Needs and Effects of Use Sprinkler Irrigation Systems in Crops Production in Central Poland on the Example of Spring Malting Barley (*Hordeum vulgare* L.)

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Abstract. The purpose of the paper was to determine the yielding and production needs and effects of sprinkler irrigated spring malting barley (*Hordeum vulgare* L.) depending on the intensity of droughts occurring during its period of high water needs spanning May and June. The paper was based on the results of field experiments with irrigated barley cultivars, carried out in 2006–2017 on Luvisol (LV) with fine sandy loam texture, in central Poland – the zone of the greatest need for supplementary irrigation in terms of climatic criterion. The results proved that the yield of non-irrigated crops depended significantly on meteorological parameters and was characterized by very high variability, while sprinkler irrigation contributed to a significant yield increase of 42% and yield stabilization in years. The coefficient of variation calculated for the yield of irrigated plants decreased from 29 to 17%. Irrigation water doses as well as grain yield increases caused by sprinkler irrigation depended significantly on weather conditions in the period of high water needs of barley. Formulas developed on the basis of this analysis enable the forecasts of needs and effects of irrigation based on rainfall totals or rainfall/evapotranspiration ratio.

Keywords: Drought · Rainfall · Evapotranspiration

1 Introduction

In the contrast to arid and semi-arid climatic zones, where irrigation is the essential treatment in crop production, in Poland irrigation has a supplementary character. The demands for the use of this treatment primarily occur during droughts, which in the central part of the country appear irregularly but at the approx. frequency of 30% [5, 15, 16]. It is noteworthy that surpluses of soil moisture, in short sections or even in the whole growing seasons, occur with the same frequency. But for this reason, inter alia, irrigation systems in Poland (according to data from National Statistical Office) [6] cover only about 73 thousand hectares, whereof sprinkler irrigation mainly used in horticultural crops accounts for 8.7 thousand ha. Research aimed at the development of irrigations in central Poland include mainly the issues concerning the advisability of its

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use in the cultivation of different plant species by determination of production efficiency and economy and changes in quality of yield or optimization irrigation doses in relation to water needs of plant [3, 4, 8, 11, 13].

The purpose of the paper was to determine the yielding and production needs and effects of sprinkler irrigated spring malting barley (*Hordeum vulgare* L.) depending on the intensity of droughts occurrence during the period of the high demand for water of barley (May-June), determined on the basis of selected meteorological parameters.

2 Materials and Methods

The needs and effects of barley irrigated by sprinkler system were developed on the basis of the results of multi-annual field experiments with spring malting barley cultivars carried out in 2006–2017 (with the exception of 2014). The experiments were conducted in the research centre of the University of Science and Technology in Bydgoszcz (53°13′N, 17°51′E, 98.5 m.a.s.l.) within the zone of the greatest need for supplementary irrigation in Poland in terms of climatic criterion on a Luvisol (LV) with a fine sandy loam texture [17].

Spring malting barley was optimally irrigated, providing plants with readily available water in the root zone throughout the period of plant high water needs, spanning May and June. The irrigation schedule was established on a constant monitoring of moisture in the root zone by a counterbalance of the amount of readily available water. The procedure was based on meteorological parameters measurements and soil moisture measurements by the soil moisture meter Fieldscout TDR 300. Barley was irrigated by a portable sprinkler system with low-pressure Nelson-type sprinklers with the discharge of 200 $dm^3\ h^{-1}$. The amount of individual irrigation rates and the total seasonal rate of discharged water depended on the weather conditions, mainly on the rainfall volume and distribution. Detailed information on the factors and design of experiments as well as farming practice are presented in the papers of Żarski et al. [14] and Błażewicz et al. [1]. The average level of nitrogen fertilization was 45 kg ha^{-1} due to intended use of grains for malting purpose. In the research, results of meteorological measurements carried out in a traditional way in accordance to the World Meteorological Organisation procedures, at the measuring point in the vicinity of experimental field, were used. To examine the strength of the relationship between results of the 11-year field experiments with barley and meteorological data, an analysis of regression was applied. In the study were searched the most significant dependencies between yielding of barley cultivated without irrigation and the needs and production effects of irrigation treatment, and selected meteorological indicators in the period of plant high water needs, i.e. from May 1 to June 31. The following meteorological indicators were taken into account: absolute rainfall (P), relative precipitation index (RPI), standardized precipitation index (SPI) [5] and the rainfall/potential evapotranspiration ratio (ET) (evapotranspiration calculated by Grabarczyk formula:

$$ET = 0.32(d + 1/3t) \quad (1)$$

where: d – average air saturation deficit (hPa), t – average air temperature (°C). According to the results of research by Grabarczyk and Żarski [2] this formula better represents plant water needs in the climatic conditions in Poland, compared to the reference model of Penman recommended by FAO. In addition, it does not require the use of plant's coefficients kr, which in the period of the plant high water needs and optimal soil moisture conditions amount to about 1.0.

