Stanisław ROLBIECKI[1], Roman ROLBIECKI[1], Cezary PODSIADŁO[2]
[1]Department of Land Reclamation and Agrometeorology, University of Technology and Life Sciences, Bydgoszcz, Poland
Katedra Melioracji i Agrometeorologii, Uniwersytet Technologiczno-Przyrodniczy w Bydgoszczy
[2]Department of Plant Production and Irrigation, Agricultural University, Szczecin, Poland
Katedra Gospodarki Wodnej, Zachodniopomorski Uniwersytet Technologiczny w Szczecinie

Comparison of 'Jagna' true millet response to sprinkler irrigation and nitrogen fertilization under rainfall-thermal conditions of Bydgoszcz and Stargard Szczeciński
Porównanie reakcji prosa odmiany 'Jagna' na deszczowanie i nawożenie azotem w warunkach opadowo-termicznych Bydgoszczy i Stargardu Szczecińskiego

Key words: true millet cv. 'Jagna', sprinkler irrigation, nitrogen fertilization, production results, soil complex
Słowa kluczowe: proso odmiany 'Jagna', deszczowanie, nawożenie azotem, efekty produkcyjne, kompleks glebowy

Introduction

Results obtained from field experiments conducted by authors have shown that, there exists the possibility of obtaining high yields of cereals on poor soils, providing intense agrotechnics (Potrzeby wodne... 1989, Żarski et al. 1999, 2001, Żarski 2006).

There are no studies in Polish literature pertaining to the cultivation of true millet under irrigation and differentiated nitrogen fertilization (Żarski 2006).

The study aimed at the assessment of the impact of sprinkler irrigation and nitrogen fertilization on the grain yields of true millet cv. 'Jagna' grown in vicinities of Bydgoszcz and Stargard Szczeciński on a soil of the V quality class and the IVb quality class, respectively.

Materials and methods

The studies were performed in 2005 and 2006 at two localities: Lipnik near Stargard Szczeciński and Kruszyn Krajeński near Bydgoszcz. Field experiment at Lipnik was conducted on a light soil of the IVb quality class, and of the good-rye-soil-complex. Field experiment at Kruszyn Krajeński was carried out on a very light soil of the V quality class, and of the weak-rye-soil-complex.

The experiments were designed by "split-plot" method in 3 replications. The following two factors were considered:

1. Irrigation: W_o – control (without irrigation), W_1 – sprinkler irrigation according to tensiometer indications (–0.03 MPa).
2. Nitrogen fertilization: $N_0 = 0$ kg N·ha^{-1}, $N_1 = 40$ kg N·ha^{-1}, $N_2 = 80$ kg N·ha^{-1}, $N_3 = 120$ kg N·ha^{-1}.

Fertilization with P and K was uniform on all plots. Cultivation measures were applied accordingly to common practice.

Water requirements of true millet were estimated as optimal rainfall amounts for this crop, according to Klatt (Ostromęcki 1973) and Press (1963) proposals. Rainfall deficiency during the vegetation period of true millet was estimated from formula:

$$N = P_O - P_A$$

where:

N – rainfall deficiency [mm],

P_O – optimal rainfall according to Klatt or Press [mm],

P_A – actual rainfall [mm].

Results and discussion

Mean air temperature value of the vegetation period (May – August) at Kruszyn Krajeński in 2005–2006 was the same like the long-period average (16.4°C). Mean monthly values of air temperature varied from 12.3°C in April to 20.9°C in July (Table 1). Temperature of July was higher by 2.4°C than the long-period average (18.5°C). Especially warm was July in 2006 (22.4°C). Mean air temperature value of the vegetation period at Lipnik in 2005–2006 was higher by 1.5°C than the long-period average (15.7°C). Monthly value of air temperature, on the average, was higher from

TABLE 1. Air temperature during the vegetation period of true millet [°C]
TABELA 1. Temperatura powietrza w okresie wegetacji prosa [°C]

Year Rok	Months / Miesiące				
	V	VI	VII	VIII	V–VIII
Kruszyn Krajeński					
2005	12.2	14.9	19.4	16.3	15.7
2006	12.5	16.8	22.4	16.6	17.1
Mean / Średnio 2005–2006	12.3	15.8	20.9	16.4	16.4
1987–2004	13.1	16.0	18.5	17.9	16.4
Lipnik					
2005	13.1	15.8	19.4	16.6	16.2
2006	13.7	18.2	23.5	17.7	18.3
Mean / Średnio 2005–2006	13.4	17.0	21.4	17.1	17.2
1961–1994	12.5	15.9	17.4	17.0	15.7

the long-period average in case of all the months of the vegetation. Temperature of July was higher by 4.0°C from the long-period average (17.4°C). Especially warm was July in 2006 (23.5°C).

