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IMPACT OF THE IRRIGATION DOSE AMOUNT ON THE WHEAT YIELD

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ABSTRACT

The paper presents analysis of the impact of irrigation dose on the winter wheat Bystra yield, which is recommended for cultivation in Poland. It is a low-growing high-yield wheat cultivar. A reel sprinkler equipped with a computer for control of parameters of its operation, which was supplied with pond water was used for irrigation. Test were carried out on five fields, where four irrigation doses were used: 15, 20, 25, 30 mm. A change of weather during research in May and June caused the need to irrigate a field four times. During research, the size of the irrigation dose was measured with rain gauges on each of the investigated fields in five measurement points. One of the fields was a control field, which was not irrigated. The investigated wheat was characterized during harvesting. Research proved that the size of the irrigation dose influences the wheat yield. The grain yield between a control field and a field with the highest irrigation dose increased by twofold. Moreover, analysis of costs incurred during sprinkling were analysed.

Introduction

The process of irrigation of plants has accompanied people from many ages. Irrigation networks were used as early as in the ancient times to increase the plant yield by supply of water during the highest demand. Fields were located the most often close to water reservoirs and rivers and irrigation of a plantation was carried out by raising the water level and covering irrigation ditches, which caused soil absorption with water. In Poland, horticultural and vegetable plantations, which do not exceed 5% of the cultivation area, are irrigated. In order to ensure yield stability the irrigated surfaces should be increased by ten times (Mielnicki, 2015). Plants need the biggest amount of water during high temperatures (a plant shows then a great trend to increase weight) and low moisture when a high level of transpiration takes place. Water secreted through stomas should be supplemented by a plant on a current basis for its correct growth. A hydration technique does not forget about farms which have traditional crop rotation in the cultivation structure, namely such plants as grains, rapeseed, sugarbeets or potatoes (Łabędzki, 2016; Treder, 2011). Hydration of potato cultivation gains many followers because with its proper level there is a great increase of bulbs and thus a high profit from cultivation is generated (Żarski et al., 2011). Hydration of fields with grain crops may also bring financial advantages. In order to install an irrigation system in such farms, firstly, high costs of investment must be incurred and numerous legal requirements must be met. Before an investment is carried out the water collection source must be determined (underground water or surface water) and relevant water law permits should be acquired. Research on the increase of yield with the use of irrigation has been carried out in Poland for a several dozens of years. In case of wheat, it shows various yield depending on the weather. Furthermore, a great attention is paid to the economy of irrigation (Żarski, 2009). Some innovations improving the quality of irrigation, which increase the comfort of operation of a sprinkler are introduced. Diesel pumps are replaced with electric ones because they are more economical.

Modern irrigation systems developed largely in the beginning of the 20th century in Europe and the United States of North America. However, Israel is a leading country in irrigation. In Poland, plant production is mainly based on precipitation water and soil retention. Scenarios concerning the use of water for irrigation in the future seem to be little optimistic since the European Union requires changes to be introduced in the Polish law and imposes charges for collection of underground and surface water, inter alia, for plant production purposes (Jeznach, 2009; Lisowski, 2011; Krajowy Zarząd Gospodarki Wodnej, 2010; www.portalhodowcy.pl).

The irrigation date is indicated based on the following criteria:

– plant criteria – irrigation needs are determined based on the parameters which reflect the physiological state of plants (hydration state of tissues),
– soil criteria – irrigation date is determined based on the measurement of moisture of water potential of soil/ground,
– climatic criteria – based on the assumptions that water consumption is determined by the weather and development phase of a plant (www.nawadnianie.inhort.pl).

Three fundamental irrigation systems can be distinguished – sprinkling irrigation, mini sprinkling systems and drip systems.

The aim of irrigation is supplementing periodical shortages of precipitation or reduction of effects of periodical lack of precipitation – namely droughts (Żarski et al., 2013).

The Water Law Act (Journal of Laws of 2001, no 115, item 1229 the act of 18th July 2001 Water Law Act) is a basic legal act which governs the water economy issues). It distinguishes three basic forms of using water – common, regular and specific. Water collection from a well or water reservoir located on a property for irrigation requires a proper permit. A charge in the amount of 4.23 $PLN\cdot m^{-3}$ is collected for water taken from a deep water well. Collection of surface water for irrigation is exempt from charges (Czarniakowska, 2008; Obwieszczenie Ministra Środowiska, 2015).

