INFRASTRUKTURA I EKOLOGIA TERENÓW WIEJSKICH
INFRASTRUCTURE AND ECOLOGY OF RURAL AREAS

Nr III/2/2017, POLISH ACADEMY OF SCIENCES, Cracow Branch, pp. 1177–1185
Commission of Technical Rural Infrastructure

DOI: http://dx.medra.org/10.14597/infraeco.2017.3.2.090

EFFECTS OF IRRIGATION ON FRUIT YIELD AND LEAVES PHOTOSYNTHETIC ACTIVITY IN EARLY AND LATE APPLE CULTIVARS

Cezary Podsiadło, Anna Jaroszewska
West Pomeranian University of Technology

Abstract

The study was conducted in 2008-2009 at the Agricultural Experimental Station in Lipnik near Stargard, on sandy soil. The aim of this study was to determine the effect of sub-crown irrigation on the yield leaves photosynthesis and transpiration capacity, as well as CO_2 concentration in the stomatal cells, and leaf greenness index of early ‚Geneva Early' cv. and late ‚Rubinola' cv. apple cultivars.

Irrigation was applied in the form of the sub-crown system, in which water is distributed through a mini-sprayers of Hadar type when water potential of soil fell below – 0.01 MPa. The experiment was established in a randomized sub-block pattern (split-plot) in 10 replicates. The study was conducted using the four-year-old trees. The trees were planted at 4 × 2 m spacing; one hectare was planted with 1250 trees. Turf was maintained between the trees, while herbicide fallow was applied in rows. Plant material for laboratory tests was collected each year in three dates: fruit setting (date 1), harvest (date 2) and one month after the harvest (date 3). Studies have shown that leaves of the irrigated apple trees were lower content of assimilation pigments in leaves than non-irrigated ones. Leaves of late 'Rubinola' cv. showed higher photosynthetic activity and pigments content than early 'Geneva Early' cv. Pigment content was the highest at the second date of measurements. Better yielding late variety ‚Rubinola' characterized by a greater intensity of transpiration, stomatal conductance and CO_2 concentration leaves than the early variety ‚Geneva Early'. The applied irrigation significantly increased the fruit yield and also increased the fruits weight of both varieties. Among the varieties of apple trees higher yield and fruit mass was found in the late variety ‚Rubinola'. This treatment and the earliness of varieties had no significant effect on the content of other macro – and micronutrients.

Key words: irrigation, yield, photosynthetic activity, apple, cultivars

INTRODUCTION

The apple is a typical temperate crop, grown in all parts of the world in the areas between 36° and 65° north latitude as well as in southern hemisphere areas with favorable climatic conditions. Cultivation of apple trees fails in hot climates, because it requires a cooling period for wintering.

According to the Central Statistical Office (GUS 2002 and 2010), a decrease in the area of apple growing, while increase in the production of cherries, sweet cherries and peaches has been observed in recent years. The most common cultivar grown in Poland is 'Idared' cv., that represents 21.1% of all cultivated apple trees, whereas the other is 'Jonagold' cv., which occupies 11.2% of the apple orchard area. 'Cortland' cv. and 'Lobo' cv. lose their importance, and they are replaced by newer varieties such as 'Ligol' cv. and 'Gala' cv. (Pacholak et al. 2007, Treder 2004).

Contents of individual chemical components of apple fruit vary depending on the cultivar, ripeness and size of the apple fruit, age of the tree, as well as the pad, fertilization, cutting, and also the weather conditions during the vegetation period. The ash components amount of 0.22-0.66% of fresh apple fruit weight depending on the cultivar. The highest quantities characterize potassium, calcium, phosphorus, magnesium, sodium and iron, and they are mainly found in organic and mineral combinations, which facilitates their availability by an organism during digestion. In addition, fruits are a source of many vitamins, such as: A, B_1, B_2, B_3, B_4, B_5, B_6, C, E, H, as well as pectin that have medicinal features (Makosz 2014, Rzekanowski and Rolbiecki 1996). The development of apple fruit production in Poland was affected by significant technological and technical advances and the progress in plantation chemization. In order to improve the quality and size of crops in orchards, irrigation has begun to introduce, because deficient precipitation is detrimental to vegetative growth as well as to fruiting.

