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EFFICIENCY OF IRRIGATION OF HIGHBUSH BLUEBERRY IN POLAND

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Abstract

In the past few years, Poland has been growing into a leader in the cultivation of highbush blueberry in Europe and now occupies a very high 3rd place in world production, just behind the USA and Canada. The leading position on the European market, the growing demand for the fruit and the possibility of entering new markets present to Polish producers new opportunities and increase the number of new plantings. In the cultivation of blueberry, irrigation is a factor determining the size and quality of the crop, as the blueberry plant, due to its shallow root system, requires adequate moisture and permeability in the topsoil, generally throughout the entire growing period. The results obtained in several studies confirm the high effectiveness of blueberry irrigation, particularly on plantations at their full fruiting potential. The rise in yield achieved through the use of irrigation averaged 95%, corresponding to 4.51 $t \cdot ha^{-1}$. The average irrigation efficiency coefficient was a 41.37 kg rise in fruit yield per 1 mm (10 m^3) of water used for irrigation.

Keywords: irrigation efficiency coefficient, yield rise, *Vaccinium corymbosum*

INTRODUCTION

In the past few years, Poland has been growing into a leader in the cultivation of highbush blueberry in Europe and now occupies a very high 3rd place in world production, just behind the USA and Canada. Because they are very tasty and rich in minerals and bio-organic components, blueberries enjoy growing popularity, and their production is increasing (Ostrowska and Ściążko, 1966). According to FAO data from 2013, the area planted with highbush blueberry in Poland increased from 425 ha in 1990 to 3,223 ha in 2013. With the increase in crop area, fruit production also increased from 1,700 tonnes in 1990 (FAO, 2013) to 14,100 tonnes in 2015 (MRiRW, 2016). According to IERiGŻ (Institute of Agricultural and Food Economics) data, the share of our country in the European Union's harvest in 2014 exceeded 20% (Zaremba, 2015). The increasing production of blueberries in Poland is the reason why exports of the fruit from our country also increase with every year. We mainly export fresh blueberries, and our main customers are the United Kingdom and Germany, as well as Belarus and Ireland. Recently, an increased interest in blueberry fruit has also been observed on Asian markets. The leading position on the European market, the growing demand for the fruit and the possibility of entering new markets present to Polish producers new opportunities and increase the number of new plantings. It is estimated that the cost of establishing 1 ha of a blueberry plantation is approx. 50-60 thousand PLN (13–15 thousand dollar), and the purchase of shrubs and irrigation, which is a factor largely affecting fruit yield and quality, is as much as 40-50% of that amount [www.sadyogrody.pl]. The blueberry plant, because of its shallow root system, requires adequate moisture and permeability in the upper layer of the soil, generally throughout the entire growing period (Holzapfel and Hepp 2002). The plant is most sensitive to drought stress during the periods of growth and fruiting (Perrier et al. 2000), but water shortages after the harvest can affect the production of the fruit in the following year by reducing the number of flower buds (Rejman and Pliszka 1991, Gruca et al. 1993). Fruit growers are well aware of the necessity to irrigate blueberry plantations. According to our estimates based on questionnaire surveys, among all the species of cultivated fruit plants, the great majority of plantations that are irrigated are those of blueberry (more than 76% – data from 2009) (Treder et al. 2011). The price of blueberries to date, which in 2015 stood on average at 10-12 PLN per kg (2.3–3.1 dollar per kg) wholesale markets, sometimes reaching up to 30 PLN per kg (7.75 dollar per kg) retail [www.freshmarket.pl], and long-term economic forecasts indicate that in the next few years the production of highbush blueberry will still be profitable. Agrotechnical experiments conducted by research centers in Poland show that with rational irrigation significant increases in yield can be achieved, and thus confirm the high efficiency of blueberry irrigation.

The aim of this study was to assess the efficiency of irrigation of highbush blueberry in Poland on the basis of own research and the available literature.

