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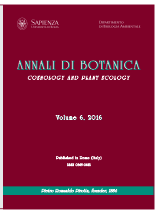

PHOTOSYNTHETIC PRODUCTIVITY OF PEAR TREES GROWN ON DIFFERENT ROOTSTOCKS

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Abstract – Since the pear is not a flagship crop in Polish orchards, very little advanced research is conducted to obtain knowledge about its photosynthetic productivity strategies. The research described in this paper involves measurements of the physiological state and yield of pear trees (cv. Conference) budded on different rootstocks. The main aim is to monitor the influence of budding on different rootstocks on photosynthetic productivity, growth, and yield of this cultivar, in order to improve agricultural practices for a sustainable horticulture. Leaf gas exchange, photosynthetic efficiency, leaf area index, and chlorophyll content were measured, as was tree yield. Our results provide better understanding of the physiological factors behind pear productivity.

Keywords: Chlorophyll Fluorescence, LAI, Photosynthesis, Photosystem II, *Pyrus communis*

Introduction

Trees grown in modern orchards should be small, with heavily abundant yielding, and exhibit optimum mineral nutrition. Many experiments have shown that these features of fruit trees are genetically determined (Lepsis & Drudze, 2011). In the case of the 'Conference' cultivar, growth and yield were proven to be dependent on proper selection of rootstock (Zygmuntowska & Jadczuk-Tobjasz, 2008). It is widely known that rootstocks affect the productivity and several physiological parameters of fruit trees of different species, however many studies reported contrary specific conclusions in this regard (Iacono et al., 1998; Muleo et al., 2002; Cinelli et al., 2004). In most cases, the studies conducted in Poland did not take into account the physiological conditions of the trees, which are modified in connection with the use of different rootstocks. These types of research are conducted for flagship species in Poland, and contribute to a better understanding of the mechanisms and processes of yield formations. Hence, there is a need to integrate the classical methods of growth and yield assessment with those that allow prediction of the photosynthetic productivity and physiological potential of pear yielding.

Photosynthetic productivity has been widely used as an important physiological parameter to evaluate the plant growth vigor, and, ultimately, biomass or economic yields (Kalaji & Pietkiewicz, 2004; Kalaji et al., 2011a, b). One of these parameters is the photosynthetic rate, which is a major factor influencing the final yield of fruit trees (Pérez et al., 1997; Liu et al., 2012). Indeed, many researchers pointed out that the rootstock has a direct influence the trees' gas exchange parameters (Fallahi et al., 2002; Losciale et al., 2008,).

Additionally, tree architecture and the efficient use of photosynthetically active radiation (PAR) can also be

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decisive for tree growth and yielding (Costes et al., 2006). It is well known that plant productivity depends on the interaction between leaf area light interception and the efficiency of the CO_2 assimilation process. However, the maximum fruit yield is ultimately limited by light interception and economic fruit yield is a function of the efficiency of light use and light distribution within the canopy.

All plants absorb light mainly through chlorophyll. Thus, chlorophyll fluorescence is a suitable indicator of photosystem II (PSII) efficiency, and has been routinely used for many years to non-invasively monitor the photosynthetic performance of plants (Kalaji et al., 2011b; Brestic et al., 2012; Kalaji et al., 2012a). Factors causing damage of the photosynthetic systems can, therefore, be recognized through changes in different fluorescence parameters. Efficiency of the PSII of fruit trees may vary depending on the rootstock (Pestana et al., 2005). Research of Pérez et al. (1997) showed that cherry trees of the same cultivar budded on three different rootstocks have very different chlorophyll fluorescence parameters. Chlorophyll fluorescence can also be used to determine potential photosynthetic productivity of plants together with gas exchange (Kalaji et al., 2012b).

Due to the increased interest in pear cultivation in Poland during the last decade, we conducted experiments to check how budding on different rootstocks influences the photosynthetic productivity, growth, and yield of the 'Conference' pear cultivar.

MATERIALS AND METHODS

The research was conducted at the experimental field of the Department of Pomology (52°9'26 north latitude and 21°6'24 east longitude), WULS-SGGW (Warsaw, Poland). This site is located in the postglacial valley of the Vistula River on alluvial land with a fertile silt loam. The mean temperature in the years when research was conducted (2011-2013) was 9.2 °C and total three year rainfall was 565.6 mm. The pear trees were planted in 2004 at (4+1) x 1.5 m (2666 trees · ha^{-1}). The distance between trees in a row was 1.5 m and the distance of rows in strip was 1 m. The distance between strips was 4 m. In trees rows herbicide fallow were maintained while in inter-rows, sward had been growing since the first year after tree planting. The average height and diameter were about 3 m and 7 cm, respectively. Tree training, protection against diseases and pests were carried out according to the recommendations for commercial orchards in Poland.