The aim of the present study was to determine the effect of irrigation on fruit yield and activity of some physiological processes occurring in the leaves of early 'Geneva Early' and late 'Rubinola'.

MATERIAL AND METHODS

The field experiment was carried out at the Experiment Station in Lipnik belonging to the West Pomeranian University of Technology in Szczecin. Lipnik is a village located in the West Pomeranian province, in Stargard County, about 2 km south-east of Lake Miedwie, on the border of two catchments: the Płonia River and the Ina River. The village is located in the area of the 7th Goleniów-Pyrzyce region, the mesoregion of Pyrzyce-Stargard plain, in the central part of the Szczecin lowland (Koźmiński and Michalska 2000). The field experiment was conducted in 2007-2008 on the soil of good rye complex. The soil was developed from lightweight loamy sand clay, with lightly clay subsoil, strongly sanded and dusty. Geologically, these are the bottom moraines of the last Baltic glaciation, washed with glacial waters, which flowed from the northern tip of Lake Miedwie to the Ina river valley from the Pyrzyce Pleistocene marginal lake. Typologically, they are classified as brown acidic soils. It is characterized by low content of humus (1.3-1.5%), alluvial parts (11-13%), as well as low content of available forms of potassium (11-16.5 $mg \cdot 100g^{-1}$) and phosphorus (12-16 $mg \cdot 100g^{-1}$) and slightly acidic reaction. In terms of cultivation, it is classified as low utility water retention soil. On the other hand, the groundwater level is below 3 m, while the field water capacity for the soil layer to a depth of 100 cm is about 169 mm (Koźmiński and Michalska 2000, Podsiadło *et al.* 2006).

In the orchard, turf was maintained in spaces, while fallow under the trees. The grass was mown eight times during the growing season. The research was carried out in the sixth year after the apple trees planting (‘Rubinola’ cv. and ‘Geneva Early’ cv.). Trees were planted in two rows with spacing of 4 × 2 m. The following fertilization was applied prior to the experiment: manure (60 $t \cdot ha^{-1}$), ammonium nitrate 36 % (60 kg N), triple superphosphate 46 % (30 kg P), and potassium salt 60 % (80 kg K). One row of trees was irrigated with a sub-crown system (mini-spraying) at water potential of soil 0.01 MPa measured using tensiometer. Mini-sprayers of the Hadar type with a spray radius of 1 m were used for irrigation. The experiment was established by means of randomized sub-blocks in split-plot pattern. The first-order factor was sub-crown irrigation for the following objects: O – without irrigation (control), W – irrigation. The second-order factor consisted of the apple tree cultivars: ‘Rubinola’ cv. and ‘Geneva Early’ cv. During the vegetation period, the photosynthetic activity of leaves was measured using a computerized LCA-4 analyser (ADC Bioscentific Ltd. Hoddesdon, UK) operating in an open system. Well developed leaves from the central part of the crown were selected to study, and measurements were made on three trees randomly selected from each combination. In addition, the leaf greenness index was measured using the electronic device Spad. The tree crown was divided into three floors: the lower floor, the middle floor, and the upper floor. In addition, before fruit harvest, the contents of chlorophyll and carotenoids were determined in the fresh leaf matter applying the method by Arnon *et al.* (1956).

Statistical calculations were performed with the analysis of variance of a two-factor experiment in split-plot pattern, with the Tukey test, applying the ANALWAR – 5.1. FR software package.

RESULTS AND DISCUSSION

The demand for water in fruit growing is increasing year by year, which is associated mainly with the ever-increasing intensification of orchard production. The effectiveness of all elements of this production intensification, such as: increased number of trees per hectare, proper care, proper cultivation, and fertilization, are often limited by the amount of water available to the plants. Therefore, to supply extra water to fruit trees has a major impact on increasing the growth rate of shoots and stems, increasing the crop yields, improving the fruit quality, and facilitating the assimilation of mineral fertilizers. Under meteorological conditions of Poland, the water lack is one of the most important factors limiting the crop yields. Its shortage is the cause of water deficit ~~at~~ in plants, resulting from the negative water balance, i.e. the advantage of transpiration over the water adsorption processes (Klamkowski and Treder 2000).