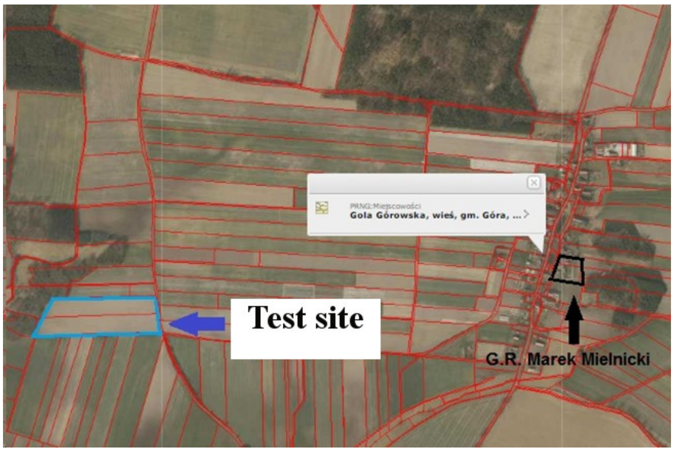
Objective of the research

The objective of the research was to determine what size of the irrigation dose of winter wheat will influence its crop and quality of the produced grain. The following parameters were determined during research: plant height, size of ears (length, weight), number of seeds in an ear, 1000 – seed weight, yield, straw weight. Additionally, analysis on the impact of yield on income in comparison to the incurred irrigation costs, was carried out.

Methodology of research

Place, method and date of the study

A field where investigations were carried out was located in Dolnośląskie Voivodeship, Górowski province, Góra municipality (Fig. 1). Taking into consideration division of Poland into physical and geographical units, the area of the research is in the macro-region of Nizina Południowo-Wielkopolska. Experiments were carried out in a farm, which deals with winter wheat cultivation, winter rapeseed and sugarbeets as well as pig breeding.



Source: www.mapy.geoportal.gov.pl

Figure 1. Test site – Gola Górowska

Research was carried out in May-June with large deficity of precipitation thus irrigation was repeated four times. Before investigations, physical and chemical composition of soil was determined on the investigated field and it was found out that it is uniform with equal resourcefulness in mineral components. Tests were carried out on 5 fields, where various doses were applied: on the field I – 15 $l{\cdot}m^{-2}$, on the field II – $20{\cdot}l{\cdot}m^{-2}$, on the field III – 25 $l{\cdot}m^{-2}$ and on the field IV IV – $30{\cdot}l{\cdot}m^{-2}$. Field no. V was not irrigated. Figure 2 presents planning of experimental fields.

Areas determined for irrigation were 60 m x 60 m ($2{\cdot}r_{of\ sprinkler}$), only the first field with the irrigation dose size 15 $l{\cdot}m^{-2}$ was longer by 10 m and on this distance a sprinkler stabilized the rolling speed. The irrigation doze size was determined in 5 measuring points within 12 m distance from each other (Fig. 2).