MATERIAL AND METHODS

The study was based on own research and articles concerning the irrigation of highbush blueberry published by the following authors: Pacholak and Gruca (1993), Gruca (1997), Rumasz-Rudnicka et al. (2009), Koszański et al. (2009, 2011), Tryngiel-Gać et al. (2013). Our own results and those reported in the other studies were used to calculate:

- the rise in yield obtained through irrigation, expressed in t/ha and %;
- irrigation efficiency coefficient expressed as the rise in yield in kg per 1 mm of water used for irrigation;

$$Irrigation\,efficiency = \frac{rise\ in\ yield}{1mm\ of\ water\ used\ for\ irrigation}$$

- yield loss coefficient in % (estimated yield loss in the absence of irrigation calculated on the assumption that the total yield under irrigation represents the full production potential, i.e. equals 100%).

$$Yield\ loss = 100\% - \frac{total\ yield\ without\ irrigation \cdot 100\%}{total\ yield\ under\ irrigation}$$

Highbush blueberry begins to bear fruit in the third year after planting and reaches its full fruiting potential after 6-7 years, and therefore all the analyses were done separately for young plantations (3-5 years old) and those at their full production potential (6 or more years after planting); average values were also given for the entire duration of the individual experiments.

RESULTS AND DISCUSSION

A study on the influence of irrigation of highbush blueberry plantations on production results was already conducted in the years 1986-1992 in the experimental orchard of the Department of Pomology of the Agricultural University in Poznań in RZD Przybroda by Gruca and Pacholak [1993]. The experiment compared two blueberry cultivars: ‘Bluecrop’ and ‘Darrow’, and three levels of maintaining soil moisture: W_0 – control combination (without irrigation), W_1 – irrigation at a soil water potential of – 0.03 MPa, and W_2 – irrigation at – 0.01 MPa. The soil water potential was measured at a depth of 15 cm using mercury tensiometers. Precipitation and temperature data over the duration of the experiment show that the years 1987 and 1988 were characterized by abundant precipitation, without any obvious prolonged periods of drought, such as those that occurred in 1986, 1989 and 1992. The results obtained clearly show that the irrigation of the highbush blueberry plantation was a necessary agrotechnical treatment to ensure proper soil moisture conditions, and the amount of water supplied in the individual years was correlated with the changes in weather conditions (Table 1).

The experiment was conducted on a blueberry plantation that was established in 1984, so it was a young plantation. According to the literature data, highbush blueberry comes into bearing fruit after 3 years, and fruit yields on a commercial scale can be achieved only from a plantation not younger than 6 or 7 years old (Bieniasz 2005, Rusnak 2012, Tryngiel-Gać et al. 2013). After analyzing the data obtained by the authors, it follows that at the average annual water consumption (amount irrigation water usage) of 19 mm (irrigation to maintain soil suction at – 0.03 MPa), they obtained, already on a young plantation, a rise in yield of 30%, which is 0.7 $t \cdot ha^{-1}$. The average irrigation efficiency coefficient was a rise in fruit yield of about 37 kg per 1 mm (10 m^3) of water used for irrigation. Increasing the amount of irrigation water to 56 mm per year (to maintain soil suction at -0.01 MPa) increased the fruit yield by an average 14%, which is 0.30 $t \cdot ha^{-1}$, and the average irrigation efficiency coefficient was a 5.99 kg rise in fruit yield per 1 mm (10 m^3) of irrigation water. On the plantation at its full fruiting potential, with the use of irrigation water in the amount of 130 mm per year (-0.03 MPa), they observed an increase in yield of 88%, which is 5.55 $t \cdot ha^{-1}$, and the average irrigation efficiency coefficient was a 43 kg rise in fruit yield per 1 mm (10 m^3) of water used for irrigation. With the consumption of irrigation water of 265 mm (-0.01 MPa), they reported a rise in yield of 91%, which corresponds to 5.6 $t \cdot ha^{-1}$, and the irrigation efficiency coefficient was a rise in fruit yield of almost 22 kg per 1 mm (10 m^3) of irrigation water. Over the duration of the experiment, they collected an average of 4.59 $t \cdot ha^{-1}$ in the control combination, 8.06 $t \cdot ha^{-1}$ in the combination irrigated to maintain soil suction at – 0.03 MPa, and 7.99 $t \cdot ha^{-1}$ in the combination irrigated to maintain soil suction at – 0.01 MPa. In the combination irrigated to maintain the water potential at – 0.03 MPa, a total of 578 mm of water was used for irrigation (over the 7-year duration of the experiment), an average of 82.57 mm per year, a cumulative rise in yield of 24.3 $t \cdot ha^{-1}$ was obtained, an average of 3.47 $t \cdot ha^{-1}$ per year (42%), and the irrigation efficiency coefficient represented a 42 kg rise in fruit yield per 1 mm (10 m^3) of water used for irrigation. In the combination irrigated to maintain the water potential at – 0.01 MPa, a total of 1,227 mm of water was used for irrigation (over the 7-year duration of the experiment), an average of 175.28 mm per year, a cumulative rise in yield of 23.8 $t \cdot ha^{-1}$ was obtained, an average of 3.4 t/ha per year (74%), and the irrigation efficiency coefficient was a 19 kg rise in fruit yield per 1 mm (10 m^3) of irrigation water. The estimated yield losses resulting from a possible lack of irrigation on the described plantation are at a level of 42% and 43% (for – 0.01 MPa and – 0.03 MPa, respectively).