Table 1. The impact of individual factors on selected indicators of the intensity of photosynthetic leaves

Objects		E**	A	G_c	C_i	T_{leaf}
Irrigation	O	1.23	6.73	85.9	201	28.3
	W	1.47	9.49	95.5	182	28.7
Variety	Rubinola	1.68	8.98	124	224	28.1
	Geneva Early	1.02	7.24	56.8	158	28.9
$LSD_{0.05}$ for:	Irrigation	n.s.*	2.51	n.s.	n.s.	n.s.
	Variety	0.36	n.s.	20.1	27.1	n.s.
	Interaction	n.s.	n.s.	n.s.	n.s.	n.s.

*n.s. – not significant
**transpiration (E) [mmol $H_2O \cdot m^{-2} \cdot s^{-1}$], assimilation (A) [µmol $CO_2 \cdot m^{-2} \cdot s^{-1}$], stomatals conductance (G_c) [mmol $H_2O \cdot m^{-2} \cdot s^{-1}$], CO_2 concentration in substomatal cells (Ci) [µmol $CO_2 \cdot mol^{-1}$powietrza], leaf temperature (T) [^oC]

Production of chemical energy accumulated in the form of organic compounds is the result of the correct photosynthesis process, which is an indispensable source of energy for all plants. The proper course of photosynthesis, in addition to solar radiation, temperature and CO_2 availability, is influenced by many factors, the most important of which are genetic properties, mineral availability, and water supply (Nalborczyk 1993, Wojcieska 1994). The activity of physiological processes, as well as the photosynthetic pigments content, affect the intensity of assimilation and transpiration, and thus the yield of cultivated plants. Our own research has shown that irrigation has only significantly increased the intensity of assimilation. In addition, the leaves of late 'Rubinola' cv. were characterized by greater transpiration intensity, stomatal conductance, and CO_2 concentration as compared to early 'Geneva Early' cv. (Table 1).

Table 2. The effect of irrigation and cultivar on the content of assimilation dyes in the leaves [ug • g^{-1} f. m.]

Objects		Chlorophyll a	Chlorophyll b	Total chlorophyll	Carotenoids
Irrigation	O	1604	697	2301	844
	W	1821	834	2655	935
Variete	Rubinola	2367	977	3344	1183
	Geneva Early	1058	554	1612	596
$LSD_{0.05}$for:	irrigation	55.8	41.7	59.7	54.3
	variety	101.2	89.7	112.4	49.0
	interaction	145.0	99.6	151.1	77.8

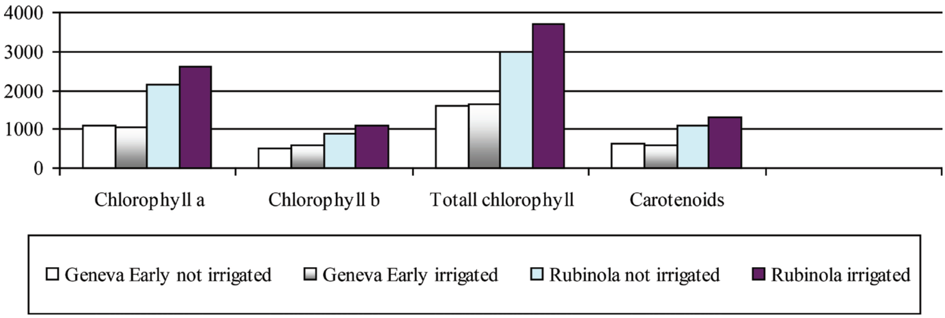

Figure 1. The effect of irrigation and varieties of apple on the content of assimilation dyes in the leaves [g·g^{-1} f. m.]

Moreover, 'Rubinola' cv. demonstrated higher contents of chlorophyll and carotenoid pigments (Table 2) and leaf greenness index at all floors of the tree crown. The effect of irrigation on this indicator was on average insignificant (Table 3).

Table 3. The effect of irrigation and cultivar on leaf greenness index

Obiects		Floor crown			Mean
		Lower	middle	top	
Irrigation	O	42.3	45.3	42.8	43.5
	W	42.8	44.3	41.3	42.8
Variete	Rubinola	45.3	47.9	45.1	46.1
	Geneva Early	39.8	41.7	39.0	40.2
$LSD_{0.05}$for:	irrigation	n.s.*	0.9	n.s.	n.s.
	variety	2.7	5.5	3.5	4.1
	interaction	3.9	n.s.	n.s.	n.s.

