

## RESPONSE OF ARTICHOKE (*Cynara scolymus* L.) PLANTS TO IRRIGATION AND HARVEST DATE

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**Abstract.** Artichoke is valued as a vegetable and medicinal plant. The aim of the study was to determine the effect of irrigation and leaf harvest date of artichoke grown in south-eastern Poland on total yield and marketable fresh leaf yield, its structure and the content of biologically active substances: total phenolic acids, flavonoids and tannins. Irrigation contributed to an increase in fresh leaf yield, percentage of marketable yield in total yield, as well as the increase in tannin content, decrease in total phenolic acid content, and no effect on the change in total flavonoid content. The plant material harvested in September was characterized by a higher content of phenolic acids and a lower content of flavonoids compared to the raw material obtained in October.

**Key words:** agronomic factors, leaf yield, biologically active substances, phenolic acids, flavonoids

### INTRODUCTION

The globe artichoke (*Cynara scolymus* L.) belongs to the Asteraceae family, genus *Cynara*. It is grown as a vegetable in Europe in a warm climate, in the Mediterranean Sea region, whereas under temperate climate conditions plantations are run mainly for the needs of the herbal industry. Artichoke leaf (*Cynarae folium*) is the raw material used as a medicine and a source of active substances. Artichoke is valued due to the presence of various biologically active compounds, primarily polyphenolic acids, flavonoids and tannins [Pinelli et al. 2007, Lutz et al. 2011, Pandino et al. 2011]. The active substances of artichoke have multiple effects, exhibiting cholagogic, hepatoprotective, antibacterial, diuretic, antioxidant and antineoplastic activity as well as preventing arte-

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riosclerosis [Bundy et al. 2004, Vamanu et al. 2011, Christaki et al. 2012, Gouveia and Castilho 2012, Al-Ahdab 2014].

A condition for successful cultivation of artichoke for use in the herbal industry is the selection of an appropriate site [De Vos 1992]. Warm and moist soils as well as sunny fields sheltered from the wind are considered to be best. Elia and Conversa [2007] report that in growing artichoke for vegetable sandy loam soils should contain at least 1% of organic matter and be characterized by a low C:N ratio and slightly alkaline pH. In the Mediterranean climate, Mansour et al. [2005] showed that a condition for successful cultivation of artichoke is to provide to plants a sufficient amount of water through irrigation. A study conducted in the south of Italy [Boari et al. 2000] proves a clear correlation of irrigation with artichoke yield and plant growth rate. In a study on the cultivation of various *Cynara* species carried out in the central part of Spain, Fernandez [1998] obtained a dry matter yield of 6.5 t·ha<sup>-1</sup> with 280 mm rainfall during the growing season, while at 529 mm rainfall – 23.7 t·ha<sup>-1</sup>. Likewise, growing artichoke for the needs of the pharmaceutical industry, Baier et al. [2005] obtained a lower raw material yield under soil water deficit conditions, while Tarantino and Caliandro [1979] found a significant inhibition of artichoke growth with insufficient water supply to plants. Bianco [2005] assessed that in vegetable cultivation under warm climate conditions the water requirement of artichoke is about 5000 m<sup>3</sup> ha<sup>-1</sup> per season. The water content in artichoke plants changes depending on soil moisture and air humidity, the season of the year and time of the day as well as plant age [Tarantino 1984]. The first symptom of soil water deficit is the wilting of artichoke plants due to reduced turgor and decreased photosynthetic rate [Khalil et al. 1996]. This phenomenon has been observed mainly in summer when transpiration exceeded water uptake as a result of strong sunlight and gusts of hot air in afternoon hours. In growing artichoke for vegetable, Pellicer et al. [2007] obtained a 50% higher flower head yield from irrigated plants compared to non-irrigated plants. In their research, Garnica et al. [2004] demonstrated that irrigated artichoke plants were characterized by strong growth and high-quality flower head yield.

Most agronomic studies on artichoke cultivation and yield are carried out under Mediterranean climate conditions. Given the fact that artichoke grown in a cooler climate accumulates more biologically active compounds than under warm climate conditions [Baier et al. 2005, Halter et al. 2005 a, b], artichoke cultivation in a temperate climate seems to be interesting for the herbal industry. The aim of the present study was to determine the effect of irrigation and leaf harvest date of artichoke grown in south-eastern Poland on total yield and marketable fresh leaf yield, its structure and the content of biologically active substances: total phenolic acids, flavonoids and tannins.

## MATERIALS AND METHODS

An agronomic study was conducted over the period 2010–2012 in a commercial artichoke plantation with an area of 0.3 ha in a private agricultural and horticultural farm located in south-eastern Poland (51.15°N, 22.6°E). Crops were grown on loess soil with the mechanical composition of loamy sand containing 1.6% of organic matter and char-

acterized by a low content of phosphorus, potassium and magnesium. The previous crop for artichoke was winter wheat. Every year in October, farmyard manure was applied at a rate of  $15 \text{ t ha}^{-1}$ , with the following average chemical composition: 0.45% N, 0.30%  $\text{P}_2\text{O}_5$ , 0.60%  $\text{K}_2\text{O}$ , and 0.45% CaO. Every year before the commencement of the study, a chemical analysis of the soil was performed and the soil contained on average:  $30 \text{ mg N}\cdot\text{dm}^{-3}$  ( $\text{NO}_3^-$ ;  $\text{NH}_4^+$ ),  $20 \text{ mg P}\cdot\text{dm}^{-3}$ ,  $60 \text{ mg K}\cdot\text{dm}^{-3}$ , and  $25 \text{ mg Mg}\cdot\text{dm}^{-3}$ . Based on the results of the soil chemical analysis, before seeding soil nutrients were replenished up to the following levels:  $120 \text{ mg N}\cdot\text{dm}^{-3}$ ,  $50 \text{ mg P}\cdot\text{dm}^{-3}$ ,  $190 \text{ mg K}\cdot\text{dm}^{-3}$ ,  $55 \text{ mg Mg}\cdot\text{dm}^{-3}$ , by applying, respectively, ammonium nitrate, granulated triple superphosphate, potassium sulfate, and magnesite. In the autumn, autumn ploughing was performed, while in the spring before the establishment of the plantation, drag harrowing was done and a seed-bed conditioner was used (a cultivator equipped with a cage roller).