Total rainfall during the vegetation period at Kruszyn Krajeński, on the average in 2005–2006, amounted 195 mm (Table 2). It was lower by 11 mm from the long-term average value. Among the months, June and July were characterized by the lower rainfall amounts as compared to long-term average values. Total rainfall of the true millet vegetation at Lipnik, on the average in 2005–2006, amounted 198 mm (33 mm lower than the long-term average value). From among the months, June and July were characterized by the lower rainfall amounts in comparison to long-term average values. Especially low monthly rainfall (7 mm only) was in July of 2006.

Water requirements of true millet during the vegetation period (May 1 – – August 31), estimated as so called optimal rainfall – according to Klatt and Press – were higher on the very light soil (V quality class) at Kruszyn Krajeński (278 and 294 mm, respectively) than those calculated in case of the light soil (IVb quality class) at Lipnik (260 and 256 mm, respectively) – Table 3 and Table 4.

The deficiency of rainfall during the vegetation period of true millet (May 1 – August 31) – estimated as a difference between the optimal rainfall according to Klatt and Press for a particular month and the rainfall total in this month – was noted in case of July (Table 5 and Table 6). At Kruszyn Krajeński this month was characterized by the deficiency in the range from 49 to 76 mm, and from 52 to 80 mm, respectively, whereas in case of Lipnik the rainfall deficiency ranged from 1 to 91 mm.

The seasonal irrigation rates were higher in Lipnik than those in Kruszyn Krajeński (Table 7). The differences were connected with weather conditions of the both experimental sites. The values of air temperature at Lipnik were higher than

TABLE 2. Rainfall during the vegetation period of true millet [mm]
TABELA 2. Opady w okresie wegetacji prosa [mm]

Year Rok	Months / Miesiące				
	V	VI	VII	VIII	V–VIII
Kruszyn Krajeński					
2005	69	31	40	21	161
2006	63	22	30	114	229
Mean / Średnio 2005–2006	66	26	35	67	195
1987–2004	40	52	63	51	206
Lipnik					
2005	67	26	76	53	222
2006	43	23	7	104	177
Mean / Średnio 2005–2006	55	24	41	78	198
1961–1994	51	61	63	56	231

TABLE 3. Water needs of true millet during the vegetation period according to Klatt [mm]
TABELA 3. Potrzeby wodne w okresie wegetacji prosa, według Klatta [mm]

Year Rok	Months / Miesiące				
	V	VI	VII	VIII	V–VIII
Kruszyn Krajeński					
2005	47	56	89	70	262
2006	48	68	106	72	294
Mean / Średnio 2005–2006	47	62	97	71	278
Long-period average Średnia z wielolecia	52	63	83	80	282
Lipnik					
2005	45	54	77	63	239
2006	48	71	97	68	284
Mean / Średnio 2005–2006	46	62	87	65	260
Long-period average Średnia z wielolecia	42	54	72	65	233

TABLE 4. Water needs of true millet during the vegetation period according to Press [mm]
TABELA 4. Potrzeby wodne w okresie wegetacji prosa, według Pressa [mm]

Year Rok	Months / Miesiące				
	V	VI	VII	VIII	V–VIII
Kruszyn Krajeński					
2005	52	63	92	74	281
2006	53	68	110	76	307
Mean / Średnio 2005–2006	52	65	101	75	294
Long-period average Średnia z wielolecia	54	66	86	83	289
Lipnik					
2005	45	54	77	63	239
2006	47	61	98	69	275
Mean / Średnio 2005–2006	46	57	87	66	256
Long-period average Średnia z wielolecia	42	55	67	65	229

those noted at Kruszyn in case of all the months of the vegetation period (Table 1). From among particular months, July was characterized by especially high temperature in 2006 at Lipnik (23.5°C, i.e. 6.1°C higher than the long-period average for this site). On the other hand, the rainfall total for this month amounted only 7 mm (Table 2), i.e. the amount which can cover the water needs of