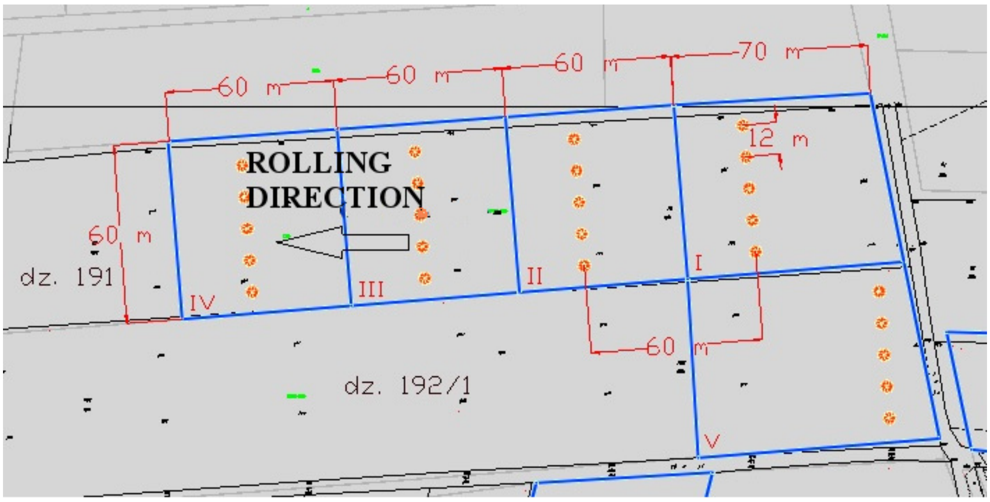


Figure 2. Planning experimental fields for irrigation

Characteristics of the investigated wheat

Winter wheat Bystra is a cultivar with the average-late maturing period. This cultivar was cultivated and registered in Poland in 2009. It is a quite low variety with a high yield potential A1 – 104.0% of a pattern, A2 – 102.0% of a pattern (A1: high level of agro-technology, A2 – average level of agrotechnology) and a very high resistance to diseases. It shows good effects at optimal and delayed date of sowing. Sugarbeets were a forecrop of wheat. Nitrogen fertilization was carried out in early spring after vegetation started with 90 kilo dose in the form of UAN and after ca. 4 weeks the second 90 kg N dose was applied also in the form of UAN. Phosphorus and potassium fertilization was not applied. Additionally, on-leave feeding with micro and macroelements was applied.

Measuring apparatus

A roller sprinkler Marani GT040C 90/450 was used in the research. This device is equipped with technologies which support the irrigation process, inter alia, with computer ODRA RAIN 2010. It analyses on a regular basis the operation of a sprinkler and controls the rolling speed and shows the time when rolling of a hose should end. Controlling computer operation parameters are as follows: smooth control of the hose rolling speed, set of the machine start, possibility of setting 4 zones of speed during rolling of the hose, pre and post irrigation zone, registration of the total time of sprinkler operation. Sprinkling was carried out with the use of Sime QUASAR sprinkler (Table 1) which can replace nozzles ϕ within 16-24 mm as a result of which efficiency of water flow at a given pressure and drop size changes. The installation was supplied with a diesel pump aggregate MARANI I75C000 with a four-cylinder diesel engine with the power of 75 KM (55kW) (Treder, 2011). Engine powered the central two-stage pump Caprari MEC MG 80/2A. The unit was equipped with MAC 1control panel, which controlled parameters of the unit. The computer was equipped with GSM interface, with which parameters of the moto-pump operation could be controlled e.g. turn on, off or set a relevant value of the working pressure and monitor on regular basis the present condition of the operation of the pump aggregate. Irrigation doses on the determined fields were measured with sprinklers (Table 1) mounted over the wheat field. ELECTRIC KS-5232 i ELDOM EK3130 scales with the maximum load of 5 kilo were used for determination of the wheat mass.

Methods of the research

Weather during research was a criterion which decided whether a treatment was performed (www.imgw.pl). In the beginning of May, rain was reported, however, amount of precipitation did not considerably affect development of plants since with the quite high daily temperature the water evaporated. On 18th May artificial supplementation of water deficiency on a plantation was started. A few days after irrigation, precipitation was reported twice. Nevertheless, it was similar to the one which occurred in the beginning of May. A decision was made to irrigate the crop one more on 29 May. In the first decade of June, high precipitation was reported (19 mm) which eliminated the need of irrigation. High average daily temperatures of air after precipitation affected intensive vaporization of some part of water from soil and thus on the 17th June the third irrigation treatment was applied. After a few days after irrigation, precipitation, which moistened the soil, occurred twice. However, high air temperatures were still occurring, 13 days after the third irrigation, decision was made to repeat this process. Irrigation made in June/July had a positive effect on the plants growth. In the beginning of July and later still high average daily temperatures occurred. Observation of the development phase of wheat enabled to make a decision to finish the irrigation period since it entered a whitening phase thus sprinkling would not be effective any more. The following parameters were entered into the computer in the investigated sprinkler (Fig. 3); length of fields: 70, 60, 60, 60 m, speeds of rolling a sprinkler were selected: 40, 30, 24, 30 $m \cdot h^{-1}$ which enabled determination of the water dose as 15, 20, 25, 30 mm.

