Larger SLA with increasing shading is likely an adaptation for more efficient light interception in low light conditions (Niinemets et al., 2001). The main aim of this study was to analyse the impact of light penetration into canopy and the effect of distances between technological tools and seasonality on photosynthetic behaviour.

MATERIAL AND METHODS

A field experiment was carried out in an intensive orchard at the Institute of Horticulture, Lithuanian Research Centre for Agriculture and Forestry, Lithuania. The apple tree (*Malus domestica* Borkh.) cultivar 'Auksis' was grafted on super-dwarfing rootstocks P22. Trees were planted in distances: 0,25 m, 0,5 m, 0,75 m and 1 m between trees in rows, while space between rows was 3 m. Pest and disease management was carried out according to the integrated plant protection practices, the orchard was not irrigated. Soil conditions of the experimental orchard were as follows: clay loam, pH 7.3, humus 2.8%, P_2O_5 255 mg kg^{-1}, K_2O 230 mg kg^{-1}. Three single trees were selected randomly. Measurements and leaf samples were taken in the middle of July (BBCH 73 – 75) and at the end of August (harvest time BBCH 87-88).

Photochemical reflectance index (PRI)was evaluated using non-destructive method (CI-710 Leaf spectrometer, CID Bio-Science, WA USA) from five leaves from each tree at two heights: 0.8 m above ground inside the canopy and 1.5 m above ground outside the canopy. The PRI combines reflectance at 531 nm (R531) with a reference wavelength insensitive to short-term changes in light energy conversion efficiency (R570) and normalizes it:

PRI= (R_{531} - R_{570})/ (R_{531} - R_{570})

Nitrogen balance index (NBI) was evaluated using non-destructive measurements of leaf chlorophyll and flavonoid content in the epidermis (Dualex ®4, Dynamax Inc., USAfrom five leaves from each tree at two heights: 0.8 m above ground inside the canopy and 1.5 m above ground outside the canopy.

To determine the leaf area (cm^2), twenty leaves were randomly sampled from the whole tree canopy and measured with a leaf area meter (AT Delta – T Device, Burwell Cambridge UK). The dry mass of twenty leaves was determined by drying apple leaves at 70ºC (Venticell 222, Medcenter Einrichtungen, Gräfeling, Germany) to constant weight (48 hours). SLA was defined as the leaf area per unit of dry leaf mass, usually expressed in $cm^2\ g^{-1}$.

The data were processed using two-way and three-way analysis of variance (ANOVA) at the confidence levels $P \leq 0.05$ and $P \leq 0.01$.

RESULTS AND DISCUSSION

Plant senescence reflectance index (PSRI) significantly changed during the season. The trees were less stressed on the beginning of July, especially on largest distance on the top of canopy (Fig. 1). As Merzlyak et al. (1999) determined that the PSRI goes less than 0 it is the begging of leaves senescence. The senescence of the most densely planted trees begun from the beginning of apple maturity (BBCH 73 – 75), meanwhile all other planting densities resulted the senescence processes only during the harvest time.

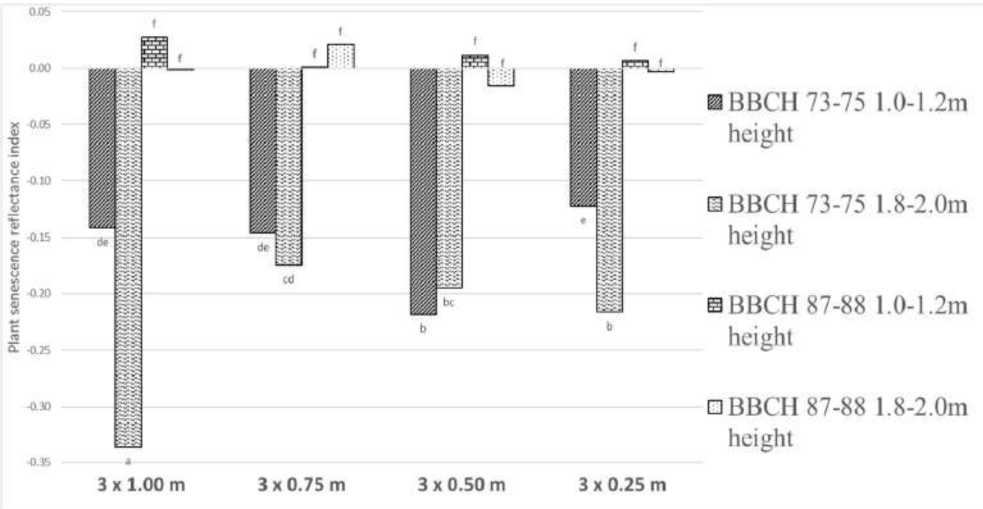

Figure 1 Plant senescence reflectance index in two heights in apple trees. Averages followed by different letter between treatments indicate significant differences according to the Duncan's least significant difference test ($P < 0.05$).

No significant impact for PRI was determined at the begging of apple maturity. Weng at al. (2010) found that PRI decreased in mango tree leaves with the increased illumination. Meanwhile, increased apple trees density from 3 x 1.00 m to 3 x 0,75 m PRI also increased 1.5 – 2.0 times irrespective of any further increase in density (Fig. 2). PRI can serve as an indicator of the seasonal variation of potential PSII efficiency (Weng et al. 2006). The leaves were rapidly senescing, as the ratio of chlorophylls to carotenoids decreased in the autumn. Because of that, PRI decreased up to 3 times on harvest time compared to the beginning of apple maturity (BBCH 73 – 75).