The experiment was set up in a randomized complete block design in 3 replicates. It included two experimental treatments: (1) crop irrigation: irrigated treatment and non-irrigated treatment, and (2) leaf harvest date: the first 10 days of September and the second leaf cutting in the third 10 days of October. The study material comprised plants of globe artichoke (*Cynara scolymus* L.) cv. 'Green Globe' (Rijnsburg seed company, Netherlands). Plants of this cultivar are characterized by quick growth rate and lush foliage. This cultivar is recommended for cultivation for the needs of the herbal industry due to its high content of active substances [Sałata and Buczkowska 2007]. Plants were grown by direct seeding which was carried out on May 5 every year. A plant spacing of  $0.4 \times 0.4 \text{ m}$  was used, while the plot area was  $1.6 \text{ m}^2$ , with 10 plants growing in each plot. Artichoke seeds were sown in holes, with three seeds in each hole, and plants were thinned to a single plant at the 2–3-leaf stage. During the water deficit period, drip irrigation was carried out using a T-Tape 508–20–400 drip irrigation system (emitters with a capacity of  $4.0 \text{ dm}^3\cdot\text{m}\cdot\text{h}^{-1}$  were spaced every 20 cm). The drip lines were installed parallel to the rows, every 40 cm and at a distance of 2–4 cm from plants. The criterion to trigger drip irrigation was assessment of soil water deficit [Prochnal 1986]. In 2010 crop irrigation was provided from the third 10 days of May until the second 10 days of October, whereas in the years 2011 and 2012 in the period from the first 10 days of May until the first 10 days of October. Timing of irrigation was determined using ceramic tensiometers (accuracy class 1.6), starting irrigation at a soil water potential of not less than  $-40 \text{ kPa}$ . The water potential value ( $-40 \text{ kPa}$ ) at which irrigation was triggered was adopted based on the determined water availability to plants (effective useful water retention). Single water doses were 3–4 mm, whereas the total irrigation rates for the individual growing seasons were the following, respectively: 80 mm in 2010, 130 mm in 2011, and 150 mm in 2012 (tab. 1). Water for irrigation was taken from the city's water mains. The indicators characterizing water quality, as determined by the Sanitary and Epidemiological Station in Lublin, classified it as consumption water.

At the leaf rosette stage, leaf harvest was carried out in each plot from a randomly selected area of  $1 \text{ m}^2$ . Leaves were picked by hand at two dates: 1. leaf cutting in the first 10 days of September; 2. leaf cutting in the third 10 days of October (from plants regrowing after the 1st harvest), by cutting them with a knife at a height of about 2 cm above soil surface. During the harvest, total fresh leaf yield ( $\text{t}\cdot\text{ha}^{-1}$ ), marketable fresh leaf yield ( $\text{t}\cdot\text{ha}^{-1}$ ), percentage of marketable fresh leaf yield in total yield (%), and num-

ber of leaves per plant ( $\text{pcs}\cdot\text{plant}^{-1}$ ) were determined. Measurements of the length and width (cm) of the largest leaf on the plant were performed on 30 randomly selected plants. The length of the entire leaf and the width in the widest place of the leaf blade were measured. Based on the ratio of leaf fresh mass to dry mass, the dry ratio was determined.

Table 1. Irrigation rate and number of irrigations of artichoke crops relative to the total rainfall during the experiment (mm)

Year	Total rainfall (April–October)	Total rainfall during irrigation period*	Total irrigation rate	Number of irrigations
2010	611.2	577.0	80.0	25
2011	428.1	387.4	130.0	40
2012	367.3	238.5	150.0	45

\* – irrigation was carried out from the third 10 days of May until the second 10 days of October (2010) and from the first 10 days of May until the first 10 days of October (2011 and 2012)

Table 2. Total fresh leaf yield of artichoke ( $\text{t}\cdot\text{ha}^{-1}$ ) depending on irrigation and harvest date

Irrigation	Harvest date	2010	2011	2012	Mean
With irrigation	harvest 1*	37.70	47.30	41.60	42.20
	harvest 2	4.08	4.39	3.43	3.96
	total	41.78	51.69	45.03	46.16
Without irrigation	harvest 1	31.50	32.60	30.40	31.50
	harvest 2	2.80	3.14	3.45	3.13
	total	34.30	35.74	33.85	34.63
Mean	harvest 1	34.60	39.95	36.00	36.85
	harvest 2	3.44	3.77	3.44	3.55
	total	38.04	43.72	39.44	40.40
LSD <sub>0.05</sub> for:					
irrigation (a)		1.701	2.123	1.130	0.879
harvest date (b)		1.701	2.123	1.130	0.879
year (c)		–	–	–	NS
interaction					
a × b		3.343	4.173	2.221	2.861
a × c		–	–	–	3.280
b × c		–	–	–	3.280