TABLE 5. Rainfall deficiency in the vegetation period of true millet according to Klatt [mm]
TABELA 5. Deficyt opadów w okresie wegetacji prosa, według Klatta [mm]

Year Rok	Months / Miesiące				
	V	VI	VII	VIII	V–VIII
Kruszyn Krajeński					
2005	–22	25	49	49	101
2006	–15	46	76	–42	65
Mean / Średnio 2005–2006	–19	36	62	4	83
Long-period average Średnia z wielolecia	12	11	20	29	76
Lipnik					
2005	–22	28	1	10	17
2006	5	48	90	–36	107
Mean / Średnio 2005–2006	–9	38	46	–13	62
Long-period average Średnia z wielolecia	–9	–7	9	9	1

TABLE 6. Rainfall deficiency in the vegetation period of true millet according to Press [mm]
TABELA 6. Deficyt opadów w okresie wegetacji prosa, według Pressa [mm]

Year Rok	Months / Miesiące				
	V	VI	VII	VIII	V–VIII
Kruszyn Krajeński					
2005	–17	32	52	53	120
2006	–10	46	80	–38	78
Mean / Średnio 2005–2006	–14	39	66	8	99
Long-period average Średnia z wielolecia	14	14	23	32	83
Lipnik					
2005	–22	28	1	10	17
2006	4	38	91	–35	98
Mean / Średnio 2005–2006	–9	33	46	–12	58
Long-period average Średnia z wielolecia	–9	–6	4	9	–2

2 days only. Higher water rates applied at Lipnik can also be explained by specific weather conditions. The experimental crop on the area in Lipnik was also influenced by stronger winds than the plants at Kruszyn Krajeński. The winds increased the evapotranspiration amounts from the cereal crop which resulted in indications of tensiometers. Additionally, in case of Lipnik the irrigation treatment was car-

TABLE 7. Seasonal irrigation water rates [mm]
TABELA 7. Sezonowe dawki nawodnieniowe [mm]

Specification Wyszczególnienie	Year / Rok	
	2005	2006
Kruszyn Krajeński	155	95
Lipnik	340	355
Mean / Średnio	247	225

ried out during a week from Monday to Friday only, but not on Saturdays or Sundays. Because of this, higher water doses were applied sometimes in Fridays (i.e. before indicating by tensiometers of the soil water potential value –0.03 MPa). Therefore, on this experiment the higher seasonal water rates were applied.

Grain yields of non-irrigated true millet cultivated on the soil of the V quality class (Kruszyn Krajeński) dependent on rainfall amount during the vegetation (Table 8). Lower yields (1.46 $t \cdot ha^{-1}$) were obtained in the first year of the study (2005) that was characterized by lower rainfall (161 mm in May 1 –

TABLE 8. Yields of true millet 'Jagna' at Kruszyn Krajeński, as dependent on sprinkler irrigation and nitrogen dose [$t \cdot ha^{-1}$]
TABELA 8. Plony prosa odmiany 'Jagna' w Kruszynie Krajeńskim zależnie od deszczowania i dawki azotu [$t \cdot ha^{-1}$]

Irrigation Nawadnianie	*N* dose Dawka *N*	Years of study / Rok badań		Mean Średnio
		2005	2006	
W_o	N_0	1.47	1.82	1.64
	N_1	1.62	2.11	1.87
	N_2	1.72	2.91	2.31
	N_3	1.02	2.96	1.99
W_1	N_0	2.99	3.02	3.01
	N_1	3.53	3.78	3.66
	N_2	4.37	4.08	4.22
	N_3	4.75	4.31	4.53
Influence of sprinkler irrigation / Wpływ nawadniania				
W_o	–	1.46	2.45	1.95
W_1	–	3.91	3.80	3.85
Influence of nitrogen fertilization / Wpływ nawożenia azotowego				
–	N_0	2.23	2.42	2.33
–	N_1	2.58	2.95	2.76
–	N_2	3.04	3.49	3.27
–	N_3	2.89	3.64	3.26

Explanations / Objaśnienia:
W_o, W_1 – without irrigation (control) and sprinkler irrigation, respectively / bez nawadniania (kontrola), deszczowanie,
N_0, N_1, N_2, N_3 – nitrogen doses: 0, 40, 80, 120 kg $N \cdot ha^{-1}$, respectively / dawki nawożenia, odpowiednio: 0, 40, 80 i 120 kg $N \cdot ha^{-1}$.