Plant gas exchange, chlorophyll content, chlorophyll fluorescence, and leaf area index measurements (see details below) were performed once a month during the vegetation period (May to August) in 2011-2013, on trees budded on three rootstocks: Quince S1, Quince MA and Pyrodwarf.

Ecophysiological measurements

Plant gas exchange parameters were measured on sunny days, between 8:00 and 11:00 AM, *in vivo*, on leaves fully expanded, directed at the sun, located in the middle part of the crown (12 measurements for each rootstock, 4 measurements per tree), by means of the Ciras-2 Photosynthesis Measurement System (PP Systems Inc., USA). Mean values of ambient light intensity, air temperature and CO_2 concentration were ca. 1300 µmol photons · m^{-2} · s^{-1}, 21 °C and 380 ppm respectively. The following parameters were measured: Net photosynthesis rate - P_N (µmol CO_2 m^{-2} s^{-1}), transpiration rate E (mmol H_2O m^{-2} s^{-1}) and stomatal conductance - gs (mmol m^{-2} s^{-1}).

Quantum efficiency of the leaves' photosynthetic light to energy conversion (36 measurements for each rootstock, 12 measurements per tree) was measured *in vivo* by the application of chlorophyll fluorescence technique. Measurements were done after the leaves' adaptation in the dark (for 30 minutes, using special leaf clips), by means of continuous excitation system – HandyPEA fluorimeter (Hansatech Instruments Ltd., UK), where a saturation light pulse of 1 s duration and 3500 µmol photons · m^{-2} · s^{-1} intensity was applied after dark adaptation to the sample. Many parameters were measured, however, in this work we discussed only the following 2 parameters: maximum quantum yield of photosystem II (Fv/Fm) and performance index (PI_{abs}). The latter is calculated on the base of the following equation:

$$PI_{abs} = \frac{1-(F_0/F_M)}{M_0/V_J} \times \frac{F_M - F_0}{F_0} \times \frac{1-V_J}{V_J}$$

where: F_0 means fluorescence intensity at 50 µs, F_J is fluorescence intensity at the J step (at 2 ms), F_M represents maximal fluorescence intensity, V_J is relative variable fluorescence at 2 ms calculated as $V_J = (F_J - F_0) / (F_M - F_0)$, M_0 represents initial slope of fluorescence kinetics, which can be derived from the equation: $M_0 = 4^* (F_{300\ \mu s} - F_0) / (F_M - F_0)$.

A CL-01 (Chlorophyll Content Meter, Hansatech Instruments Ltd., UK) was used to measure relative chlorophyll content *in vivo* (36 measurements for each rootstock, 12 measurements per tree). The trees' Nitrogen Balance Index (NBI) was measured on fully expanded leaves (36 measurements for each rootstock, 12 measurements per tree), using a Dualex fluorimeter (Force-A, France).

The Leaf Area Index (LAI) was measured on 12 trees of each rootstock, using an AccuPAR-LP 80 Ceptometer (Decagon Devices Inc., USA).

Plant growth

Tree vigor was assessed on the basis of the trunk cross-sectional area parameter (TCSA). The TCSA parameter was derived from a diameter measurement made at 30 cm above the ground (12 replications). The yield was assessed on the basis of yield obtained per hectare.

Statistical analysis

Measurements of plant gas exchange, NBI, chlorophyll fluorescence and its content were done on the same leaves. The results presented, are average values from the whole season. The results were elaborated by a one-way analysis of variance with the use of FR – ANALWAR software. Tukey's test at $\alpha = 0.05$ was used to evaluate the significance of differences between treatment means. However, only significantly differentiated data are shown in this work.

RESULTS AND DISCUSSION

In this work, we studied the effect of rootstocks on the productivity and yield of the pear, as this has been considered an important factor in pear cultivation (Zygmuntowska & Jadczuk-Tobjasz, 2008). To date, pear productivity has been evaluated based on the growth model and yield parameters. Additionally, in the recent years, some studies started to consider certain physiological parameters, such as the photosynthetic rate, capacity and efficiency (Lin & Wang, 2007, Cui et al., 2009, Lin et al., 2010). Thus, the aim of our research was to obtain more knowledge about the mechanisms and strategies which can be responsible for varied tree performance on different rootstocks, by analyzing some physiological parameters in a non-invasive way, e.g. through photosynthetic efficiency and tree architecture assessment.

