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YIELDING AND ENERGY VALUE OF WINTER RYE DEPENDING ON SPRINKLING IRRIGATION AND NITROGEN FERTILIZATION

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Abstract. The effect of sprinkling irrigation and nitrogen fertilization on yield of grain, protein and energy value of winter rye was investigated in a six-year period of field trials in the Wielkopolska region (52°29′ N, 16°49′ E, Poland) in Central Europe on soils classified to quality classes IVa and IVb. The first degree factor was the water variant: no sprinkling irrigation vs. sprinkling irrigation applied, while nitrogen fertilization was the second degree factor at 0, 50, 100, 150 kg $N \cdot ha^{-1}$. It was found that sprinkling irrigation on average for the years of the study caused an increase in grain yielding of rye cv. Dańkowskie Złote by 0.20 $t \cdot ha^{-1}$. In two years a positive effect of this measure was observed, while in four years no significant changes were found in grain yield volume under the influence of fertilization. Sprinkling irrigation increased grain yield in rye in each of the nitrogen fertilized treatments. Moreover, the effect of irrigation increased with an increase in nitrogen fertilization. Protein yield and energy calculated for rye grain depended on the interaction of sprinkling irrigation and nitrogen fertilization.

Key words: winter rye, irrigation, nitrogen fertilization, grain yield, protein yield, energy yield

INTRODUCTION

Despite the tendency to reduce rye cultivation area, this cereal continues to account for a considerable share in the cropping structure and the area cropped to this cereal is approx. 16% arable land. Causes for the reduction of rye cultivation are associated first of all with its limited use as animal feed [Dubis et al. 2008], which partly results from its substitution with triticale grain [Krasowicz and Nieściór 2001].

Rye grain is used for diverse purposes, predominantly as feed. For this reason the most important task, apart from high yields of grain, is to improve its nutritive value. Among cultivation factors the greatest effect on grain winter rye properties and processability is observed for cultivar as well as the application rate and date of nitrogen fertilization [Budzyński et al. 2004, Nedzinskiene and Asakavičiūte 2008]. Also according to Maral et al. [2013] nitrogen is this nutrient which has the greatest effect on grain yield and protein content. In studies assessing the effect of nitrogen it is recommended to apply the measure of effectiveness of nitrogen fertilization such as the agricultural efficiency of application of this nutrient. This index makes it possible to determine the capacity of plants to convert nitrogen uptake into harvestable yield [Fotyma 1990, Novoa and Loomis 1981].

Efficiency of nitrogen fertilization, particularly on light soils, is frequently reduced by the amount and distribution of precipitation. At an adverse pattern of weather factors the interaction of sprinkling irrigation and fertilization may determine both quality and volume of obtained yields, as well as the effectiveness of these two cultivation measures.

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It was assumed in the research hypothesis that sprinkling irrigation and nitrogen fertilization have an advantageous effect on yield and feeding value of rye grain. The aim of this study was to determine the effect of sprinkling irrigation and nitrogen fertilization on the yield of grain, as well as protein yield and energy value of winter rye grain.

MATERIALS AND METHODS

The field trials on winter rye cv. Dańkowskie Złote were conducted in the years 2002–2007 in the fields of the Research and Education Center Gorzyń, Experimental Station in Złotniki near Poznań (52°29′ N, 16°49′ E, Poland) in Central Europe. Soils in the experimental field are classified to quality classes IVa and IVb, while in terms of their agricultural suitability they belong to complexes 4 (very good rye complex) and 5 (good rye complex). These soils are lessive soils formed from light loamy sands and light sandy loam with the O horizon of 27–30 cm, humus content of 0.9–1.0%, pH 5.7 (in 1 M KCl), high phosphorus content and medium contents of potassium and magnesium. Due to the deep ground water table and subsoil structure these soils are periodically too dry.

Rye cv. Dańkowskie Złote was grown in a four-course crop rotation after potatoes. The first degree factor was the water variant: no sprinkling irrigation vs. sprinkling irrigation applied – at a decrease of soil moisture content in the 0–30 cm layer to 70% field capacity in the period of the greatest sensitivity of plants to water shortage. Basic plot area for non-irrigated was 288 m^2 (24x12 m) and for sprinkling irrigation – 576 m^2 (48x12 m). Amount of water respectively for years: 90, 120, 60, 120, 190, 140 mm.