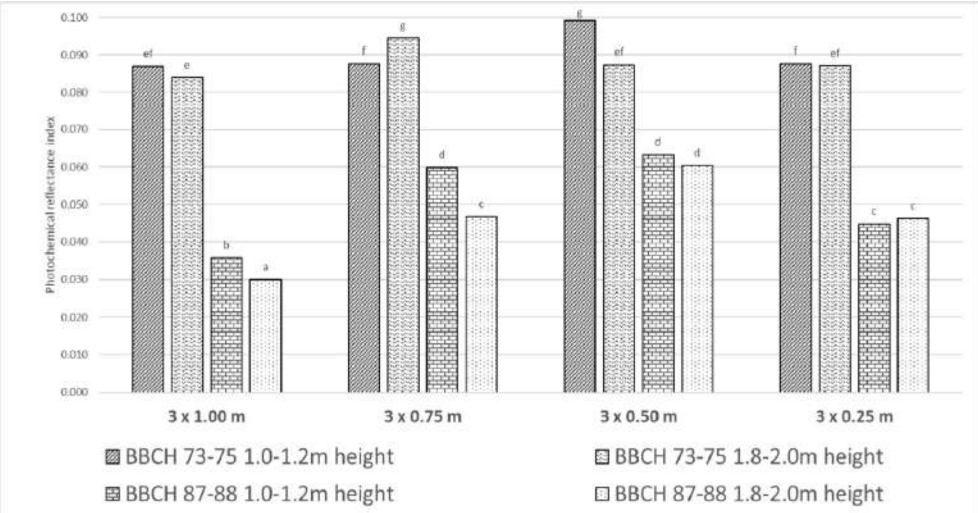

Figure 2. The effect of light penetration into the canopy, the distance between trees and seasonality on the photochemical reflectance index. Averages followed by different letter within between treatments indicate significant differences according to the Duncan's least significant difference test ($P < 0.05$).

SLA was significantly higher at the beginning of apple maturity (BBCH 73 – 75), leaves accumulate less dry matter compared to harvest time. Jagodzinski et al. (2016) shows diferences between flowering ang growing stages during different seasons in 12 forest herb species, and the trends are the same as in our research. Decreased density between apple trees resulted the increase of SLA (Fig. 3). This means that there is bigger competitive stress between apple trees and they form bigger leaves, but less dry matter. Bigger leaves is response to lack of light (Niinemets et al., 2001). Higher SLA can lead to higher photosynthetic efficiency (Wright et al., 2004), but also shows that leaves were shaded and indicates ligth deficiency (Wyka et al. 2012, Neufeld and Young, 2014, Konopka et al. 2016). Apple tree leaves accumulated more dry matter during harvest time compared to summer time. The higher dry to fresh weight ratio was obtained in leaves from trees planted in distance of 0.75 m between apple trees. By the increased density between apple trees, the dry mass decreased (at the same time Dry/fresh weith ratio decrease was observed), but it resulted the increase of SLA. This is in agreement with results of Sims et al. (1994), and Poorter & Nagel (2000).

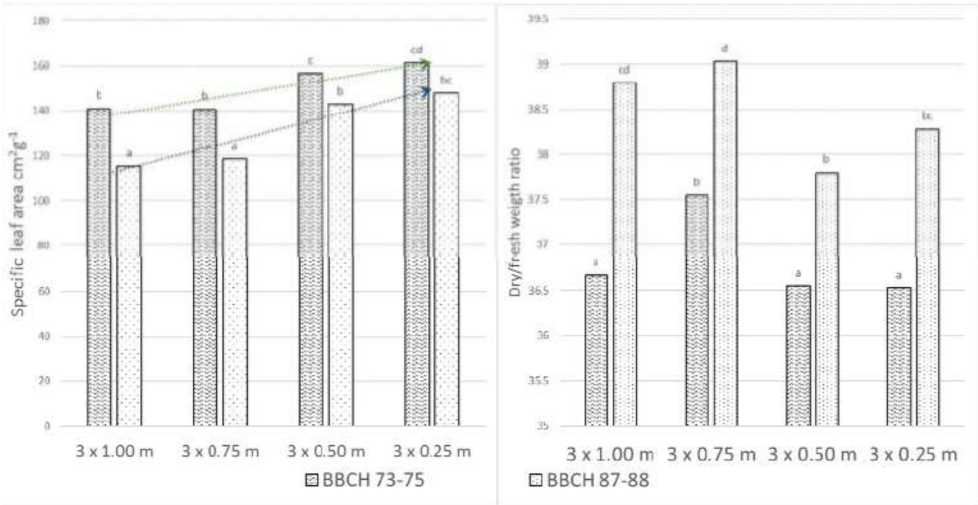

Figure 3 The effect of the distance between trees and seasonality on Specific leaf area and on dry and fresh weight ratio in 'Auksis' apple tree. Averages followed by different letter within between treatments indicate significant differences according to the Duncan's least significant difference test (P < 0.05).

CONCLUSIONS

Decreased light penetration into canopy resulted the decrease of PRI, but PSRI increased, the same tendency of photochemical indices variation during both measurements was observed. Increased density between apple trees lead to increased SLA, but it resulted the decrease of dry/fresh weight ratio, however, bigger leaves, but less dry weight were formed. The accumulation of dry weight was more intensive in autumn.

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