\* – 1<sup>st</sup> cutting in the first 10 days of September; 2<sup>nd</sup> cutting in the third 10 days of October

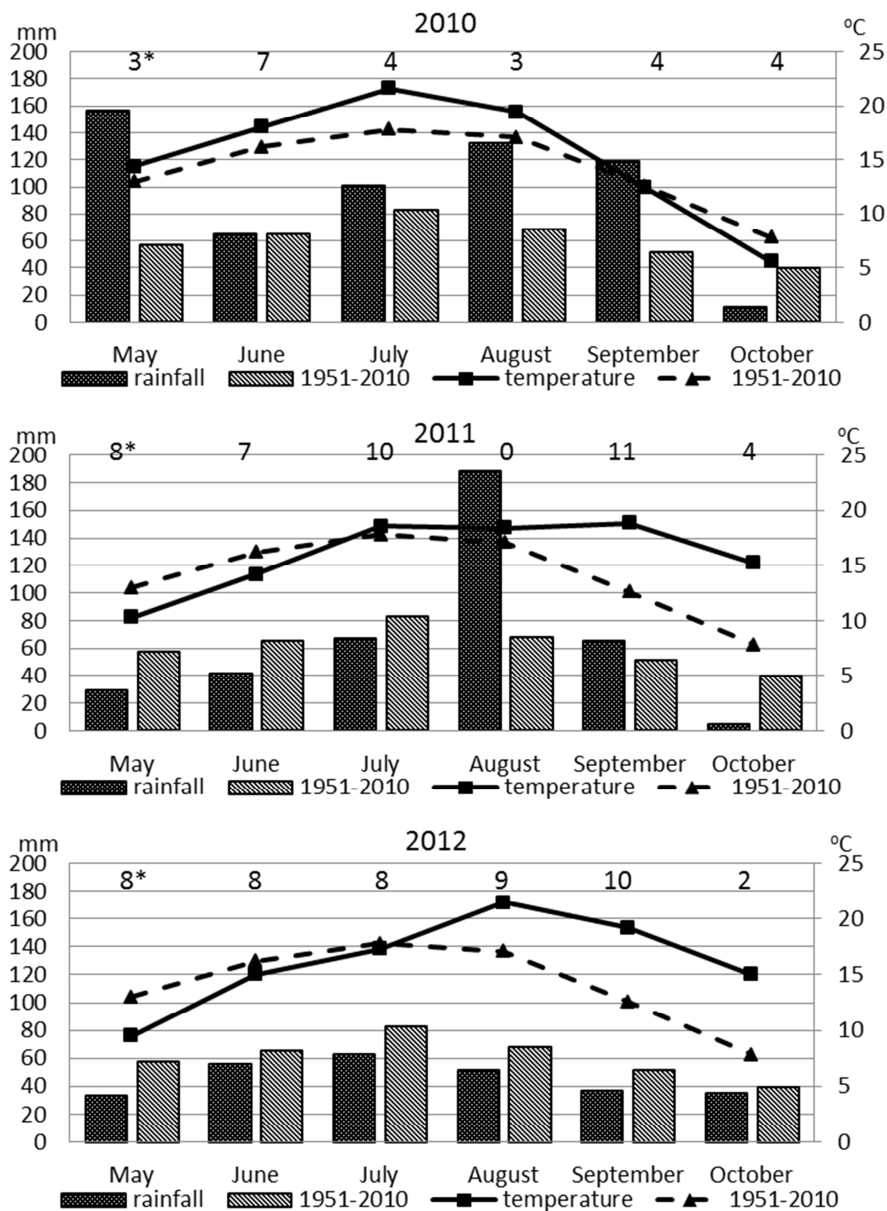
From each harvest date, 6 plants from each of the 3 replicates were selected for drying and chemical analysis. A primary leaf sample of 9 kg was prepared. The primary sample was spread on a clean surface; subsequently, the leaves were mixed, distributed evenly in the form of a square, and divided into 4 parts along the diagonals. Two opposite parts were rejected and the remaining ones were mixed. This procedure was repeat-

ed until 3 kg of fresh herbage was left. The leaves were dried in a drying oven at a temperature of 40°C. 0.5 kg samples were prepared from air-dried leaves which had been ground immediately after drying. The ground plant material samples for laboratory analysis were stored in hermetically sealed containers. The plant material samples were used to carry out chemical analyses in order to determine the content (%) of active compounds: total phenolic acids, flavonoids and tannins. Tannin content was determined by the titration/gravimetric method according to Polish Pharmacopoeia [Farmakopea Polska IV 1970]. Flavonoid content expressed as quercetin equivalents was determined spectrophotometrically according to Christ and Muller [Farmakopea Polska VI 2002]. Total phenolic acids expressed as caffeic acid equivalents were determined spectrophotometrically [Farmakopea Polska V 1999].

The study results were statistically analyzed by analysis of variance. The significance of differences was determined by Tukey's test at a significance level of  $\alpha = 0.05$ . Statistical calculations were performed using a one-way ANOVA model and Statistica 9.0 PL software package [Rabiej 2012].