The second degree factor was nitrogen fertilization at 0, 50, 100 and 150 kg $N \cdot ha^{-1}$. Nitrogen fertilization was applied in the form of ammonium nitrate at three dates: before sowing and in respective treatments at the phases of tillering (BBCH 21) and heading (BBCH 51) at 50 kg $N \cdot ha^{-1}$. The other cultivation operations were performed following cultivation principles for this species.

Analyses of the chemical composition of grain were performed using the generally accepted methods. Crude protein was determined according to Kjeldahl.

The energy value of grain was calculated using the method recommended by Deutsche Landwirtschafts-Gesellschaft [DLG- Futterwerttabellen für Schweine, 1984]. Digestible components were determined applying digestibility coefficients according to DLG and they were expressed in grams per 1 kg dry matter. Energy value was expressed in the form of metabolic energy applying the formula proposed by Hoffmann and Schiemann:

$$EM\ [MJ \cdot kg^{-1}\ s.m] = 0.021 \cdot DCP + 0.0374 \cdot DCF + 0.0144 \cdot DCF + 0.0171 \cdot DNFE$$

where: DCP – digestible crude protein [$g \cdot kg^{-1}$ DM]
DCF – digestible crude fat [$g \cdot kg^{-1}$ DM]
DCF – digestible crude fiber [$g \cdot kg^{-1}$ DM]
DNFE – digestible nitrogen-free extract [$g \cdot kg^{-1}$ DM].

Agronomic efficiency [AF] was calculated by Novoa and Loomis [1981]:

AF = yield of N-fertilized plots – yield of zero-N plots/N fertilizer rate

Results were analyzed statistically by the analysis of variance for orthogonal factorial experiments and the analysis of variance in the split-plot design. The means of treatment were compared by means of Tukey's Multiple Range test and least significant difference (LSD) was declared at $P<0.01$ and $P<0.05$.

RESULTS

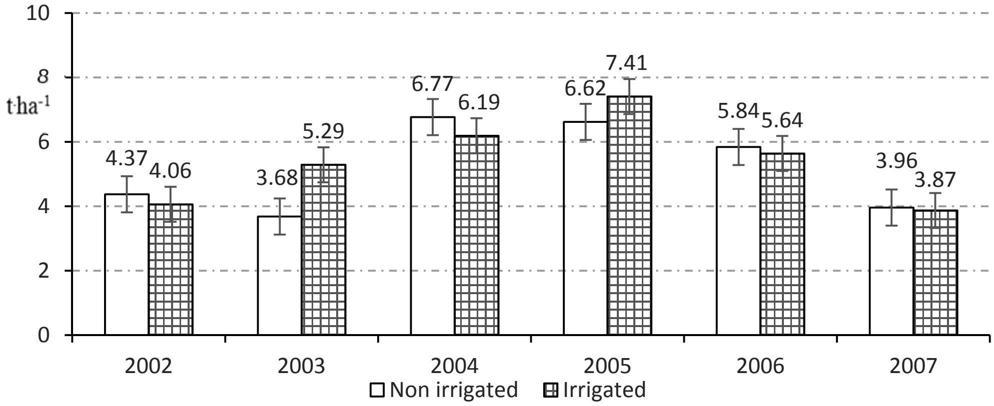
Analysis of weather conditions in the period of field experiments showed considerable variation in individual years of the study (Table 1). In all the analyzed years air temperature exceeded the multiannual mean. The highest temperature in the period from April to June was recorded in 2002 (16.6ºC), while the lowest – in 2004 (14.3ºC). Annual precipitation totals ranged from 335.9 to 613.4 mm. Very low precipitation totals in the vegetation period of rye were recorded