August 31). Higher yields (2.45 t·ha^{-1}) were noted in the second year (2006) with higher rainfall (229 mm). Similar tendency was observed in field experiment on 'Gierczyckie' cultivar (Rolbiecki et al. 2007).

Yield increases due to irrigation dependent on the soil complex. Under conditions of the very light soil – V quality class (Kruszyn Krajeński), the use of sprinkler irrigation significantly increased grain yields of true millet cv. 'Jagna' by 1.9 t·ha^{-1} (97%), whereas under conditions of the light soil – IVb quality class (Lipnik), sprinkler irrigation caused the increase in the grain yield by 0.6 t·ha^{-1} (17%) – Table 9. These results are confirmed by investigations on irrigation with other cereal crops conducted under different soil conditions which were reported by Żarski (2006).

Interaction of sprinkler irrigation and nitrogen fertilization was observed. Increased nitrogen fertilization doses (from 0 to 120 kg N·ha^{-1}) – under conditions of sprinkler irrigation – caused a significant grain yield increase of true millet to the amount 4.53 t·ha^{-1} and 4.07 t·ha^{-1}, on the soil of the V quality class and IVb quality class, respectively. In case of true millet cv. 'Gierczyckie'– which was investigated in the another field experiment in Kruszyn Krajeński (Rolbiecki 2007) – the yield obtained on irrigated plots fertilized with the highest nitrogen dose (120 kg N·ha^{-1}) was slightly lower than that of 'Jagna' (4.42 t·ha^{-1}).

TABLE 9. Yields of true millet 'Jagna' at Lipnik, as dependent on sprinkler irrigation and nitrogen dose [t·ha^{-1}]
TABELA 9. Plony prosa odmiany 'Jagna' w Lipniku zależnie od deszczowania i dawki azotu [t·ha^{-1}]

Irrigation Nawadnianie	*N* dose Dawka *N*	Years of study / Rok badań		Mean Średnio
		2005	2006	
W_o	N_0	1.28	1.55	1.41
	N_1	3.30	3.70	3.50
	N_2	3.55	3.50	3.52
	N_3	3.45	3.05	3.25
W_1	N_0	2.12	2.10	2.11
	N_1	3.77	3.55	3.66
	N_2	4.01	4.05	4.03
	N_3	4.07	4.35	4.21
Influence of sprinkler irrigation / Wpływ nawadniania				
Wo	–	2.89	2.95	2.92
W1	–	3.49	3.51	3.50
Influence of nitrogen fertilization / Wpływ nawożenia azotowego				
–	N_0	1.70	1.81	1.76
–	N_1	3.53	3.63	3.58
–	N_2	3.78	3.78	3.78
–	N_3	3.76	3.70	3.73

Conclusions

1. Water needs of true millet during the vegetation period (May–August), were higher on the very light soil (V quality class) at Kruszyn Krajeński than those – on the light soil (IVb quality class) at Lipnik.
2. Highest rainfall deficiency during the vegetation period of true millet for a particular month and the rainfall total in this month – was noted in July.
3. Production results of irrigation dependent on the soil complex. Sprinkler irrigation significantly increased grain yields of true millet cv. 'Jagna' on the very light soil (Kruszyn Krajeński). Under conditions of the light soil (Lipnik) sprinkler irrigation increased the grain yield much lower.
4. Under conditions of sprinkler irrigation, increased nitrogen fertilization doses (from 0 to 120 kg $N \cdot ha^{-1}$) caused a significant grain yield increase of true millet.

REFERENCES

OSTROMĘCKI J. 1973: Podstawy melioracji nawadniających. PWN, Warszawa.

Potrzeby wodne roślin uprawnych, 1989. Red. J. Dzieżyc. PWN, Warszawa.

PRESS H. 1963: Praktika selskochozjajstvennych melioracij. Selchozizdat, Moskva.

ROLBIECKI S., ROLBIECKI R., RZEKANOWSKI C., GRZELAK B. 2007: Wstępne wyniki badań nad wpływem deszczowania i zróżnicowanego nawożenia azotem na plonowanie prosa odmiany 'Gierczyckie' na glebie bardzo lekkiej. *Infrastruktura i Ekologia Terenów Wiejskich* 1: 179–186.