3 Results and Discussion

Meteorological conditions in the period of plant high water needs, in subsequent seasons of the experiments with irrigated barley, differed greatly. The total rainfall was on average of 117.7 mm, varying from 27.0 mm in 2008 to 178.6 mm in 2007. The values of RPI ranged from 26 to 175%, SPI from −2.45 to 1.58, and the ET/P ratio from 0.11 to 0.92. Based on the results of the analysis, the following seasons were identified: 2 dry, 3 averages, 3 wet, 1 moderately wet and 3 very wet (Table 1). Irrigation was carried out in almost all years of experiments except 2009 – the wet one, when no demand for water supplementation occurred. In the remaining seasons referred to as wet and moisture, the need for sprinkler irrigation use resulted from the uneven rainfall distribution during the period of barley high water needs. Summarizing, the 11–year research period was wetter than the average multi-annual rainfall conditions in the region: RPI was 115%, and SPI 0.46.

Table 1. Meteorological indicators and the total irrigation rates over the period of high water needs in malting barley from May to June. (P – rainfall total, RPI – relative precipitation index, SPI – standardized precipitation index, P/ET – rainfall total to potential evapotranspiration ratio, D – total irrigation rate).

Year	Drought level acc. to SPI	P mm	RPI%	SPI	ET mm	P/ET	D mm
2006	Normal	81.7	80	−0.40	245	0.33	90
2007	Very wet	178.6	175	1.58	195	0.92	30
2008	Extremely dry	27.0	26	−2.45	235	0.11	180
2009	Wet	142.7	140	0.96	165	0.86	0
2010	Normal	110.7	108	0.31	161	0.69	105
2011	Wet	139.2	136	0.89	231	0.60	75
2012	Moderately wet	159.2	156	1.25	209	0.76	70
2013	Wet	141.0	138	0.92	193	0.73	60
2015	Moderately dry	54.6	53	−1.23	241	0.23	135
2016	Moderately wet	149.5	146	1.08	268	0.56	67
2017	Normal	110.6	108	0.31	223	0.50	55
Average	**Normal**	**117.7**	**115**	**0.46**	**215**	**0.55**	**79**

The analysis showed that grain yield of non-irrigated barley in the years of research was on average 4.09 t ha^{-1} (Table 2). In the individual seasons, barley yields were characterized by a high variability – from 1.98 to 5.90 t ha^{-1}; the coefficient of variation (CV) amounted to 29%. Regression analysis showed that the yield depended significantly on rainfall totals during the period of high water needs of spring malting barley, in the period spanning May and June. Among the analyzed indicators, stronger correlation with the non-irrigated barley grain yield revealed the P/ET ratio (Fig. 1), but also the absolute rainfall totals determined the yield in the similarly significant extent. In three May–June periods, in which the total rainfall in the period critical for plant, was less than 82 mm and the P/ET ratio did not exceed 0.33, the grain yield was lower than the multi-annual mean, by an average of 37%. The yield decrease resulting from the occurrence of meteorological and agricultural droughts during plant vegetation is a distinctive feature of crop production in central Poland. It affects all crops, but to a greater extent the spring cultivars compared to the winter ones; it is recorded at the frequency of about 30%. Therefore it means that it occurs on average once every 3 years [5, 15, 16].

Table 2. Seed yields and sprinkler irrigation effectiveness in malting barley depending on drought level (O – non-irrigated, W – irrigated).

Year	SPI	Drought level acc. to SPI	Yield 15% moisture content ($t\ ha^{-1}$)		Yield increase under irrigation		
			O	W	$t\ ha^{-1}$	%	$kg\ mm^{-1}$
2006	−0.40	Normal	2.64	5.32	2.68	102	29.8
2007	1.58	Very wet	4.79	5.03	0.24	5	8.0
2008	−2.45	Extremely dry	1.98	5.37	3.39	171	18.8
2009	0.96	Wet	5.90	5.90	0.00	0	0.0
2010	0.31	Normal	3.76	5.17	1.41	38	13.4
2011	0.89	Wet	3.67	4.83	1.16	32	15.5
2012	1.25	Moderately wet	4.45	5.64	1.19	27	17.0
2013	0.92	Wet	4.95	5.64	0.69	14	11.5
2015	−1.23	Moderately dry	3.11	7.51	4.40	141	32.6
2016	1.08	Moderately wet	5.07	7.83	2.76	54	41.2
2017	0.31	Normal	4.69	5.70	1.01	22	18.4
Average	**0.46**	**Normal**	**4.09**	**5.81**	**1.72**	**42**	**21.8**

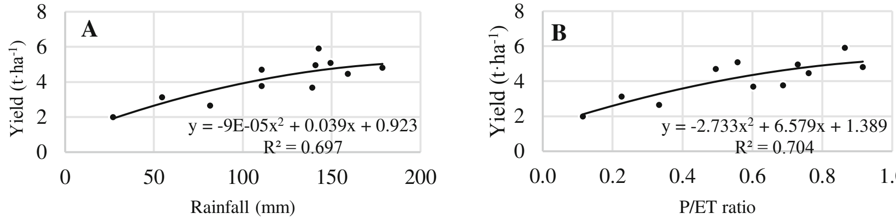

Fig. 1. Dependence of grain yield of non-irrigated spring malting barley ($t\ ha^{-1}$) and meteorological parameters in May-June; A – rainfall (mm), B – P/ET ratio.