The net photosynthetic rate (P_N) depended on the rootstock type. The highest P_N was observed, in each year of research, in trees growing on Pyrodwarf. However, in 2011 and 2013 only differences between trees budded on Quince MA and Pyrodwarf were statistically significant (Tab. 1). The rate of photosynthesis is generally lower for trees on dwarf rootstocks (Ferree & Barden, 1971; Schechter et al., 1991). The same observations have been made by Baugher et al. (1994), who reported significantly higher values of P_N in apple trees (cv. 'Golden delicious') on strongly growing MM.111 EMLA and semi-dwarf M.7 EMLA in comparison to the M.9 EMLA dwarf rootstock. Rootstock type had an influence on stomatal conductance (gs) and transpiration rate (E). The highest values of these parameters were noted for trees budded on Pyrodwarf, except in 2011, when no significant differences between rootstocks were found (Tab. 1). Many authors reported changes in gas exchange of fruit trees grown on various rootstocks. Fallahi et al. (2002) identified a higher transpiration rate for 'Fuji' apple trees on M.9 EMLA compared to M.7 EMLA, while Garcia-Sanchez et al. (2002) have found no differences in mandarin trees on various rootstocks. Also other gas exchange parameters and water use efficiency (WUE) can change depending on rootstock. Bongi et al. (1994) and Matos et al. (1997) reported significant differences in P_N for peach and almond trees respectively, however they did not find changes in stomatal conductance. Nevertheless, since gas exchange can be influenced by other factors (morphological features, mineral nutrition, water availability, models of assimilate distribution, etc.), the reasons of such influence of the rootstock remain unknown.

Table 1. Trees gas exchange parameters in leaves of pear trees grown on different rootstocks in the three years of research. Values marked with the same letters are not significantly different according to Tukey's test ($\alpha = 0.05$).

	Trees gas exchange parameters					
	2011		**2012**		**2013**	
Net photosynthesis rate P_N (µmol CO_2 m^{-2} s^{-1})						
Quince MA	11.2	a	6.4	a	8.6	a
Quince S1	12.2	ab	6.4	a	9.2	ab
Pyrodwarf	13.2	b	7.2	b	10.2	b
Stomatal conductance gs (mmol m^{-2} s^{-1})						
Quince MA	164	a	124	a	145	a
Quince S1	153	a	97	a	124	a
Pyrodwarf	165	a	173	b	170	b
Transpiration rate E (mmol H_2O m^{-2} s^{-1})						
Quince MA	2.1	a	2.6	a	2.4	a
Quince S1	2.1	a	2.1	a	2.1	a
Pyrodwarf	2.2	a	3.0	b	2.7	b

Rootstock type has an influence on the maximum quantum yield of photosystem II (Fv/Fm) and performance index (PI_{abs}) (Losciale et al., 2008), the leaf area index (LAI) (Costes et al., 2006) and chlorophyll content (Sabajeviene et al., 2006; Lepsis & Drudze, 2011). Trees budded on Pyrodwarf rootstock showed higher values of all mentioned parameters when compared with other studied rootstocks (Tab. 2, Fig. 1-2). Our work confirms the results of Pérez et al. (1997), who reported that changes in chlorophyll fluorescence parameters and pigment composition reflect the different suitability of various rootstocks. They reported that the same variety of *Prunus avium* grafted onto three different rootstocks shows different photosynthetic capacities. Also Martinazzo et al. (2011) found differences in some parameters, such as PI_{abs}, depending on rootstock type, in peach trees. The decrease of this value may be related to a reduction of the photosynthetic rate because, in favorable conditions, the "potential" and "real" efficiencies tend to be related (Bussotti et al., 2011).

Table 2. Chlorophyll fluorescence parameters in dark-adapted leaves of pear trees grown on different rootstocks in the three years of research. Values marked with the same letters are not significantly different according to Tukey's test (α = 0.05).