## RESULTS AND DISCUSSION

**Artichoke leaf yield.** Drip irrigation had a significant effect on artichoke leaf yield (tab. 2). The studies of other authors [Boari et al. 2000, Imityaz et al. 2000, Tiwari et al. 2003, Šturm et al. 2010] reveal that drip irrigation in horticultural crops is an important technique that increases yield. The average total fresh leaf yield from irrigated artichoke plants was 46.16 t·ha<sup>-1</sup>, while the marketable yield 43.02 t·ha<sup>-1</sup>, and it was higher by respectively 25% and 37% compared to the yield obtained from plants grown without irrigation (tab. 2). It was shown that in 2010 the average fresh leaf yield obtained from irrigated plants was higher by 16% relative to the yield obtained from plants grown without irrigation, while in 2011 by 31%, and in 2012 by 27%. In 2012 the beneficial effect of irrigation on yield could be seen, since in this year of the study there were long periods without rainfall in the summer months, while in the period from May to October the total rainfall was barely 238.5 mm (fig. 1). In this period during soil water deficit, at a soil water potential of not less than -40 kPa 45 irrigations were carried out at a total rate of 150 mm (tab. 1). In 2010 a soil water deficit occurred as late as the third 10 days of June and therefore in the period from May to October 25 irrigation applications were made at a total rate of 80 mm. In 2011 a total of 130 mm of water was supplied to the plants in 40 single doses. The obtained results confirm the results of other authors [Boari et al. 2000, Garnica et al. 2004, Baier et al. 2005] and indicate that irrigation in growing artichoke is an agronomic technique that has a great effect on increasing yields. The presented results are in agreement with the results of the research conducted under similar environmental conditions [Kołodziej and Winiarska 2010] which proved the positive influence of drip irrigation in combination with fertilization on artichoke raw material yield within a range of 32.8–51.6%. Conducting a study in the south of the USA, Shinohara et al. [2011] demonstrated that under limited water availability conditions irrigation is a more efficient method of optimization of artichoke head yield quantity and quality than nitrogen fertilization.



\* – number of irrigations per month

Fig. 1. 10-day and monthly rainfall totals and average air temperatures during the study period according to the data of the Felin Meteorological Station of the University of Life Sciences in Lublin

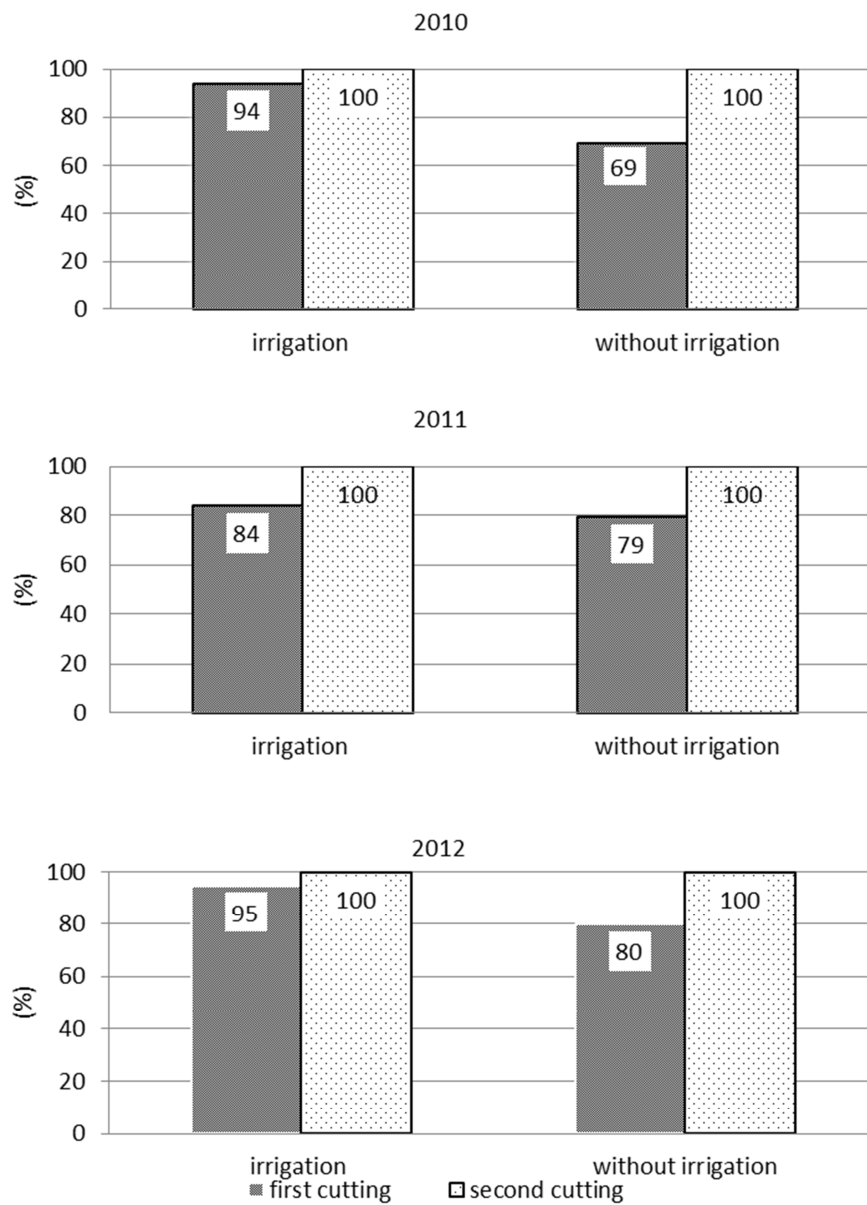
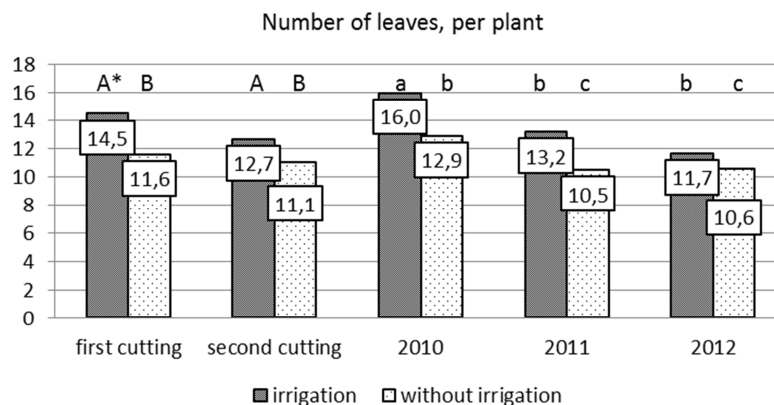