Table 1. Effect of below-canopy irrigation on fruit yield and production efficiency of highbush blueberry according to Gruca and Pacholak (1993, amended)

Year	Control	Irrigation to maintain soil suction at – 0.03 MPa					Irrigation to maintain soil suction at – 0,01 MPa				
	Yield	Amount irrigation water usage	Yield	Rise in yield		Irrigation efficiency coefficient	Amount irrigation water usage	Yield	Rise in yield		Irrigation efficiency coefficient
	$t \cdot ha^{-1}$	mm	$t \cdot ha^{-1}$	$t \cdot ha^{-1}$	%	$kg \cdot mm^{-1}$	mm	$t \cdot ha^{-1}$	$t \cdot ha^{-1}$	%	$kg \cdot mm^{-1}$
1986	0.3	57	0.5	0.2	67	3.51	134	0.4	0.1	33	0.75
1987	2.0	0	3.4	1.4	70	0	27	2.9	0.9	45	33.3
1988	4.7	0	5.2	0.5	11	0	6	4.7	0	0	0
1989	6.1	158	9.8	3.7	61	23.4	216	10.5	4.2	72	20.37
1990	8.0	0	10.5	2.5	31	0	182	7.8	0	0	0
1991	9.2	97	16.4	7.2	78	74.2	276	16.1	6.9	75	25.00
1992	1.8	266	10.6	8.8	489	33.1	386	13.5	11.7	650	30.31
Average – young plantation (1986-1988)	**2.3**	19	3.0	**0.70**	30	36.84	56	2.6	**0.30**	14	5.99
Average – full fruiting potential (1989-1992)	**6.3**	130	11.8	**5.55**	88	42.61	265	11.9	**5.60**	91	21.70
Average (1986-1992)	**4.6**	83	8.1	**3.47**	76	42.04	175	8.0	**3.40**	74	19.56

The above results indicate a high efficiency of irrigation to maintain the water potential at – 0.03 MPa. The applied doses of water were sufficient to obtain a satisfactory increase in yield, and the costs associated with irrigation (water charges) were much lower than in the combination to maintain the water potential at – 0.01 MPa. Young blueberry plants are particularly sensitive to excessive doses of water because they do not yet have a well-developed root system, hence the large differences in the efficiency of irrigation occurring in the first three years of fruiting on this plantation.