The needs of sprinkler irrigation of spring malting barley determined by means of seasonal irrigation doses were on average 79 mm, ranging from 0 to 75 mm in moist and wet periods, to 135–180 mm in dry periods (Table 1). The needs significantly depended on both: the rainfall totals as well as the P/ET ratio (Fig. 2).

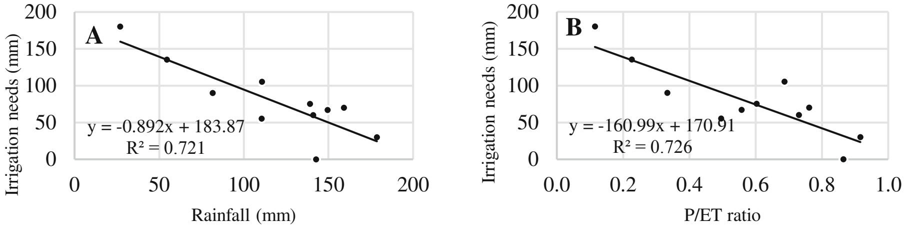

Fig. 2. Dependence of spring malting barley irrigation needs (mm) on meteorological parameters in May-June period; A – rainfall (mm), B – P/ET ratio.

The grain yield of irrigated barley averaged 5.81 t ha^{-1} in the years of study, varying in different growing seasons from 4.83 to 7.83 t ha^{-1} (Table 2). Irrigation contributed to the stabilization of the crop, since the coefficient of variation (CV) of the yield obtained from irrigated plots amounted 17%. Irrigation assured the correct rhythm of growth and development of plants and intensified their physiological processes.

As the result, the average long-term production effect of irrigation applied in spring barley, destined for malting, amounted to 1.72 t ha^{-1}, which determined an increase in the grain yield of 42%. One mm of water from the irrigation system made an average increase in grain yield of 21.8 kg mm^{-1} ha^{-1}. In the individual seasons, the production effects of irrigation depended significantly and linearly on meteorological parameters in the period spanning May and June (Fig. 3). The P/ET ratio (R^2 = 0.7921) was a better indicator of these effects compared to the absolute rainfall totals.

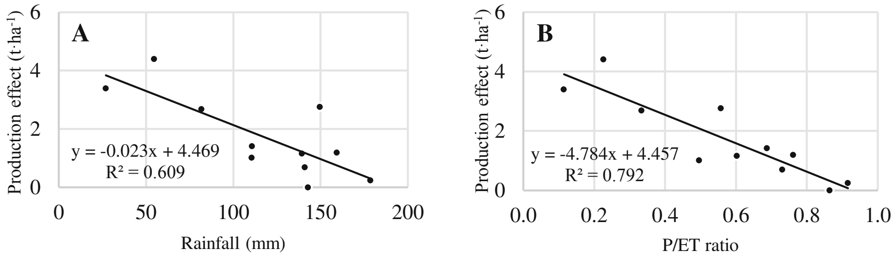

Fig. 3. Dependence of production effects of irrigated spring malting barley (t ha^{-1}) on meteorological parameters in in May-June period; A – rainfall (mm), B – P/ET ratio.

The production effects of sprinkler irrigation obtained in the studies indicate that there is a great potential for increasing crop production in central Poland, provided that the water factor is at the optimal level. Based on the obtained results, the introduction of available sprinkler irrigation systems to the cultivation technology of spring malting barley is a procedure that assures the growth and stabilization of grain production, whereas in dry vegetation periods – it prevents radical yields decreases. In practice, however, the popularisation of this system in the climatic conditions of central Poland will depend primarily on its economic efficiency, which depends on grain purchase price [3] as well as the infrastructural conditions, mainly including the access to water sources available for irrigation [13]. Regional character of the study showing the needs and effects of use sprinkler irrigation in the production of spring malting barley in Poland is justified by other results obtained in research carried out in different climate zones [7, 9, 10, 12].

4 Conclusions

The results of long-term (2006–2017) field experiments dealing with sprinkler irrigation in spring malting barley production in central Poland proved that the yield of non-irrigated crops depended significantly on meteorological parameters and was characterized by a high variability. Sprinkler irrigation contributed to a significant 42% increase in grain yield and its stabilization in years. The coefficient of variation calculated for the yields of irrigated plants decreased from 29 to 17%. Irrigation water rates as well as increases in grain yields caused by sprinkler irrigation depended significantly on meteorological parameters in the period of barley high water needs, spanning May and June. Formulas developed on the basis of this analysis enable the forecasts of needs and effects of irrigation based on rainfall totals or rainfall/evapotranspiration ratio.

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