Fig. 2. Percentage of marketable yield in total yield depending on irrigation and harvest date



\* – the same letters mean that there are no statistical differences

Fig. 3. Number of artichoke leaves (pcs·plant<sup>-1</sup>) depending on irrigation and harvest date

Table 3. Marketable fresh leaf yield of artichoke (t·ha<sup>-1</sup>) depending on irrigation and harvest date

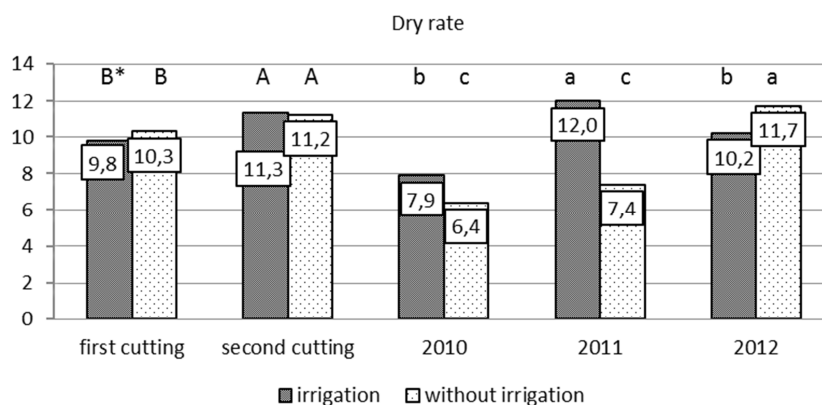
Irrigation	Harvest date	2010	2011	2012	Mean
With irrigation	harvest 1*	35.25	42.30	39.60	39.05
	harvest 2	4.08	4.39	3.43	3.97
	total	39.33	46.69	43.03	43.02
Without irrigation	harvest 1	21.50	25.60	24.40	23.83
	harvest 2	2.80	3.14	3.45	3.13
	total	24.30	28.74	27.85	26.96
Mean	harvest 1	28.37	33.95	32.00	23.83
	harvest 2	3.44	3.76	3.44	3.55
	total	31.81	37.71	35.44	34.99
LSD <sub>0.05</sub> for:					
irrigation (a)		2.417	3.039	3.186	1.499
harvest date (b)		4.750	5.973	6.261	2.220
year (c)		–	–	–	2.833
interaction					
a × b		2.417	3.039	3.186	3.887
a × c		–	–	–	3.887
b × c		–	–	–	1.499

\* – 1<sup>st</sup> cutting in the first 10 days of September; 2<sup>nd</sup> cutting in the third 10 days of October

In the cultivation of artichoke for herbal raw material, it is possible to carry out two harvests of plant material. In spite of the late first harvest in September, rosette leaves were observed to quickly regrow in both irrigated and non-irrigated plants, which allowed a second cutting to be done. Under the climatic conditions of Germany, Matthes



and Honermeier [2007] showed that a triple artichoke leaf harvest is most effective, since with a single harvest the proportion of plants producing inflorescence stems is higher. Crop irrigation significantly affected the yield obtained from the first harvest performed in the first 10 days of September, but did not affect the leaf yield from the second harvest (in the third 10 days of October). The total yield obtained from the first harvest from plants in the irrigated treatment was higher by 25% compared to that from plants in the non-irrigated plots, while the marketable yield was higher by 19%. The percentage of marketable yield in total yield in the irrigated treatment was high, and depending on the year, it was from 69 to 95%, while from the second harvest 100% (fig. 2). This percentage in the treatment without irrigation for the first harvest date was lower than for the irrigated treatment. The obtained results are not in agreement with the results of the study by Kołodziej and Winiarska [2010] who, when carrying out the harvest in August, showed irrigation of artichoke crops to have a significant effect on the yield from both the first and second harvest. Growing artichoke without irrigation, Sałata and Buczkowska [2007] also obtained several times higher yield from the harvest carried out in September than from the harvest done a month later. In central Spain, irrigation of artichoke crops significantly contributed to increased yield [Gominho et al. 2001, Grammelis et al. 2008]. Most papers confirm the need to irrigate plantations of herbal crops, in particular under warm and dry climate conditions [Muchow 1989, Lawal and Rahman 2007]. Carrubba and Ascolillo [2009] demonstrated that the highest water requirement of coriander occurs during the period of maximum leaf growth. Baher et al. [2002] found that soil water deficit contributes to a decrease in summer savory herbage yield, but at the same time to an increase in essential oil content.