Irrigation was carried out the following way – when 70 m was rolled with the speed of 40 $m \cdot h^{-1}$ (does 15 mm) the speed was automatically changed into 30 $m \cdot h^{-1}$ (dose 20 mm), after 60 m the speed decreased to 24 $m \cdot h^{-1}$ (dose 25 mm). When the field was crossed the final rolling speed was obtained – 20 $m \cdot h^{-1}$ (dose 30 mm). The crossing time of a sprinkler during the entire cycle is as follows:

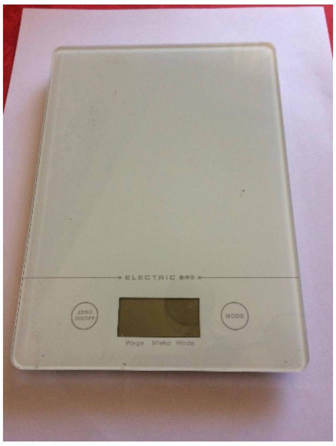
T_I = 70 m/40 $m \cdot h^{-1}$ = 1.75 h → 105 min – field I
T_{II} = 60 m/30 $m \cdot h^{-1}$ = 2.0 h → 120 min – field II
T_{III} = 60 m/24 $m \cdot h^{-1}$ = 2.5 h → 150 min – field III
T_{IV} = 60 m/20 $m \cdot h^{-1}$ = 3.0 h → 180 min – field IV
$T_0 = T_I + T_{II} + T_{III} + T_{IV} =$ 9.25 h → 555 min - total irrigation time.

Before the wheat was harvested samples were collected from two places 0.5^2 from particular fields in order to determine the characteristics of the harvested wheat. 5 samples were collected from each field, which were subjected to individual analysis. 10 wheatears and 10 stalks were randomly collected and then their length was measured and average values were calculated. Then, wheatears were threshed manually and the number of seeds in wheatears was determined. The results were calculated by determination of the wheat seeds yield from 1 ha and the weight of straw. 1000 seeds were separated from the sample and the thousand seed weight was determined.

Devices used in the research

It.	Device	Description		
1	MARANI GT040C 90/450 Sprinkler	Hose diameter PE [mm]	90	
		PE hose length [m]	450	
		Water expense [$m^3 \cdot h^{-1}$]	18 - 53	
		Working speed [bar]	4,5 - 10,5	
		Optimal irrigation belt [m]	51 - 76	
		Standard equipment		
		turbine with external circulation, manometer, hydraulic car jack, galvanized car of a water cannon with regulation of wheel track, speed corrector, six-gear transmission		
2	QUASAR Sprinkler	Range[m]	22 - 85	
		Nozzles [mm]	16, 18, 20, 22, 24	
		Drive	impulse, striker	
		Standard equipment		
		Sprinkler is equipped with the set of replaceable nozzles which are used for regulation of water expense and the size of precipitation drop		

3	ODRA RAIN 2010 computer	Computer comprises electronic system box, wires with systems: PE hose length, rolling speed, cut off. It also comprises water flow control engine, solar panel for charging battery and supplying battery. Interface menu in Polish.		
4	MARANI I75C000 Diesel aggregate	I	max 2200	
		Performance [$l \cdot min^{-1}$]	max 2400	
		Lift height [m]	max 112	
		Equipment		
		4 -cylinder engine IVECO motors F32MNSX00, cubic capacity 3 200 cm^3 , TURBO, power 75 KM (55 kW)		
		pump MEC MG 80/2A (suction Ø 100, outlet Ø 80).		

<table>
<tr><td>5</td><td>Garden rain meter</td><td>Maximum measurement of precipitaiton [mm]</td><td>35</td><td></td></tr>
<tr><td rowspan="4">6</td><td rowspan="4">Electronic kitchen scales ELECTRIC KS-5232</td><td>Maximum load [kg]</td><td>5</td><td rowspan="4"></td></tr>
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<tr><td rowspan="4">7</td><td rowspan="4">Electronic kitchen scales ELDOM EK3130</td><td>Maximum load [kg]</td><td>5</td><td rowspan="4"></td></tr>
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<tr><td colspan="2">Functions</td></tr>
<tr><td colspan="2">precise tensometer sensor, balancing function</td></tr>
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Source: www.nawadnianie.com, www.eldom.eu

Figure 3. Values declared during tests – length and speed of rolling of the sprinkler hose