ŻARSKI J. 2006: Potrzeby i efekty nawadniania zbóż. W: Nawadnianie roślin. Red. S. Karczmarczyk, L. Nowak, PWRiL, Warszawa: 383–403.

ŻARSKI J., RZEKANOWSKI C., DUDEK S., ROLBIECKI S. 1999: Cost-effectiveness of overhead irrigation of field crops cultivated in the vicinity of Bydgoszcz. *Zeszyty Naukowe ATR w Bydgoszczy* 220, *Rolnictwo* 44: 315–320.

ŻARSKI J., ROLBIECKI S., RZEKANOWSKI C., ROLBIECKI R., DUDEK S., GRZELAK B. 2001: Cost-effectiveness of sprinkler irrigation of field crops and vegetables in central Poland. *Przegląd Naukowy Wydziału Inżynierii i Kształtowania Środowiska* 22: 375–382.

Streszczenie

Porównanie reakcji prosa odmiany 'Jagna' na deszczowanie i nawożenie azotem w warunkach opadowo-termicznych Bydgoszczy i Stargardu Szczecińskiego. Doświadczenia polowe przeprowadzono w latach 2005 i 2006 w dwóch miejscowościach: Lipniku, koło Stargardu Szczecińskiego (gleba klasy bonitacyjnej IVb, kompleks przydatności rolniczej żytni dobry), i Kruszynie Krajeńskim, koło Bydgoszczy (gleba klasy bonitacyjnej V, kompleks przydatności rolniczej żytni słaby. Doświadczenia założono w układzie zależnym „split-plot" w 3 powtórzeniach. Badano dwa czynniki: nawadnianie (kontrola, deszczowanie) i nawożenie azotem (0, 40, 80 i 120 kg $N \cdot ha^{-1}$). Plony prosa uprawianego na glebie klasy V bez nawadniania zależały od ilości opadów w okresie wegetacji. Mniejsze plony (1.46 $t \cdot ha^{-1}$) zanotowano w roku o niższych opadach (161 mm od 1 maja do 31 sierpnia). Większe plony (2,45 $t \cdot ha^{-1}$) otrzymano w roku z wyższymi opadami (229 mm). Potrzeby wodne prosa w okresie wegetacji (maj – sierpień), oszacowane jako tzw. opady optymalne według Klatta i Pressa, były większe na glebie bardzo lekkiej (V klasa) w Kruszynie Krajeńskim (wynosząc odpowiednio 278 i 294 mm) niż policzone dla gleby lekkiej (klasa IVb) w Lipniku (odpowiedno 260 i 256 mm). Najwyższe niedobory opadów w okresie wegetacji prosa, policzone jako różnica pomiędzy opadami optymalnymi według Klatta i Pressa dla określonego miesiąca a sumą opadów rzeczywistych, zanotowano w lipcu. Efekty produkcyjne nawadniania zależały od kompleksu glebowego. Deszczowanie istotnie zwiększyło plony ziarna prosa odmiany 'Jagna' o 1,9 $t \cdot ha^{-1}$ (97%) na glebie bardzo lekkiej (Kruszyn Krajeński). W warunkach gleby lekkiej (Lipnik) deszczowanie zwiększyło plony ziarna o 0,6 $t \cdot ha^{-1}$ (17%). Wzrastające dawki nawożenia azotowego (od 0 do 120 kg $N \cdot ha^{-1}$) spowodowały (w warunkach deszczowania) istotny przyrost plonu ziarna prosa do poziomu 4,53 $t \cdot ha^{-1}$ na glebie V klasy i 4,07 $t \cdot ha^{-1}$na glebie klasy IVb.

Authors' addresses:
Stanisław Rolbiecki
Department of Land Reclamation and Agrometeorology, University of Technology and Life Sciences
6 Bernardyńska St., 85-029 Bydgoszcz
Poland
e-mail: rolbs@utp.edu.pl

Roman Rolbiecki
Department of Land Reclamation and Agrometeorology, University of Technology and Life Sciences
6 Bernardyńska St., 85-029 Bydgoszcz
Poland
e-mail: rolbr@utp.edu.pl

Cezary Podsiadło
Department of Plant Production and Irrigation, Agricultural University
17 Słowackiego St., 71-430 Szczecin
Poland
e-mail: cpodsiadlo@agro.ar.szczecin.pl