The above results are also confirmed by the work of Gruca (1997), which assessed the yielding of highbush blueberry 'Bluecrop' depending on the applied irrigation (Table 2). The research methodology was the same as in the previous work by Gruca and Pacholak (1993). After analyzing the data obtained by the author, it follows that with the average annual consumption of irrigation water of 19 mm (-0.03 MPa) on a young plantation, a rise in yield of 60% was obtained, which is 1.24 $t \cdot ha^{-1}$. The average irrigation efficiency coefficient was a rise in fruit yield of about 65.4 kg per 1 mm of water used for irrigation. Increasing the amount of irrigation water to 56 mm per year (-0.01 MPa) increased the yield by an average 31%, which is 0.63 $t \cdot ha^{-1}$, and the average irrigation efficiency coefficient was an 11.37 kg rise in fruit yield per 1 mm of water used for irrigation. On the plantation at its full fruiting potential, an increase in yield of 147% was observed, which corresponds to 7.90 $t \cdot ha^{-1}$(-0.03 MPa). An analysis of the irrigation efficiency coefficient cannot be performed here because the work does not contain complete data on irrigation conducted in the years 1993-1995, which is why this coefficient was estimated based on the data on irrigation doses from the previous years of the experiment. According to the estimates, the irrigation efficiency coefficient amounted to a 60 kg rise in fruit yield per 1 mm of irrigation water. With irrigation to maintain soil suction at – 0.01 MPa, a rise in yield of 183% was reported, which corresponds to 9.8 $t \cdot ha^{-1}$, and the estimated irrigation efficiency coefficient was a 37 kg rise in fruit yield per 1 mm of water used for irrigation. Over the duration of the experiment, an average of 4.37 $t \cdot ha^{-1}$ were collected in the control combination, 10.27 $t \cdot ha^{-1}$ in the combination irrigated to maintain the water potential at – 0.03 MPa, and 11.44 $t \cdot ha^{-1}$ in the combination irrigated to maintain the water potential at – 0.01 MPa. In the combination irrigated to maintain soil suction at – 0.03 MPa, a cumulative rise in yield of 59.02 $t \cdot ha^{-1}$ was obtained (over the 10-year duration of the experiment), an average of 5.9 $t \cdot ha^{-1}$ per year (135%), and the estimated irrigation efficiency coefficient constituted a 57 kg rise in fruit yield per 1 mm of irrigation water. In the combination irrigated to maintain soil suction at – 0.01 MPa, a cumulative rise in yield of 70.63 $t \cdot ha^{-1}$ was obtained (over the 10-year duration of the experiment), an average of 7.1 $t \cdot ha^{-1}$ per year (161%), and the estimated irrigation efficiency coefficient was a 40 kg rise in fruit yield per 1 mm of water used for irrigation. The estimated yield losses due to a possible lack of irrigation on the described plantation are at a level of 62% and 57% (for – 0.01 MPa and -0.03 MPa, respectively).

Table 2. Effect of irrigation on fruit yield of highbush blueberry 'Bluecrop' (Gruca, 1997, amended)