\* – the same letters mean that there are no statistical differences

Fig. 4. The dry ratio (%) of artichoke leaves depending on irrigation and harvest date

Table 4. Total phenolic acid content (expressed as caffeic acid equivalents) (%) in the dry matter of artichoke leaves depending on irrigation and harvest date

Irrigation	Harvest date	2010	2011	2012	Mean
With irrigation	harvest 1*	1.69	1.43	1.48	1.54
	harvest 2	0.48	0.73	0.79	0.67
	mean	1.09	1.08	1.13	1.10
Without irrigation	harvest 1	1.74	1.47	1.50	1.57
	harvest 2	0.46	0.86	0.92	0.74
	mean	1.20	1.16	1.21	1.16
Mean	harvest 1	1.71	1.45	1.49	1.55
	harvest 2	0.47	0.80	0.85	0.71
	mean	1.09	1.12	1.17	1.13
LSD <sub>0.05</sub> for:					
irrigation (a)		NS	0.050	0.043	0.022
harvest date (b)		0.030	0.050	0.043	0.022
year (c)		–	–	–	0.032
interaction					
a × b		0.060	0.099	0.085	0.041
a × c		–	–	–	0.056
b × c		–	–	–	0.056

\* – 1<sup>st</sup> cutting in the first 10 days of September; 2<sup>nd</sup> cutting in the third 10 days of October

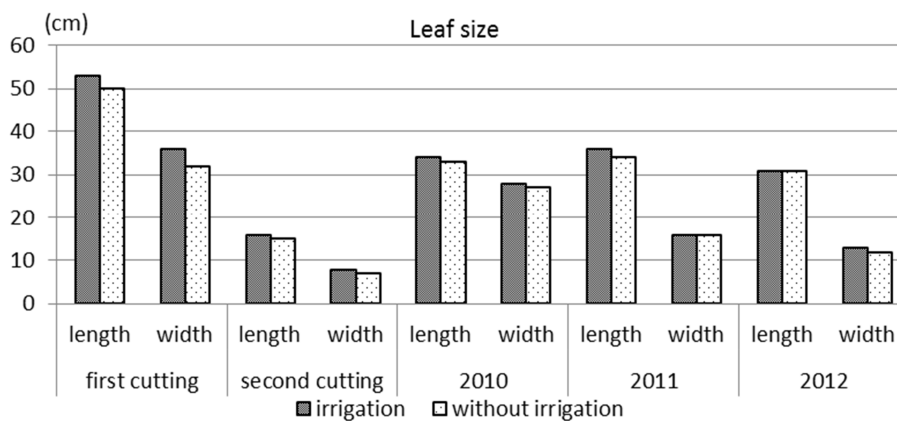


Fig. 5. Artichoke leaf size (cm) depending on irrigation and harvest date

Regardless of crop irrigation, the artichoke yield from the first harvest was more than ten times higher than the yield from the second harvest (tab. 2). Irrigated plants harvested on the first and second harvest dates produced more leaves (respectively, 14.5 and 12.7 pcs·plant<sup>-1</sup>) compared to non-irrigated plants (respectively, 11.6 and 11.1 pcs·plant<sup>-1</sup>) (fig. 3). In all years of the study, plants in the irrigated plots produced more leaves compared to non-irrigated crops (in 2010 on average by 3.1 pcs·plant<sup>-1</sup>, in 2011 by 2.7 pcs·plant<sup>-1</sup>, while in 2012 the average difference was 1.1 pcs·plant<sup>-1</sup>). Irrigation and artichoke leaf harvest date were not found to significantly affect the dry ratio (tab. 4). However, differences were revealed when the data obtained from the individual years of the study were compared. In the herbage harvested from plants grown without irrigation, the water content was lower (dry ratio from 6.4 to 11.7%), whereas in the irrigated treatment the value of this indicator was higher (dry ratio from 7.9 to 12.0%). Leaves obtained from the first harvest, both from irrigated and non-irrigated plants, were characterized by greater length and width compared to the size of leaves from the second harvest (fig. 5). This is corroborated by the results obtained by other authors [Fernandez et al. 2006, Falleh et al. 2008, Kołodziej and Winiarska 2010, Sałata 2010, Pandino et al. 2013], indicating that one of the factors that most strongly influence artichoke leaf yield is plant growth rate as expressed by the number of leaves per rosette and leaf size. Wagenbreth et al. [1996] report that valuable artichoke raw material should be characterized by a favorable yield structure and a high proportion of leaves. According to Halter et al. [2005 a], artichoke cultivars with a higher content of biologically active substances and higher raw material yield are most suitable to be grown for the pharmaceutical industry.

**Phenolic compounds content.** Polyphenols are one of the most desired phytochemicals due to their antioxidant activity. The following main groups of polyphenols are distinguished: flavonoids, phenolic acids, tannins, stilbenes and lignans [Ignat et al. 2011]. There are large differences between the total content of phenolic compounds in different fruits, vegetables and herbs, and even for the same products [Balasundram et al. 2006, Falleh et al. 2008]. These differences may be due to the complexity of these groups of compounds and extraction methods. Besides, polyphenol content depends on a number of internal factors (genus, species, cultivar, ontogenesis) and external factors (agronomic, environmental, technological) [Balasundram et al. 2006, Brasileiro et al. 2015]. The total phenolic acid content (expressed as caffeic acid equivalents) in the dry matter of artichoke leaves was on average 1.13% and significantly dependent on irrigation (tab. 4). Leaves of plants in the non-irrigated plots were characterized by a significantly higher content of phenolic acids (on average 1.16%) than in the irrigated treatment (on average 1.10%), except for the year 2010 when the difference in the content of these compounds was not dependent on irrigation. This is corroborated by the results of Shinohara et al. [2011] who showed an increase in the content of phenolic acids and chlorogenic acid through irrigation deficit, in particular in the case of later harvests of artichoke crops. These authors conclude that the increase in the content of phenolic compounds under the influence of water deficit can be the plant's response to drought stress. Kołodziej and Winiarska [2010], on the other hand, obtained different results when they found a higher content of dicaffeoylquinic acids and flavonoids in the herb-