*n.s. – not significant

Table 4. The effect of irrigation and cultivar on yield and fruit weight of 100 [kg ·tree^{-1}]

Objects		Yield	Fruit weight of 100
Irrigation	O	9.86	13.9
	W	16.3	14.2
Variety	Rubinola	19.6	16.,7
	Geneva Early	6.59	11.4
$LSD_{0.05}$ for:	irrigation	5.68	n.s.*
	variety	3.45	1.48
	interaction	4.88	n.s.

*n.s. – not significant

Statistic analysis based on our own research has shown that sub-crown irrigation has a significant impact on the yield size resulting in its increase by 65.3% as compared to non-irrigated object (Table 4).

A similar effect was obtained by Podsiadło et al. (2005), who achieved peach fruit yields higher by 16.8% as compared to the control after irrigation application. Pacholak (1985) reported that irrigation, independently of the planting system, pads, number of trees per hectare, cultivar, and the crown type, had a positive effect on yield growth (on average from 4.4 to 9.5 t/ha), although the yields strongly correlated with atmospheric conditions. This was also confirmed by he pluvio-thermal conditions during growing seasons in the experiments. In studies carried out in Lipnik, later cultivar (‘Rubinola’ cv.) fruited better than the earlier one (‘Geneva Early’ cv.). The difference in yield was about 13 kg·tree^{-1}. A similar relationship was related to the weight of 100 fruits. ‘Rubinola’ cv. was characterized by a greater fruit weight (by 5.3 kg) as compared to ‘Geneva Early’ cv. (Table 4). Similar dependencies have been demonstrated by other authors in earlier experiments (Pacholak *et al.* 2007, Szewczuk 2002, Treder *et al.* 1992, Treder 2004). In addition to the significant impact of habitat conditions and genotype on the size and appearance of the fruit yield, its chemical composition is also very important. In the experiment, the irrigation decreased the contents of P, K in fruits of 'Geneva Early' cv., and Ca, Mg, Fe, Zn in 'Rubinola' cv., while increased the contents of N, Zn in 'Geneva Early' cv. and N, P in 'Rubinola' cv. (Table 5). Nevertheless, that was not confirmed in previous studies (Podsiadło *et al.* 2005), in which irrigation resulted in the increase in P, K, Fe, Zn concentrations and decrease in N total level in peach fruits. The beneficial effect of irrigation is the reduction in nitrate content, which is of particular importance for yield quality. The own study revealed that this factor contributed to the reduced concentration of nitrates in fruits by 23.3 % ('Geneva Early' cv.) and by 20.9 % ('Rubinola' cv.).

Table 5. The effect of irrigation on the content of macro – and microelements in fruits

Obiekty		N	P	K	Ca	Mg	Fe	Zn	$N\text{-}NO_3$
		$[g \cdot kg^{-1}]$					$[mg \cdot kg^{-1}]$		
Geneva Early	O	7.49	1.47	10.6	0.96	0.12	80.0	10.0	150.0
Rubinola	O	9.17	1.12	7.88	0.96	0.22	90.0	11.0	215.0
Geneva Early	W	8.54	1.23	9.3	0.96	0.12	80.0	11.0	115.0
Rubinola	W	9.24	2.33	7.88	0.72	0.15	80.0	10.0	170.0

CONCLUSIONS

1. Irrigation has increased the intensity of assimilation as compared to the trees in the non-irrigated object. The better yielding late 'Rubinola' cv. was characterized by greater transpiration intensity, stomatal conductivity, and CO_2 concentration in leaves than early 'Geneva Early' cv.
2. Irrigation increased the content of chlorophyll and carotenoids in leaves of tested apple tree cultivars. Their greater concentration was found in 'Rubinola' cv., in which higher values of the greenness index were also observed.
3. Applied irrigation significantly increased the fruit yield and also affected the fruit weight gain at both cultivars. Among apple tree cultivars, greater yield and fruit weight were found in late 'Rubinola' cv.