Chlorophyll fluorescence parameters						
	2011		**2012**		**2013**	
Maximum quantum yield of PSII (Fv/Fm) (arbitrary units)						
Quince MA	0.80	a	0.81	a	0.80	a
Quince S1	0.80	a	0.81	a	0.80	a
Pyrodwarf	0.81	b	0.82	b	0.81	b
Performance Index (PI_{abs}) (arbitrary units)						
Quince MA	4.42	a	3.01	a	5.55	a
Quince S1	4.38	a	3.27	a	5.38	a
Pyrodwarf	5.77	b	3.94	a	6.48	b

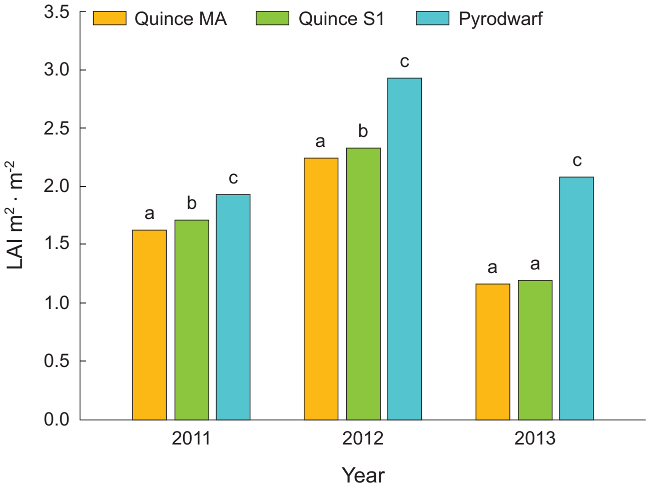

Fig. 1. Leaf Area Index (LAI) of pear trees grown on different rootstocks in the three years of research. Bars marked with the same letters are not significantly different according to Tukey's test (α = 0.05).

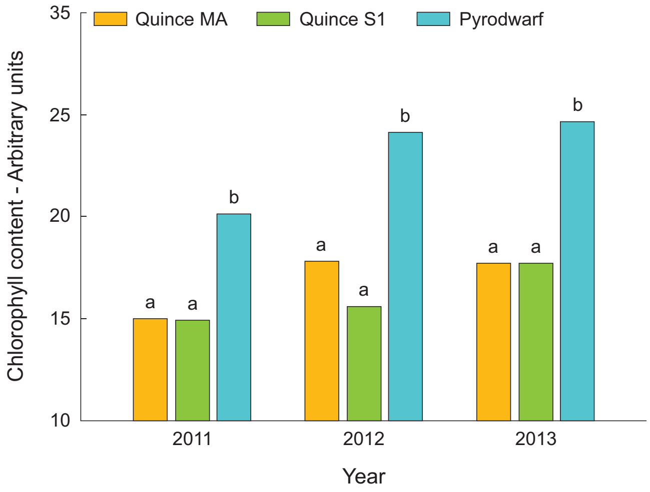

Fig. 2. Chlorophyll content in leaves of pear trees grown on different rootstocks in the three years of research. Bars marked with the same letters are not significantly different according to Tukey's test (α = 0.05).

Dependence of photosynthetic efficiency of fruit trees on different rootstocks may be due to the different chlorophyll content in leaves (García-Sanchez et al., 2002; Kosina, 2003; Pestana et al., 2005; Sabajeviene et al., 2006; Abdollahi et al., 2010; Francescatto et al., 2010; Lepsis & Drudze, 2011) and leaf area index (Costes et al., 2006). Gjamowski & Kiprijanovski (2011) and Gyeviki et al. (2012) have concluded that strongly growing rootstocks cause an increase of LAI in apple and cherry trees respectively. In our research trees grown on Pyrodwarf rootstock showed higher values of LAI (Fig. 1) and chlorophyll content (Fig. 2) compared to trees grown on Quince MA and Quince S1. At the same time, trees on Pyrodwarf had a higher nitrogen balance index (NBI) (Fig. 3), which is an indicator of better photosynthetic potential. A higher NBI value means that plant favors primary metabolism and synthesizes proteins (nitrogen-containing molecules) containing chlorophyll and just a few flavonols (carbon-based secondary compounds).