Year	Control	Irrigation to maintain soil suction at – 0.03 MPa					Irrigation to maintain soil suction at – 0,01 MPa				
	Yield	Amount irrigation water usage	Yield	Rise in yield		Irrigation efficiency coefficient	Amount irrigation water usage	Yield	Rise in yield		Irrigation efficiency coefficient
	t·ha^{-1}	mm	t·ha^{-1}	t·ha^{-1}	%	kg· mm^{-1}	mm	t·ha^{-1}	t·ha^{-1}	%	kg· mm^{-1}
1986	0.27	57	0.60	0.33	122	5.79	134	0.40	0.13	48	0.97
1987	1.73	0	3.76	2.03	117	0	27	3.10	1.37	79	50.74
1988	4.16	0	5.53	1.37	33	0	6	4.56	0.40	10	66.67
1989	4.79	158	10.42	5.63	117	35.63	216	11.12	6.33	132	29.30
1990	6.66	0	11.79	5.13	77	0	182	8.76	2.10	31	11.54
1991	7.43	97	17.18	9.75	131	100.21	276	17.52	10.09	136	36.56
1992	1.8	266	11.25	9.45	525	35.53	386	15.52	13.72	762	35.54
1993	7.9	-	16.88	8.98	114	-	-	18.25	10.35	131	-
1994	3.53	-	12.12	8.59	243	-	-	16.65	13.12	372	-
1995	5.46	-	13.22	7.76	142	-	-	18.48	13.02	238	-
Average – young plantation (1986-1988)	**2.06**	19	3.30	**1.24**	60	65.44	55.7	2.69	**0.63**	31	11.37
Average – full fruiting potential (1989-1995)	**5.37**	130	13.27	**7.90**	147	-	265.0	15.19	**9.82**	183	-
Average (1986-1995)	**4.37**	83	10.27	**5.90**	135	-	175.3	11.44	**7.06**	161	-

The obtained results confirm the high efficiency of irrigation to maintain soil suction at – 0.03 MPa, especially on the young plantation. On the plantation at its full fruiting potential, the highest rise in yield (183%) occurred in the combination irrigated to maintain soil suction at – 0.01 MPa, which confirms the high water requirements of blueberry plants.

The high sensitivity of young blueberry plantings to excessive irrigation is also confirmed by the study by Tryngiel-Gać et al. (2013). The experiment was conducted in the years 2009-2012 in the Experimental Orchard in Dąbrowice on young plantings of 5 cultivars of highbush blueberry: ‘Bluecrop’, ‘Chandler’, ‘Duke,’ ‘Nelson’, and ‘Spartan’. The experiment assessed the impact of varied irrigation applied by using drip lines with emitters, with different delivery rates, spaced along the rows of plants. The treatments were as follows: control – without irrigation; 100% of reference water dose (1 drip line per row of plants, emitters spaced 50 cm apart, emitter delivery rate 1.6 $l \cdot h^{-1}$), 125% of reference water dose (2 lines, emitters 50 cm apart, delivery rate 1 $l \cdot h^{-1}$). The irrigation was carried out based on measurements of soil suction in the 100% reference treatment to maintain moisture at 80-100% of Field Water Capacity (FWC). The frequency of irrigation and the amount of water delivered depended on the distribution and amount of atmospheric precipitation each year. The blueberry shrubs came into fruiting in the third year after planting and produced yields that varied across the years of the study (Table 3). After analyzing the data obtained by the authors, it follows that with the average annual consumption of irrigation water in the amount of 20.8 mm (irrigation at 100%), a rise in yield of 35% was obtained, which is 1.23 $t \cdot ha^{-1}$. The average irrigation efficiency coefficient represented a rise in fruit yield of about 68 kg per 1 mm of water used for irrigation. Increasing the amount of water to 26 mm per year (irrigation at 125%) increased the yield by an average of 28%, corresponding to 0.97 $t \cdot ha^{-1}$, and the average irrigation efficiency coefficient was a 44.94 kg rise in fruit yield per 1 mm of irrigation water. In the combination irrigated at 100%, a total of 62.5 mm of water was used for irrigation (over the 3-year duration of the experiment), and a cumulative rise in yield of 3.69 $t \cdot ha^{-1}$ was obtained. In the combination irrigated at 125%, a total of 78 mm of water was used for irrigation (over the 3-year duration of the experiment), and a cumulative rise in yield of 2.92 $t \cdot ha^{-1}$ was obtained. The applied doses of water were too high for the young plantation, hence the lower efficiency of irrigation in the treatment at 125% FWC. With the price of blueberries in that period (2010-2012) standing at an average of 10 PLN per kg (wholesale markets), this constitutes a rise in production revenue by approx. 37 thousand PLN per hectare for irrigation at 100%, and 29 thousand PLN per hectare for irrigation at 125%. The estimated yield losses due to a possible lack of irrigation on the described plantation are at a level of 26% and 22% (for 100% and 125% of reference water dose, respectively).