Table 1. Weather conditions at Meteorological Station at Złotniki in 2002–2007

Months	Years						1951–2000
	2002	2003	2004	2005	2006	2007	
Temperature (°C)							
I	1.5	-1.4	-3.2	2.4	-5.3	4.7	-1.5
II	5.1	-2.1	2.3	-0.9	-0.5	1.2	-0.5
III	3.8	4.9	5.7	2.5	1.7	6.9	3.3
IV	10.7	10.2	11.4	11.6	10.5	10.9	8.3
V	19.2	18.0	14.1	14.6	15.9	15.7	13.9
VI	19.8	21.1	17.5	18.5	20.1	20.1	17.2
VII	22.2	21.7	19.6	21.3	24.4	20.4	18.8
VIII	23.7	22.0	21.2	19.1	18.6	20.5	18.1
IX	15.9	16.5	15.9	17.3	18.3	14.6	13.5
X	7.3	6.6	11.1	12.1	11.8	9.0	8.9
XI	4.1	6.1	4.7	4.1	5.0	2.8	3.6
XII	-2.7	2.0	3.3	0.7	3.1	1.5	0.0
Average	10.9	8.8	9.5	10.3	10.3	10.7	8.6
Average IV–VI	16.6	16.4	14.3	14.9	15.6	15.6	13.1
Rainfall (mm)							
I	34.2	48.0	45.2	33.9	11.8	51.6	28.3
II	67.2	7.0	30.4	51.1	21.7	54.0	26.5
III	57.0	12.0	18.8	36.7	18.3	65.3	29.8
IV	37.0	24.0	19.6	20.5	40.4	7.4	31.4
V	69.0	20.0	52.0	20.5	37.9	82.2	48.5
VI	48.0	27.0	56.4	14.2	43.9	44.3	59.6
VII	26.0	85.0	43.4	88.2	14.5	39.6	76.4
VIII	70.0	8.9	71.7	49.7	124.8	65.7	53.2
IX	45.0	21.8	31.5	27.8	23.3	32.6	46.0
X	91.0	30.4	46.2	6.7	21.7	20.3	34.4
XI	46.0	18.5	43.8	13.3	11.5	46.6	35.4
XII	23.0	33.3	23.0	71.5	22.0	36.7	39.0
Sum	613.4	335.9	482.0	434.1	391.8	546.3	508.5
Sum IV–VI	154.0	71.0	128.0	55.2	122.2	133.9	139.5

in 2003 and 2005, when they amounted to as little as 40 and 50% multiannual mean precipitation total for that period.

Weather conditions in the years of the study to a considerable extent affected the volume of winter rye grain yield. A greater variation was found for the yield of grain in rye grown with no irrigation applied (CV = 26.4%). Sprinkling irrigation proved to be a factor stabilizing yielding in this species, although it was only to a slight degree (CV = 24.6%). Grain yield ranged from 3.68 to 6.77 t·ha^{-1} with non-irrigation and from 3.87 to 7.41 t·ha^{-1} when irrigation was used (Fig. 1). A small reduction of the coefficient of variation for yielding as a result of sprinkling irrigation of rye may be explained by slight differences between minimum yields obtained in the two irrigation variants and a considerable increase in maximum yields in the irrigated treatments. The greatest yield of rye grain in cultivation under natural conditions was recorded in 2004, while for the applied irrigation – in 2005. The exceptional increment in grain yield amounting to 1.61 t·ha^{-1}, i.e. 43.8%, modified by sprinkling irrigation was recorded in 2003, characterized by the lowest precipitation total among the analyzed years.



Non-irrigation – CV = 26.4%; Sprinkling irrigation – CV = 24.6%

Fig. 1. Influence of water variant on grain yield of winter rye in 2002–2007

Results of the analysis of variance indicate that yielding in rye depended to a significant extent on the interactions of factors investigated in the experiments. Sprinkling irrigation increased the yield of rye grain on average by 0.2 t·ha^{-1}, but this difference was not confirmed statistically (Table 2). Nitrogen fertilization, on average for sprinkling irrigation, caused an increase in yields with an increase in nitrogen application rates, while no significant difference was observed between yields obtained at 100 and 150 kg N·ha^{-1}. In rye grown with non-irrigation the greatest grain yield (5.97 t·ha^{-1}) was observed at the application of 100 kg N·ha^{-1}, while in irrigated rye (6.75 t·ha^{-1}) it was at the fertilization with 150 kg N·ha^{-1}, and it was significantly greater than the yield harvested from the treatments fertilized at 100 kg N·ha^{-1}. Moreover, it may be stated that nitrogen fertilization enhanced the effect of sprinkling irrigation, since in the control treatments sprinkling irrigation did not increase the yield of grain and at 150 kg N·ha^{-1} this increment was as high as 0.92 t·ha^{-1} at a relatively high yield (5.83 t·ha^{-1}) of non-irrigated rye.