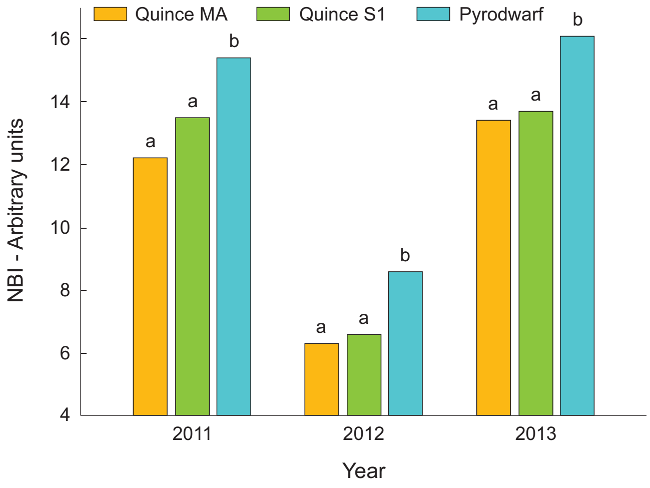

Fig. 3. Nitrogen Balance Index (NBI) of pear trees grown on different rootstocks in the three years of research. Bars marked with the same letters are not significantly different according to Tukey's test (α = 0.05).

Rootstock type also has an influence on the trunk cross-sectional area, i.e. TCSA, but does not affect the yield of trees (Lepsis & Drudze, 2011). In our experiment, the TCSA was higher for trees budded on Pyrodwarf than for Quince MA and Quince S1 (Fig. 4) and yield was generally lower for trees on Pyrodwarf (Tab. 3). Similar results were obtained by Lewko et al. (2007), who found that seedlings on Pyrodwarf achieved higher vigour and better branching than on Cydonia. Additionally, seedlings on Pyrodwarf developed the strongest root system; the other rootstocks had weaker roots. Research conducted by Kviklys (2006) in Lithuania indicates that trees on Pyrodwarf have stronger growth than others (e.g. Quince C). Loreti et al. (2002) also concluded that the 'Conference' cultivar has weaker growth and yielding on Quince MA and C rootstocks.

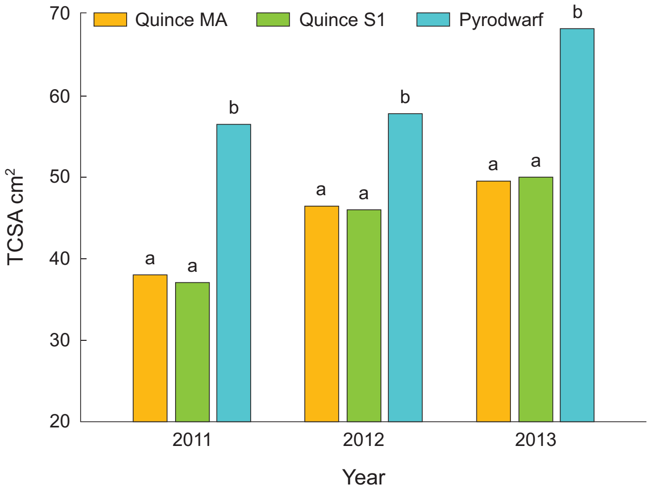

Fig. 4. Trunk cross-sectional area (TCSA) of pear trees grown on different rootstocks in the three years of research. Bars marked with the same letters are not significantly different according to Tukey's test (α = 0.05).

Table 3. Final yield of pear trees grown on different rootstocks in the three years of research (t · ha^{-1}). Values marked with the same letters are not significantly different according to Tukey's test (α = 0.05).

	Yield (t · ha^{-1})					
	2011		2012		2013	
Maximum quantum yield of PSII (Fv/Fm) (arbitrary units)						
Quince MA	24.9	a	7.3	a	35.2	a
Quince S1	28.1	a	7.8	ab	31.6	a
Pyrodwarf	23.5	a	8.8	a	28.2	a

It is known that the upper limit of plantation productivity is imposed by the capacity of the site to supply the resources for plant growth and the ability of the plantation species to acquire resources and convert them into harvestable products. The Pyrodwarf rootstock enhanced light conversion efficiency for wood production, which might result partly from an improvement in the leaves' photosynthetic capacity and partly from and an increase in the proportion of dry matter allocated to wood production.

CONCLUSIONS

Pear trees (cv. 'Conference') growing on Pyrodwarf rootstock have higher values of leaf area index and chlorophyll content in the leaves. This results in higher photosynthetic apparatus efficiency and photosynthetic productivity of trees. However higher photosynthetic efficiency of pear trees on Pyrodwarf was not reflected in a higher yield.

We also concluded that the use of physiological parameters related to photosynthetic plant productivity is an appropriate method for characterizing the productivity strategies of pear trees budded on different rootstocks.

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