Table 3. Blueberry fruit yield ($t \cdot ha^{-1}$) depending on the irrigation used, according to Tryngiel-Gać et al. (2013) – amended.

Year	Control	100% of reference water dose					125% of reference water dose				
	Yield	Amount irrigation water usage	Yield	Rise in yield		Irrigation efficiency coefficient	Amount irrigation water usage	Yield	Rise in yield		Irrigation efficiency coefficient
	$t \cdot ha^{-1}$	mm	$t \cdot ha^{-1}$	$t \cdot ha^{-1}$	%	$kg \cdot mm^{-1}$	mm	$t \cdot ha^{-1}$	$t \cdot ha^{-1}$	%	$kg \cdot mm^{-1}$
2010	3.29	14.6	3.88	0.59	18	40.41	18.2	3.88	0.59	18	32.42
2011	2.63	13.9	2.08	0	0	0	17.4	2.04	0	0	0
2012	4.61	34.0	8.26	3.65	79	107.35	42.5	7.53	2.92	63	68.70
Average (2010-2012)	3.51	20.8	4.74	1.23	35	67.84	26.0	4.48	0.97	28	44.94

Table 4. Effect of irrigation on fruit yield (Mg·ha^{-1}) of highbush blueberry 'Patriot' according to Rumasz-Rudnicka et al. (2009), and Koszański et al. (2009, 2011) – amended.

Year	Control	Irrigation to maintain soil suction at – 0.01 MPa				
	Yield	Amount irrigation water usage	Yield	Rise in yield		Irrigation efficiency coefficient
	t·ha^{-1}	mm	t·ha^{-1}	t·ha^{-1}	%	kg· mm^{-1}
2000	1.67	131	2.96	1.29	77	9.85
2001	4.99	70	6.33	1.34	27	19.14
2002	3.79	120	6.87	3.08	81	25.67
2003	4.25	150	12.21	7.96	187	53.07
2004	13.00	63	14.46	1.46	11	23.17
2005	3.87	128	12.46	8.59	222	67.11
2006	1.96	300	16.87	14.91	761	49.70
2007	8.37	40	10.12	1.75	21	43.75
2008	2.40	200	10.40	8.00	333	40.00
2009	8.69	127.5	18.67	9.98	115	78.27
Average – young plantation 2000-2002	**3.48**	107.0	5.38	**1.90**	55	17.79
Average – full fruiting potential (2003-2009)	**6.07**	144.1	13.59	**7.52**	124	52.21
Average (2000-2009)	**5.30**	132.9	11.14	**5.84**	110	43.90

Long-term studies on the irrigation of highbush blueberry were also conducted by Rumasz-Rudnicka et al. (2009) and Koszański et al. (2008, 2009, 2011) in SD Lipnik near Stargard Szczeciński – the experimental station of the West Pomeranian University of Technology in Szczecin. Blueberry plants of the cultivars 'Patriot' and 'Spartan' were grown in the years 2000-2009 under varied water conditions: O – control plots (without irrigation), W – plots irrigated to maintain soil suction at -0.01 MPa. Irrigation times and doses were based on the water potential of the soil, determined with tensiometers placed at a depth of about 25 cm. The results obtained by the authors clearly indicate that the irrigation of highbush blueberry plantation was a necessary agrotechnical treatment to ensure proper soil moisture conditions, and the amount of water delivered was correlated with the variations in rainfall (Table 4). After analyzing the data obtained by the authors, it follows that with the average annual consumption of irrigation water of 107 mm on the young plantation, a rise in yield of 55% was obtained, corresponding to 1.9 $t \cdot ha^{-1}$. The average irrigation efficiency coefficient was a rise in fruit yield of about 18 kg per 1 mm of water used for irrigation. On the plantation at its full fruiting potential, with the use of irrigation water at an average of 144 mm per year, an increase in yield of 124% was observed, which corresponds to 7.52 $t \cdot ha^{-1}$, and the irrigation efficiency coefficient was a 52 kg rise in fruit yield per 1 mm of water used for irrigation. Over the duration of the experiment, an average of 5.29 $t \cdot ha^{-1}$were collected in the control combination, and 11.13 $t \cdot ha^{-1}$ in the irrigated combination. A total of 1,329 mm of water was used for irrigation (over the 10-year duration of the experiment), an average of 133 mm per year, a cumulative rise in yield of 58.36 $t \cdot ha^{-1}$ was obtained, an average of 5.83 $t \cdot ha^{-1}$ per year (110%), and the irrigation efficiency coefficient represented a 44 kg rise in fruit yield per 1 mm of water used for irrigation. With the price of blueberries during that period (2000-2009) standing at an average of 12 PLN per kg (wholesale markets), this represents a rise in production revenue by about 700 thousand PLN per hectare. The estimated yield losses due to a possible lack of irrigation on the described plantation are at a level of 52%.