Irrigation costs were related to exploitation of devices for irrigation. A diesel pump was used in the research. The determined profit was only a gross margin related to exploitation of the diesel engine. Hour diesel oil consumption of the unit at the set parameters was 4.9 $l \cdot h^{-1}$. This consumption was determined by multiplying: the length of a PE hose, working width (60 m), rolling time and hour consumption of fuel. The remaining costs not related to irrigation were the same for each field. Length of the rolled hose per 1 ha was: 167 m. The rolling time of the hose for particular irrigation doses was for the field I – 4.2 h for field II -5.6 h, for field III – 7.0 h, for field IV – 8.35 h. Fuel consumption was from 20.58 l of field I to 40.92 on field IV. It was assumed that the average retail price of diesel oil in the period when tests were carried out was PLN 4.17 **(***www.nafta.wnp.pl***).** No indirect costs, which did not influence the profit from the investigated fields were taken into consideration.

Research results

Table 1 presents the values of irrigation doses on four investigated fields. Analysis of particular fields indicates that field no. I – at.

The assumed dose of 15 mm in two cases was exceeded on 15th May and 17th June 17.0 mm. Average dose for the field was 15.5 mm and the minimum 10.0 mm and the maximum 24.0 mm. Field no. II at the assumed dose of 20 mm only in one case was exceeded on 17th June with 22.o mm. The average dose for the field was 19.1 mm, the minimum dose – 12.0 mm and the maximum one – 25.0 mm. Field no. III at the assumed dose of 25 mm only in one case was exceeded on 15th May 27. 5 mm and on the remaining days the doses were close to the standard. The average dose for the field was 22.7 mm and the minimum was 18.0 mm and the maximum one – 30.0 mm. Field no. IV – at the assumed dose of 30 mm in any time limit was not exceeded. The average dose for the field was 27.7 mm, the minimum dose was 24.0 mm and the maximum one – 31.0 mm.

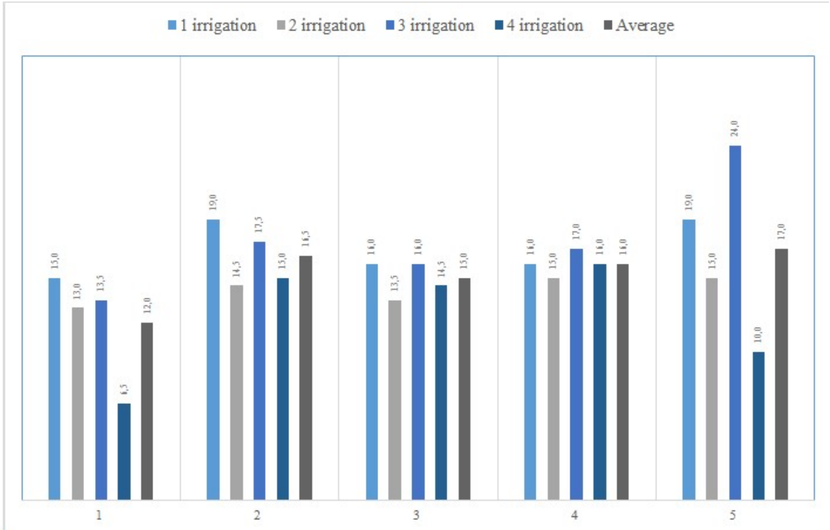
Table 1.
Average value of irrigation dose in mm on investigated fields

Field no.	Irrigation dose				Average for field	Dose (mm)	
	15th May	29th May	17th June	30th June		min.	max.
I	17.0	14.2	17.6	13.1	15.5	10.0	24.0
II	17.2	19.6	22.0	17.4	19.1	12.0	25.0
III	27.5	22.8	23.1	22.4	22.7	18.0	30.0
IV	26.2	29.6	27.9	27.0	27.7	24.0	31.0
V	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Analysis of irrigation results on particular fields was presented in figure 4. Irrigation doses on field I (Fig. 4a) are as follows: the lowest dose was 10 mm for point 1, for irrigation 1 and for point 1 for irrigation 5, the highest precipitation was 24 mm for point 5, for irrigation 3, the lowest average dose was 12 mm for point 1 and the highest average dose was 17 mm for point 5. Results on field II (Fig. 4b) were as follows: the lowest dose was 12 mm for point 1, for irrigation 1, the highest sprinkling dose was 25 mm for point 5, for irrigation 3, the lowest average dose was 17 mm for point 1, and the highest average precipitation was 22 mm for point 5. For field III (Fig. 4c) the lowest dose was 18 mm for point 1, for irrigation 1 and for point 5 for irrigation 4, the highest sprinkling dose was 30 mm for point 4, for irrigation 4, the lowest average dose was 19 mm for point 1 and the highest average precipitation was 27 mm for point 4. For field IV (Fig. 4d): the lowest dose was 23 mm for point 2, for irrigation 3, the highest precipitation was 31 mm for point 5, for irrigation 2, the lowest average dose was 26 mm for point 2, the highest average precipitation was 29 mm for point 5.