Analysis of the effect of the tested factors on the yield of protein also showed a significant interaction of sprinkling irrigation with nitrogen fertilization in the modification of the volume

Table 2. The influence of sprinkling irrigation and nitrogen fertilization on grain yield, protein yield and energy yield of winter rye (mean of 2002–2007)

Water variant (A)	Nitrogen ferilization (B) (kg·ha^{-1})				Average
	0	50	100	150	
Grain yield (t·ha^{-1})					
Non-irrigation	3.80	5.22	5.97	5.83	5.21
Sprinkling irrigation	3.20	5.24	6.45	6.75	5.41
Average	3.50	5.23	6.21	6.29	–
LSD$_{0.05}$	A – n.s.; B – 0.27; AxB – 0.39				
Protein yield (kg·ha^{-1})					
Non-irrigation	330	445	588	628	498
Sprinkling irrigation	263	427	605	713	502
Average	297	436	597	671	–
LSD$_{0.05}$	A – n.s.; B – 26; AxB – 36				
Energy yield (GJ·ha^{-1})					
Non-irrigation	46.8	64.2	70.6	71.8	63.4
Sprinkling irrigation	39.4	64.3	79.6	83.6	66.7
Average	43.1	64.3	75.1	77.7	–
LSD$_{0.05}$	A – n.s.; B – 4.4; AxB – 6.2				

n.s. – no significant differences

of this parameter. Sprinkling irrigation, on average for fertilization, increased the protein yield by as little as 4.0 kg·ha^{-1}, i.e. 0.8%, and this difference was not confirmed statistically. The presented interaction of sprinkling irrigation with fertilization resulted from the fact that both in non-irrigated and irrigated rye the yield of protein increased with an increase in fertilization to 150 kg N·ha^{-1}, while a significant increase in the value of this parameter under the influence of irrigation was shown only at the highest application rate of 150 kg N·ha^{-1}.

Yield expressed in energy units was modified by the interaction of sprinkling irrigation with nitrogen fertilization. Sprinkling irrigation caused an increase in the energy yield on average by 3.3 GJ·ha^{-1}, but similarly as in the case of yield of protein this difference was not confirmed statistically.

Nitrogen fertilization significantly increased the value of this parameter with an increase in application rates to 100 kg N·ha^{-1}. The energy yield of rye increased under the influence of sprinkling irrigation only in the treatments fertilized with nitrogen and the greatest increment (11.8 GJ·ha^{-1}) under the influence of this factor was recorded for the highest fertilization level.

Agricultural effectiveness of nitrogen increased under the influence of irrigation at all the investigated fertilization levels (Table 3). The greatest improvement of agronomic efficiency, by 12.4 kg grain·kg^{-1} N, was recorded under the influence of sprinkling irrigation for 50 kg N·ha^{-1}. Agronomic efficiency of nitrogen in non-irrigated rye decreased from 28.4 kg grain at the application of 50 kg N·ha^{-1} to 13.5 kg grain at 150 kg N·ha^{-1}, while in the cultivation of rye applying irrigation it was from 40.8 to 23.7 kg grain.

Table 3. The influence of water variant and nitrogen fertilization on agronomic efficiency of winter rye – $kg \cdot kg^{-1}$ (mean of 2002–2007)

Water variant	Nitrogen ferilization ($kg \cdot ha^{-1}$)				
	0–50	0–100	0–150	50–100	100–150
Non-irrigation	28.4	21.7	13.5	15.0	–
Sprinkling irrigation	40.8	32.5	23.7	24.2	6.0

Productivity of 1 kg nitrogen within the range of 50–100 kg $N \cdot ha^{-1}$ for the above mentioned irrigation variants amounted to 15.0 and 24.2 kg $grain \cdot ha^{-1}$, while in the range of 100–150 kg $N \cdot ha^{-1}$ increased fertilization did not cause an increased yield in non-irrigated rye, whereas in irrigated rye the effectiveness amounted to 6.0 kg grain.

DISCUSSION

Variation in yielding of crops very often results from weather conditions in their vegetation periods, which was confirmed by the experiments conducted by the authors of this study as well as earlier studies on rye carried out by Wojciechowski and Parylak [2006], on winter wheat by Małecka [2003], Panasiewicz and Koziara [2007] as well as spring and winter triticale by Koziara [1996] and spring triticale by Kalbarczyk [2008]. According to Banaszkiewicz et al. [2005] in their study conducted in north-eastern Poland, the least advantageous precipitation conditions for rye were observed in May.

Appel [1994] and Czyż [2000] were of an opinion that yielding of crops is dependent on the amount of precipitation in individual vegetation periods, particularly in the case of weak soils, when the amount and dates of precipitation are the primary reference for yields of grain and indirectly for the requirement of nitrogen fertilization.