A high rise in yield was also recorded in the irrigation of the blueberry cultivar 'Spartan' (Koszański et al. 2009, 2011). The research methodology was the same as in the work of Rumasz-Rudnicka et al. (2009). After analyzing the data obtained by the authors (Table 5), it follows that with the average annual consumption of irrigation water of 159 mm on the plantation at its full fruiting potential, a rise in yield of 138% was obtained, which corresponds to 8.47 $t \cdot ha^{-1}$. The average irrigation efficiency coefficient was a 53 kg rise in fruit yield per 1 mm of water used for irrigation. Over the duration of the experiment, an average of 6.13 $t \cdot ha^{-1}$ were collected in the control combination, and 14.6 $t \cdot ha^{-1}$ in the irrigated combination. A total of 795 mm of water was consumed for irrigation (over the 5-year duration of the experiment), and a cumulative rise in yield of 42.36 $t \cdot ha^{-1}$ was obtained. With the price of blueberries during that period (2005-2009) standing at an average of 12 PLN per kg (wholesale markets), this represents a rise in production revenue by approx. 500 thousand PLN per hectare. The estimated yield losses due to a possible lack of irrigation on that plantation are at a level of 58%.

Table 5. Effect of irrigation on fruit yield (Mg·ha^{-1}) of highbush blueberry 'Spartan' according to Koszański et al. (2009, 2011) – amended.

Year	Control	Irrigation to maintain soil suction at – 0.01 MPa				
	Yield	Amount irrigation water usage	Yield	Rise in yield		Irrigation efficiency coefficient
	t·ha^{-1}	mm	t·ha^{-1}	t·ha^{-1}	%	kg· mm^{-1}
2005	4.37	128	12.58	8.21	188	64.14
2006	3.29	300	18.33	15.04	457	50.13
2007	11.04	40	12.91	1.87	17	46.75
2008	3.92	200	10.56	6.64	169	33.20
2009	8.04	127.5	18.64	10.60	132	83.14
Average (2005-2009)	**6.13**	159.1	14.60	**8.47**	138	53.25

The high efficiency of irrigation of highbush blueberry is also confirmed by our own research conducted with the cultivar 'Bluecrop' in the Experimental Orchard in Dąbrowice in 2010-2015 (Table 6). After analyzing the data, it follows that with the average annual consumption of irrigation water of 26 mm on the young plantation, a 14% rise in yield was obtained, which corresponds to 0.16 t·ha^{-1}. The average irrigation efficiency coefficient was a 30 kg rise in fruit yield per 1 mm of water used for irrigation. On the plantation at its full fruiting potential, with irrigation water used at an average of 68 mm per year, a 236% increase in yield was observed, which corresponds to 6.99 t·ha^{-1}, the irrigation efficiency coefficient was a 103 kg rise in fruit yield per 1 mm of water used for irrigation. Over the duration of the experiment, an average of 3.6 t·ha^{-1} were collected in the control combination, and 7.4 t·ha^{-1} in the irrigated combination. A total of 281 mm of water was consumed for irrigation (over the 6-year duration of the experiment), an average of 46.9 mm per year, a cumulative rise in yield of 22.81 t·ha^{-1} was obtained, an average of 3.81 t·ha^{-1} per year (105%), and the irrigation efficiency coefficient was an 82 kg rise in fruit yield per 1 mm of water used for irrigation. With the price of blueberries during that period (2010-2015) standing at an average of 10 PLN per kg (wholesale markets), this represents a rise in production revenue by approx. 228 thousand PLN per hectare. The estimated yield losses due to a possible lack of irrigation on that plantation are at a level of 51%.