In order to characterize the collected wheat from particular fields samples were collected therefrom. A clear difference was observed between the irrigated wheat and the control field during collection of samples. Plants were clearly developed, healthier and the field was more compacted.

Table 2 includes results of characteristics of the investigated wheat. The highest average mass of the entire sample of plants was 1.8 kilo on field no IV which was irrigated with 30 mm dose. In comparison to the sample from the control field, the value increased twice. It was stated that there are no considerable differences in the height of plants from the investigated fields. The total length of plants was within 52.9 cm to 60.4 cm, only from the control field it was 45.1 cm. For the mass of wheatears the samples from field I and II had the lowest values and the average value was 30.2 g, while the mass of wheatears from the control sample was 22.8 g which means that the average weight of wheatears from irrigated fields was significantly higher than the control field.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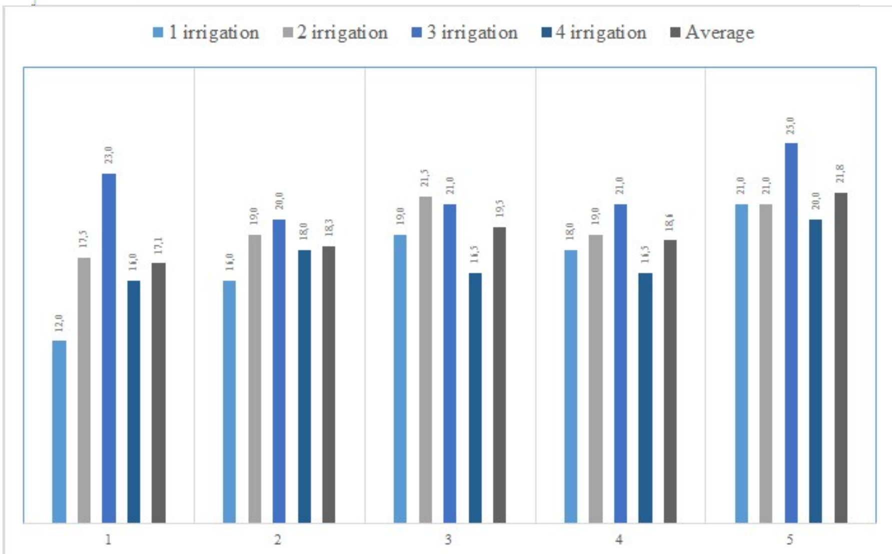
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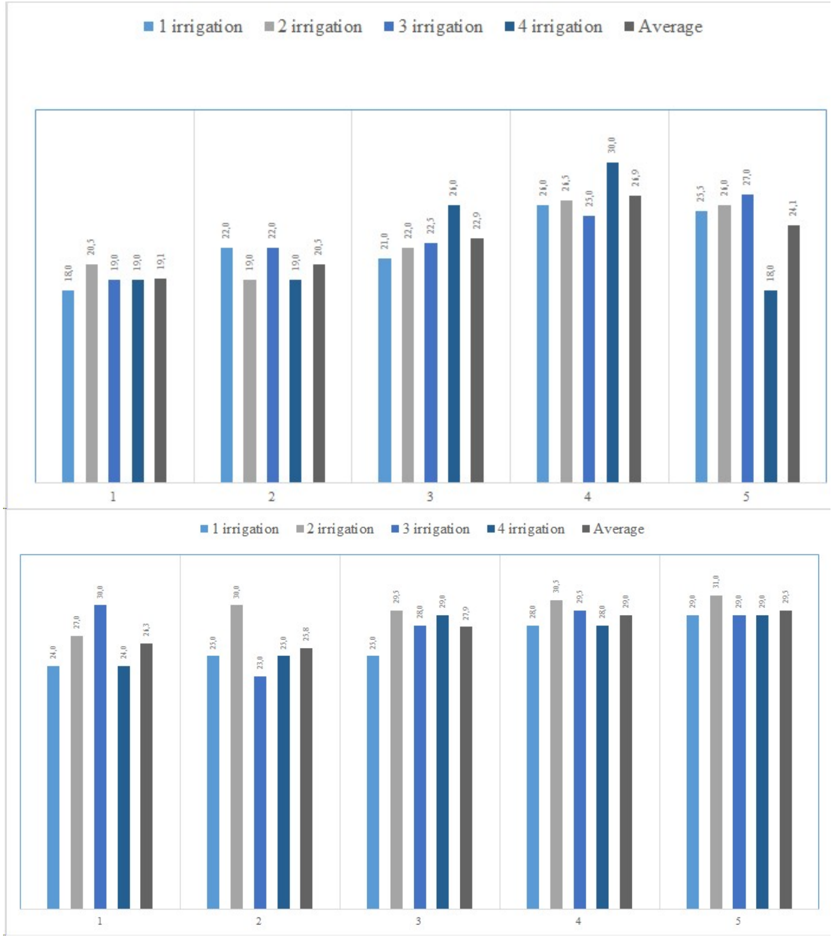