4. The improvement in the yield quality is the beneficial effect of irrigation as evidenced by the reduced nitrate content in the fruits of both varieties. This treatment and earliness of the cultivar did not significantly affect the content of other macro and micronutrients.

REFERENCES

Arnon D. J., M. B. Allen, Whatley F. (1956). *Photosynthesis by isolated chloroplasts. IV General concept and comparison of three Photochemical reactions*. Biochemistry Biophysics Acta 20: 449-461.

Klamkowski K., Treder W., (2000). *Wpływ stresu wodnego na dynamikę przyrostu średnicy pędu głównego jabłon*i. Zeszyty Naukowe Instytutu Sadownictwa i Kwiaciarstwa 8: 141-147.

Koźmiński Cz., Michalska B. (2000). *Klimatyczna charakterystyka rejonu stacji agrometeorologicznej w Lipkach k. Stargardu Szczecińskiego*. Zeszyty Naukowe Akademii Rolniczej w Szczecinie: 11-16.

Makosz E. (2014). *Sytuacja na rynku jabłek i ZSJ w Polsce i na świecie.* Przemysł Fermentacyjny i Owocowo-Warzywny", 4: 10.

Nalborczyk E. (1993). *Biologiczne uwarunkowania produktywności roślin strączkowych*. Fragmenta Agronomica 4:147-150.

Pacholak E., (1985). *Wpływ nawadniania kroplowego na plonowanie i jakość owoców trzech odmian jabłoni*. Prace Instytutu Sadownictwa i Kwiaciarstwa. Seria C 2-4: 99-100.

Pacholak E., Zydlik Z., Zachwieja M. Rutkowski K. (2007). *Effect of irrigation and fertilization on the growth and yielding of apple-trees cultivar 'Sampion' in a replanted orchard*. Acta Scientiarum Polonorum – hortorum Cultus 6 (3): 3-13.

Podsiadło C., Jaroszewska A., Biczak R., Herman B., Rumasz-Rudnicka E. (2005). *Wpływ nawadniania podkoronowego i nawożenia mineralnego na wielkość i jakość owoców brzoskwini.* Inżynieria Rolnicza 4 (64): 117-124.

Podsiadło C., Jaroszewska A., Biczak R., Herman B. (2006). *Wpływ mikronawadniania i nawożenia na zawartość azotanów w wybranych roślinach sadowniczych*. Zeszyty Problemowe Postępu Nauk Rolniczych z. 513: 323-331.

Rzekanowski Cz., Rolbiecki S. (1996). *Wpływ nawadniania kroplowego na niektóre cechy jakościowe plonu wybranych gatunków roślin sadowniczych*. Zeszyty Problemowe Postępu Nauk Rolniczych z. 438: 213-217.

Szewczuk A., (2002). *Wpływ nawadniania na wzrost i owocowanie drzew jabłoni szczepionych na różnych podkładkach*. Zeszyty Naukowe Akademii Rolniczej we Wrocławiu 445: 247-259.

Treder W., Mika A., Cegłowski S. (1992). *Wpływ nawadniania na wzrost, plonowanie i jakość jabłek odmiany 'Cortland'*. Prace Instytutu Sadownictwa i Kwiaciarstwa. Seria C 3-4: 63-64.

Treder W. (2004). *Wpływ nawadniania kroplowego na dynamikę wzrostu jabłek*. Zeszyty Naukowe Instytutu Sadownictwa i Kwiaciarstwa 12: 79-85.

Uprawy ogrodnicze 2002. Główny Urząd Statystyczny Warszawa.

Uprawy Ogrodnicze 2010. Powszechny Spis Rolny, Główny Urząd statystyczny Warszawa

Wojcieska U. (1994). *The effect of nitrogen nutrition of soybean on plant growth and* CO_2 *exchange parameters.* Acta Physiologica Plantarum 16: 262-268.

Corresponding author: Prof. Cezary Podsiadło, PhD, DSc
Eng. Anna Jaroszewska, PhD

Department of Agronomy,
West Pomeranian University of Technology,
ul. Słowackiego 17, 71-434 Szczecin,
e-mail: Cezary .Podsiadlo@zut.edu.pl

Received: 3.03.2017
Accepted: 29.05.2017