age of plants grown without irrigation. Helyes et al. [2012] think that the high variation in the content of active compounds in artichoke as affected by irrigation may be evidence of complex plant response mechanisms to water stress. Rzekanowski et al. [2007] emphasize that the effect of water on yield of herbal crops is also modified by light, temperature and nutrients, while soil moisture content remains one of the main factors that determine herbage yield and chemical composition. An increase in the amount of water supplied to plants positively influences artichoke growth and productivity [Saleh et al. 2012], but irrigation of a plantation means an additional cost and may affect the profitability of crops [Garnica et al. 2004].

Accumulation of polyphenolic compounds by plants seems to be associated not only with season, but also with harvest date [Brasileiro et al. 2015]. The results of the study by Lombardo et al. [2010] prove the effect of climatic conditions on the profile of phenolic compounds in artichoke and suggest that special attention should be paid to harvest time. In the present study, significantly more total phenolic acids were found in plants from the first harvest (1.55%) than in those from the second harvest (0.71%). Moreover, more phenolic acids were detected in plants in 2012 (on average 1.17%) than in 2010 (1.09%) and 2011 (1.12%). The content of phenolic compounds can change during plant growth [Pandino et al. 2011, Shinohara et al. 2011], depends on extraction method [Llorach et al. 2002, Vamanu et al. 2011], and is subject to genetic variation [Fратиanni et al. 2007, Pandino et al. 2011]. Frатиanni et al. [2007] revealed that artichoke plants accumulate more polyphenolic compounds than cardoon plants and that individual polyphenols accumulate selectively in different parts of the inflorescence and in specific genotypes. Growing artichoke in southern Italy, Lombardo et al. [2010] proved that the content of phenolic compounds in different parts of the artichoke inflorescence is dependent on harvest date and increases from winter to spring. Shinohara et al. [2011] think that the content of phenolic compounds in artichoke can increase with plant growth, similarly as in other species [Deepa et al. 2007, Mahmood et al. 2012]. In the case of cardoon plants, there are significantly more polyphenolic compounds in leaves and seeds than in flowers [Falleh et al. 2008]. The results of the study by Wang et al. [2003] prove that most polyphenolic compounds accumulate in artichoke leaves. On the other hand, different relationships were revealed by Frатиanni et al. [2007] who found more polyphenols in artichoke inflorescences than in leaves. It should be added that the profile of phenolic compounds in artichoke proved to vary much more than in cardoon [Gouveia and Castilho 2012].

**Flavonoid content.** Flavonoids are included in the group of important plant compounds with broad biological activity, among others antioxidant, anti-inflammatory and antineoplastic [Agrawal 2011, Ignat et al. 2011, Kumar and Pandey 2013]. Fruits and vegetables are mentioned as the main natural sources of flavonoids [Kumar and Pandey 2013], but these compounds are also found in herbal raw materials. The leaves of artichoke contain more flavonoids than the other parts of this plant and their quantity is different in particular cultivars [Romani et al. 2006]. Some therapeutic effects of artichoke are attributed to the presence of flavonoids whose level depends, among others, on extraction method [Li et al. 2004, Vamanu et al. 2011]. The average flavonoid content in artichoke leaves studied was 0.19% (tab. 5). Irrigation did not affect significantly

the flavonoid content in artichoke leaves. This is confirmed by the results of the study on pot marigold plants conducted by Rahmani et al. [2012] which suggests that water stress has no effect on flavonoid content. Different data are presented by Khan et al. [2012] who show the maximum level of flavonoids in basil leaves at a 25% irrigation rate compared to other water supply regimes. These authors find that too high water stress may negatively influence photosynthesis, antioxidant production and other important metabolic processes. Harvest date is an important factor that affects herb yield quantity and quality [Brasileiro et al. 2015]. Nevertheless, it is not always possible to indicate the optimum harvest date which determines the best herbage yield in quantitative and qualitative terms. Kim et al. [2013] show the optimum harvest time for *Artemisia montana* in the period between September and October, though a higher level of total flavonoids was found in plants harvested in June. In the present study, the content of flavonoids in leaves of plants from the second harvest was 0.25% and almost twice higher than their content in leaves of plants from the first harvest (0.13%). The obtained data corroborate the findings of Matthes and Honermeier [2007] which demonstrate that at the early growth stages artichoke plants contain more polyphenolic acids than flavonoids. On the other hand, the study by Mahmood et al. [2012] proves increased synthesis of flavonoids and phenolic compounds with the growth of some plants.