On average for the six-year period of the study sprinkling irrigation caused an increase in the grain yield of rye by 3.8%. Numerous experiments on the effect of irrigation on the yield of cereal grain indicate that this factor contributes to an increment in the discussed parameter on average by 10 to 35% [Barber and Jessop 1987, Dzieżyc and Trybała 1989, Erekul et al. 2012, Koziara 1996, Panek 1989].

In the opinion of Dzieżyc [1985] irrigation of cereals is the least attractive and rather economically unsound. However, in view of the high share of light soils with poor water holding capacity over a considerable area of Poland, as well as the high probability of extended periods with precipitation shortages, particularly in periods critical for water requirements of cereals, sprinkling irrigation may prove to be a factor determining the volume and quality of yields.

One of the measures of fertilization efficiency is provided by agricultural effectiveness [Panasiewicz and Koziara 2004]. The assessed effect of investigated factors on this measure indicates a decrease in the efficiency of fertilization with an increase in the application rate, which is a phenomenon known from available literature [Wróbel and Budzyński 1994].

In this study agricultural effectiveness increased under the influence of irrigation in the case of all applied nitrogen doses. The greatest increase in efficiency under the influence of irrigation, i.e. 12.4 kg $grain \cdot kg^{-1}$ N, was recorded for 50 kg $N \cdot ha^{-1}$. In non-irrigated rye agronomic efficiency decreased from 28.4 $kg \cdot grain$ at 50 kg $N \cdot ha^{-1}$ to 13.5 $kg \cdot grain$ for 150 kg $N \cdot ha^{-1}$.

A study by Dubis et al. [2008] showed that for cv. Amilo the most efficient utilization of nitrogen was observed at the application rate of 30 kg N·ha^{-1}, while each 1 kg of applied nitrogen provided an increase in yield of 34.6 kg grain. Those authors considered values of 10.6 and 8.3 kg grain as very good agronomic agronomic efficiency for the ranges of application rates of 30–60 and 60–90 kg N·ha^{-1}. In relation to these values a greater fertilization effectiveness in both irrigation variants was obtained in this study for slightly higher doses, i.e. 50–100 kg N·ha^{-1}.

CONCLUSIONS

On average for a 6-year period of the study sprinkling irrigation caused an increase in the yield of grain in winter rye cv. Dańkowskie Złote by 0.20 t·ha^{-1}. In two years a positive effect of this operation was found, while in four years no significant changes were observed in the volume of yield of grain under the influence of irrigation. Sprinkling irrigation increased the yield of winter rye grain for almost all applied fertilization levels, except for the treatment with no nitrogen applied, while the effect of irrigation increased with an increase in fertilization with this nutrient. Protein yield and energy yield calculated for rye grain depended also on the interaction of sprinkling irrigation with nitrogen fertilization. Fertilization at 150 kg N·ha^{-1} proved to be most advantageous for the effectiveness of sprinkling irrigation and the protein yield. In turn, for the volume of energy yield the application rate of 100 kg N·ha^{-1} turned out to be sufficient.

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PLONOWANIE I WARTOŚĆ PASZOWA ŻYTA OZIMEGO W ZALEŻNOŚCI OD DESZCZOWANIA I NAWOŻENIA AZOTEM

Synopsis. W sześcioletnim okresie prowadzenia ścisłych doświadczeń polowych na glebach Zakładu Doświadczalno-Dydaktycznego Gorzyń, filia Złotniki koło Poznania (52°29′ N, 16°49′ E) oceniano wpływ deszczowania i nawożenia azotem na plon ziarna, białka oraz plon energii żyta ozimego. Czynnikiem pierwszego rzędu był wariant wodny (niedeszczowany, deszczowany), a drugiego rzędu – nawożenie azotem (0, 50, 100, 150 kg N·ha^{-1}). Stwierdzono, że deszczowanie średnio dla lat badań, powodowało wzrost plonu ziarna żyta odmiany Dańkowskie Złote o 0,20 t·ha^{-1}. W dwóch latach stwierdzono dodatni efekt tego zabiegu, a w czterech latach nie zaobserwowano istotnych zmian wielkości plonu ziarna pod wpływem nawadniania. Deszczowanie powodowało wzrost plonu ziarna żyta ozimego na każdym z obiektów nawożonych azotem. Ponadto efekt nawadniania zwiększał się wraz ze wzrostem nawożenia tym składnikiem. Plony białka i energii wyliczone dla ziarna żyta zależały od współdziałania deszczowania z nawożeniem azotem.

Słowa kluczowe: żyto ozime, deszczowanie, nawożenie azotem, plon ziarna, plon białka, plon energii

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