Table 6. Fruit yield (t·ha^{-1}) of blueberry 'Bluecrop' depending on the irrigation used.

Year	Control	125% of reference water dose				
	Yield	Amount irrigation water usage	Yield	Rise in yield		Irrigation efficiency coefficient
	t·ha^{-1}	mm	t·ha^{-1}	t·ha^{-1}	%	kg· mm^{-1}
2010	3.30	18.2	3.50	0.20	6	10.99
2011	4.62	17.4	4.12	0	0	0
2012	4.86	42.5	7.01	2.10	44	50.66
2013	2.73	48.4	7.07	4.30	159	89.61
2014	4.30	48.0	10.70	7.70	180	161.32
2015	1.83	106.6	12.05	8.87	485	83.18
Average – young plantation (2010-2012)	**4.26**	26.0	4.88	**0.62**	14	30.13
Average – full fruiting potential (2013-2015)	**2.95**	67.7	9.94	**6.99**	236	103.20
Average (2010-2015)	**3.61**	46.9	7.41	**3.80**	105	82.90

Source: own research.

On the basis of the above analyses of results, it can be stated that high yields of blueberries are only possible with the use of irrigation. Due to limited water resources, water should be used rationally, and therefore it is necessary to implement into practice the system of integrated irrigation based on reliable decision criteria. The results presented here showed a very large variation in the applied doses of water. The lowest doses, with excellent results, were used in Skierniewice (Dąbrowice). This probably resulted from the use of automatic irrigation controls and precise determination of a single dose of water that had to wet the soil to a depth of 40 cm. In addition, weather forecasting was used to discontinue irrigation before an approaching rain. The experience gained was used during the development of the Internet Platform for Irrigation Decision Support (www.nawadnianie.inhort.pl) undertaken within the framework of the Multi-Year Programme of the Research Institute of Horticulture, Task 3.1. 'Development of water – and energy-efficient technologies for growing horticultural crops'. The aim of the Platform is to optimize the use of water for irrigation, and the information contained there is to help producers in applying in practice the principles of integrated irrigation.

CONCLUSIONS

1. Irrigation of highbush blueberry is a necessary agrotechnical treatment in Poland to ensure proper soil moisture conditions, and the amount of water being delivered should be closely correlated with the changes in weather conditions.
2. The rise in yield achieved through the use of irrigation averaged 33% (1.02 $t \cdot ha^{-1}$) on young plantations, and 144% (7.42 $t \cdot ha^{-1}$) on plantations at their full fruiting potential.
3. The average irrigation efficiency coefficient on young plantations was a 26.94 kg rise in fruit yield per 1 mm of water used for irrigation, and on plantations at their full fruiting potential a 54.59 kg rise in fruit yield per 1 mm of irrigation water. After recalculation, it follows that to obtain a 1 kg rise in yield, as much as 371 litres of water must be used on a young plantation and 183 litres on a plantation at its full fruiting potential.
4. The yield loss coefficient for estimating losses in the absence of irrigation averaged 24% on young plantations and 57% on plantations at their full fruiting potential.
5. Due to its shallow root system, highbush blueberry is sensitive not only to periodic shortages of water but also to high doses of water, especially in the first years after planting.

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