Table 5. Flavonoid content (expressed as quercetin equivalents) (%) in the dry matter of artichoke leaves depending on irrigation and harvest date

Irrigation	Harvest date	2010	2011	2012	Mean
With irrigation	harvest 1*	0.13	0.11	0.12	0.12
	harvest 2	0.29	0.24	0.26	0.26
	mean	0.21	0.18	0.19	0.19
Without irrigation	harvest 1	0.16	0.11	0.12	0.13
	harvest 2	0.20	0.25	0.26	0.24
	mean	0.18	0.18	0.19	0.18
Mean	harvest 1	0.15	0.11	0.12	0.13
	harvest 2	0.25	0.25	0.26	0.25
	mean	0.20	0.18	0.19	0.19
LSD <sub>0.05</sub> for:					
irrigation (a)		NS	NS	NS	NS
harvest date (b)		0.035	0.054	0.054	0.025
year (c)		–	–	–	NS
interaction					
a × b		0.069	0.105	0.106	0.047
a × c		–	–	–	0.065
b × c		–	–	–	0.065

\* – 1<sup>st</sup> cutting in the first 10 days of September; 2<sup>nd</sup> cutting in the third 10 days of October

Table 6. Tannin content in the dry matter of artichoke leaves (%) depending on irrigation and harvest date

Irrigation	Harvest	2010	2011	2012	Mean
With irrigation	harvest 1*	8.52	7.91	8.46	8.30
	harvest 2	9.55	6.95	7.43	7.98
	mean	9.03	7.43	7.94	8.14
Without irrigation	harvest 1	8.12	6.55	7.07	7.25
	harvest 2	9.43	7.05	7.54	8.01
	mean	8.77	6.80	7.30	7.63
Mean	harvest 1	8.32	7.23	7.76	7.77
	harvest 2	9.49	7.00	7.48	7.99
	mean	8.90	7.11	7.62	7.88
LSD <sub>0.05</sub> for:					
irrigation (a)		NS	0.410	0.311	0.192
harvest date (b)		0.411	NS	NS	NS
year (c)		–	–	–	0.294
interaction					
a × b		0.822	0.820	0.622	0.378
a × c		–	–	–	0.500
b × c		–	–	–	0.500

\* – 1<sup>st</sup> cutting in the first 10 days of September; 2<sup>nd</sup> cutting in the third 10 days of October

**Tannin content.** Plant raw materials can be a rich source of tannins whose presence in diet helps maintain good health and reduces the risk of chronic diseases [Lipińska et al. 2014, Yang and Liu 2014]. Tannins occur in all organs of artichoke and cardoon, but in the largest amount in cardoon seeds [Soumaya et al. 2013]. Similarly as climatic conditions, the location of crops can significantly influence plant tannin content [Nikolopoulou et al. 2007]. The tannin content in the leaf dry matter of artichoke plants studied was 7.88% (tab. 6). Irrigation was found to significantly affect the tannin content in artichoke herbage. Leaves harvested from irrigated plants contained more tannins (on average 8.14%) than those harvested from non-irrigated plants (on average 7.63%). An exception was the year 2010 in which irrigation was not found to significantly influence the tannin content in artichoke leaves. The relationship between plant material harvest date and leaf tannin content in plants of the family Asteraceae is described differently. Koukounaras et al. [2016] inform that lettuce harvest date has a significant effect on the content of secondary metabolites, including tannins. On the other hand, Adamczak et al. [2012] report that the tannin content in coltsfoot leaves is primarily associated with genetic factors and does not depend on harvest date. In the present study conducted in 2011 and 2012, harvest date was not found to significantly affect the tannin content in leaf dry matter, but in 2010 leaves from the second harvest contained significantly more tannins (9.49%) than those from the first harvest (8.32%). The tannin content in artichoke leaves significantly varied between years. In 2010 the herbage was characterized by significantly the highest tannin content (8.90%), while the lowest con-

tent (7.11%) was found in 2011. It seems that the tannin content in artichoke leaves is more determined by climatic factors than agronomic ones, for example harvest date.

## CONCLUSIONS

Drip irrigation of the artichoke plantation contributed to an increase in fresh leaf yield by 25–37% on average as well as in the percentage of marketable yield in total yield. The present experiment does not show a clear effect of irrigation on the content of active compounds in artichoke leaves. Irrigation resulted in a significant decrease in total phenolic acid content, with a simultaneous increase in tannin content, but at the same time had no effect on the change in total flavonoid content.

The artichoke leaf yield from the first harvest carried out in the first 10 days of September was more than 10 times greater than that from the second harvest performed in the third 10 days of October. On the other hand, the percentage of marketable yield in total yield was higher in the case of the second harvest. The plant material harvested in September was characterized by a higher content of phenolic acids and a lower content of flavonoids compared to the raw material obtained in October. The tannin content in artichoke leaves was not dependent on harvest date.

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**REAKCJA ROŚLIN KARCZOCHA (*Cynara scolymus* L.)  
NA NAWADNIANIE ORAZ TERMIN ZBIORU**

**Streszczenie.** Karczoch zwyczajny ceniony jest jako roślina warzywna i lecznicza. Celem badań było określenie wpływu nawadniania oraz terminu zbioru liści karczocha uprawianego w południowo-wschodniej Polsce na wielkość plonu ogółem i plonu przemysłowego świeżego surowca, jego strukturę oraz zawartość substancji biologicznie aktywnych: kwasów fenolowych ogółem, flawonoidów i garbników. Nawadnianie wpłynęło na zwiększenie plonu świeżych liści karczocha oraz udziału plonu handlowego w plonie ogółem, przyczyniło się do zwiększenia zawartości garbników, obniżenia zawartości kwasów fenolowych ogółem, nie zmieniając zawartości flawonoidów. Surowiec zbierany we wrześniu odznaczał się większą zawartością kwasów fenolowych i mniejszą zawartością flawonoidów, w porównaniu z surowcem pozyskiwanym w październiku.

**Słowa kluczowe:** czynniki agrotechniczne, plon liści, substancje biologicznie czynne, kwasy fenolowe, flawonoidy

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