Figure 4. Size of irrigation doses during research: a – no I , b – nr II, c – nr III, d – nr IV

Table 2.
Data which characterise the investigated wheat

No. of a sample	Weight of a sample (kilo)	Length of a plant (cm)	Weight of wheatears (g)	Length of a wheatear (cm)	Number of seeds in a wheatear (pcs)	1000-seeds weight (g)	Yield of seeds for the field ($t\cdot ha^{-1}$)	Weight of straw ($t\cdot ha^{-1}$)
I	1.14	52.9	30.2	9.3	53.3	50.0	5.95	5.41
II	1.40	60.4	30.4	9.3	52.6	50.0	7.47	6.55
III	1.61	56.3	30.2	9.3	54.1	52.2	8.88	7.20
IV	1.80	59.2	32.4	9.8	58.8	49.8	10.08	7.91
Control sample		45.1	22.8	8.1	34.4	45.4	4.98	4.16

Wheatears from the irrigated fields were by 1.2 cm longer than wheatears from the control sample. The shortest wheatears were on fields I, II and III. A clear difference was reported in the examination of the number of seeds in a wheatear. A control sample showed an average number in a wheatear which was 34.4 pcs. The lowest average number of seeds among the irrigated field was obtained on field II, which was 52.6 pcs on field IV – 58.8 pcs of seeds. The difference in the size of the irrigation dose did not affect the 1000-seed weigth; it was within 49.8 g to 52.2 g while the control sample obtained a slightly lower value by approximately 5 g. The biggest differences between field were observed based on the analysis of the seeds weight after threshing of the entire sample. From the control sample the average yield of seeds was obtained 4.98 t·ha^{-1}, from the field I – 5.95 t·ha^{-1}, from the field II – 7.47 t·ha^{-1}, from the field III – 8.88 t·ha^{-1}, and from the field IV –10.08 t·ha^{-1}. Yield from IV field in comparison to a control field increased almost double.

A similar relation was reported during analysis of the size of the yield of straw. A difference between the control field and the highest average yield from field IV was 3.75 t, the straw weight increased double. The increase of the wheat yield and straw weight in relation to the amount of the irrigation dose was presented in figure 5.

During the research it was found out that the number of seeds in a wheatear was the factor influencing the size of the yield. It was observed that wheatears with a similar number of caryopses differ in the total yield since they have a varied degree of wheatear filling. Moreover, attention was paid to the number of caryopses in a wheatear, which translated into the total yield. It resulted from, inter alia, a higher yield of seeds, higher density of a field, growth and healthyiness of plants.

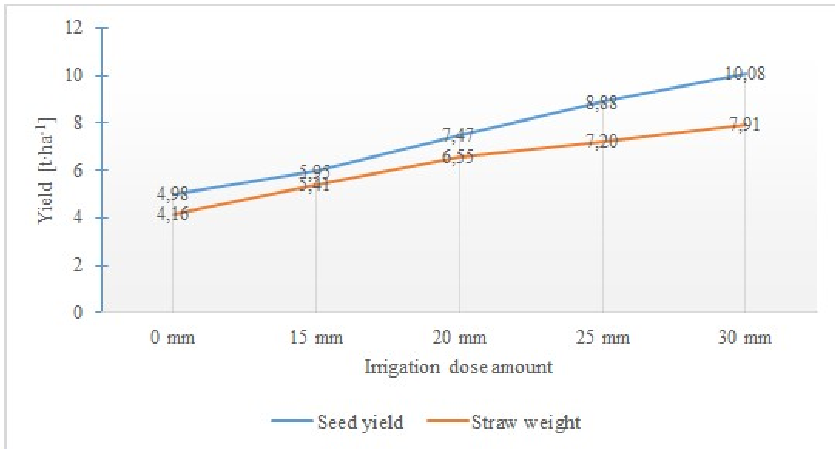

Figure 5. Impact of irrigation dose on wheat yield increase and straw weight

Irrigation costs of 1 ha on the investigated fields were within PLN 43.38 to PLN 682.52. In order to determine the profitability of irrigation with particular doses, the gross margin was calculated from the obtained yield. According to the Main Statistical Office the average price of wheat in the investigated period was 68.47 PLN·dt^{-1} (*www.stat.gov.pl*). Gross margin from 1 ha was within PLN 4073.97 and PLN 6901.76. Net profit after deduction of the consumed fuel costs from particular fields was as follows: field I = PLN 3730.69, field II = PLN 4657.03, field III = PLN 5508.14, field IV = PLN 6219.24. For the control field the profit was PLN 3409.81.

Conclusions

Based on the research the following conclusions were made:

1. Change of the irrigation dose from 15 mm to 30 mm on four investigated fields caused the increase of the wheat seeds yield from approximately 6 $t \cdot ha^{-1}$ to approximately 10 $t \cdot ha^{-1}$.
2. The wheat yield increased twofold in comparison to the non-irrigated field (4.98 $t \cdot ha^{-1}$) with a field irrigated with a 30 mm dose (10.09 $t \cdot ha^{-1}$).
3. The applied sprinkling doses did not affect the 1000 – seed weight (49.8g – 52.2g).
4. Along with the increase of the irrigation degree the weight of straw increased from 5.41 $t \cdot ha^{-1}$ to 7.91 $t \cdot ha^{-1}$.
5. The irrigation cost of 1 ha of cultivation of the investigated wheat was from PLN 343.28 for the 15 mm dose to PLN 682.52 for the 30 mm dose.
6. Gross margin from 1 ha of wheat crop was within PLN 3409 without irrigation to PLN 6219 at the maximum irrigation dose.

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WPŁYW WIELKOŚCI DAWKI NAWADNIANIA NA PLON PSZENICY

Streszczenie. W pracy przedstawiono analizę wpływu wielkości dawki nawadniania na plon pszenicy ozimej Bystra, która jest rekomendowana do uprawy w Polsce. Jest odmianą pszenicy niskopiennej o wysokim plonowaniu. Do nawadniania użyto deszczowni szpulowej wyposażonej w komputer do sterowania parametrami jej pracy, którą zasilano wodą ze stawu. Badania przeprowadzono na pięciu poletkach, na których stosowano cztery dawki nawadniania: 15, 20, 25, 30 mm. Zmiana pogody podczas badań w maju i czerwcu spowodowała konieczność czterokrotnego nawadnianie pola. W czasie badań mierzono wielkość dawki irygacji za pomocą deszczomierzy na każdym z badanych poletek w pięciu punktach pomiarowych. Jedno z poletek było poletkiem kontrolnym, które nie było nawadniane. W czasie zbioru dokonano charakterystyki badanej pszenicy. Badania dowiodły, że wielkość dawki nawadniania ma wpływ na plon pszenicy. Plon ziarna między poletkiem kontrolnym, a poletkiem o największej dawce nawadniania wzrósł 2-krotnie. Dodatkowo dokonano analizy kosztów poniesionych w trakcie deszczowania.

Słowa kluczowe: deszczownia, nawadnianie, eksploatacja, pszenica