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INVITED ORIGINAL RESEARCH PAPER

The impact of drought stress on the yields and food value of selected forage grasses

Mariola Staniak*

Department of Forage Crop Production, Institute of Soil Science and Plant Cultivation – State Research Institute, Czartoryskich 8, 24-100 Puławy, Poland

* Email: staniakm@iung.pulawy.pl

Abstract

The aim of the study was to compare yields and nutritional value of selected species and cultivars of forage grasses under the optimal moisture conditions and long-term drought stress. The regenerative capacity of plants after dehydration was also assessed. The pot experiment was conducted in years 2009–2010 in IUNG-PIB's greenhouse in Puławy, Poland. Nine cultivars of four species: *Dactylis glomerata* ('Amera', 'Minora'), *Festuca pratensis* ('Skra', 'Fantazja'), *Festulolium braunii* ('Felopa', 'Agula', 'Sulino'), and *Lolium multiflorum* ('Gisel', 'Lotos') were investigated in well-watered conditions (70% field water capacity – FWC) and under a long-term drought stress (40% FWC).

The study showed that stress caused by soil moisture deficiency significantly reduced yields of *D. glomerata*, *F. pratensis*, *F. braunii*, and *L. multiflorum*. The total yield of dry matter under stress conditions was about 31% lower, compared to the performance achieved on the optimally moisturized treatment. The smallest reduction in dry matter yield under the conditions of water deficit was recorded for *D. glomerata*, which makes it the most resistant to stress, followed by *F. pratensis*. The resistance of *F. braunii* and *L. multiflorum* to stress was similar and significantly lower. There was a various response of different grasses to the water stress. On the basis of the value of the DSI (drought susceptibility index), the tested cultivars were ranked depending on the sensitivity to drought, starting with the most resistant cultivar: 'Minora', 'Skra', 'Fantazja', 'Amera', 'Sulino', 'Agula', 'Gisel', 'Lotos', and 'Felopa'. The digestibility of dry matter and nutrient value of the grasses depended on both the level of soil moisture and grass species. Under the water stress, the digestibility and protein value increased compared to the control objects. *Lolium multiflorum* and *F. braunii* had the best nutritional value, while *D. glomerata* – the weakest.

Keywords

water stress; protein value; energy value; DSI index; *Festulolium*

Introduction

In Poland there are more and more frequent periodic water shortages on large areas of country, which cause large losses in agricultural production [1–4]. In the last decade, severe droughts occurred in the years of: 2005, 2006, 2008, 2010, 2011, 2013, and 2015 [5]. Droughts can occur at different times of the year, with varying intensity, duration and scope, but most commonly begins in the spring and summer (65% of cases) [5]. In the system of agricultural drought monitoring, meteorological conditions causing drought are determined by climatic water balance (CWB). According to Doroszewski et al. [6], after 2000 in Poland, in spring and early summer, CWB values have been getting lower and lower, which means that droughts are becoming more and more severe. This coincides with a period when plants have the highest demand for water, which leads to a number of negative environmental and economic consequences.

Forage grasses have a high demand for water. Their daily need is from 0.5 to 3.0 liters per m^2, and the amount of water transpired per year from 1 m^2 of turf grass may reach 1000 L [7]. According to Łabędzki [8], summer drought accompanied by high temperature, can cause a decrease in grass yield by about 30%. The reduction of the yield caused by a given stress factor is a good indicator of plant resistance to this stress [9]. Regrowth after dehydration is another important property of grasses. The plants switch from the state of dormancy caused by drought to the state of growth after rehydration of their habitat. Regrowth after a drought often reveals differences among different species and cultivars in terms of the resistance to stress [7,10]. Stress affects also the chemical composition and nutritional value of forage grasses. According to some authors [11–13], it increases the total protein content and lowers the content of crude fiber, while according to others [14], total protein concentration decreases under the conditions of lower soil moisture. The contents of protein and fiber are the basic elements of the chemical composition of grasses, affecting the protein value and digestibility of feed.

The aim of the study was to compare yields and nutritional value of selected species and cultivars of forage grasses under the optimal moisture conditions, as well as under the conditions of long-term drought stress, and to assess the regenerative capacity of plants after dehydration.

Material and methods

Two-factor pot experiment was performed in years 2009–2010, in a greenhouse of the Institute of Soil Science and Plant Cultivation – State Research Institute in Puławy, Poland (Lubelskie Voivodeship). The completely randomized block design method, with four replication was performed. Nine cultivars of grasses, belong to four species, were tested: *Dactylis glomerata* L. 'Amera' and 'Minora', *Festuca pratensis* L. 'Skra' and 'Fantazja', *Festulolium braunii* (K. Richt.) A. Camus 'Felopa', 'Agula' and 'Sulino', *Lolium multiflorum* Lam. 'Gisel' and 'Lotos'. Grasses were evaluated at two levels of soil moisture: 70% field water capacity (FWC; optimum soil moisture) and 40% FWC (drought stress) [15]. In order to maintain the appropriate soil moisture, water losses were made up on a daily basis, to achieve a specified weight of the pot with soil. Soil moisture was differentiated in the spring, 8 weeks after sowing and lasted the whole vegetation season (long-term stress). In the second year of growing, the observations were continued only in the first, spring regrowth. Regenerative abilities of grasses were evaluated after a 10-day drying period, i.e., a complete suspension of all watering until the drying of approximately 50% of shoots of the most sensitive cultivar.

The seeds were sown in Mitcherlich pots in 7 of April 2009, on a lessive soil from arable layer (0–30 cm). Three seeds of each grass were sown at 30 points per pot. After the emergence of plants, only 15 of them were left. The collection of plants was carried out three times during the growing season. The contents of available nutrients (mg per 100 g soil) were: phosphorus 32.0, potassium 12.3, and magnesium 5.1. Soil pH KCl was 6.2. The pots were fertilized at doses (g pot^{-1}): 3.6 N in three rates, 1.0 P, 1.5 K, 0.5 Mg in the form of solutions: NH_4NO_3, KH_2PO_4, K_2SO_4, and $MgSO_4 \times 7\ H_2O$. The yield of plants and the drought susceptibility index (DSI) were determined, which allowed for dividing cultivars into groups with different tolerance to water shortages in the soil. The value of DSI index was estimated based on the formula [16]: $DSI = [1 - (D_n K_n - 1)][1 - (D_x K_x - 1)] - 1$, where: D_n – dry matter yield of the plants subjected to stress; K_n – dry matter yield of the plants grown under optimal moisture; D_x – the mean dry matter yield of all treatments under drought conditions; K_x – the mean dry matter yield of all optimally moisturized treatments. A low value of DSI index indicates a relative resistance to stress conditions, while a high – a low resistance to stress.

Chemical analyses of plant material were based on mean treatment samples of grass dry matter from the first regrowth in the first and second year, due to its highest quantitative and qualitative changes and the importance in the annual yield, at the Main Laboratory of Chemical Analysis of IUNG – PIB in Puławy. The contents of dry matter (by weighing method at 105°C) and of total N (by the flow spectrophotometric method) were determined. They were used as a basis for calculating the contents of total protein (BO = N × 6.25), crude fiber (by conventional method), and the digestibility of dry matter (by enzymatic method). Protein and energy values of the feed obtained at the optimal moisture conditions and drought conditions were calculated according to the French system INRA [17], using WINWAR 1.3 program cooperating with the INRA program. The results were statistically analyzed with the use of the analysis of variance using Statistica v. 10.0 program. Tukey's multiple comparison test was used to compare differences between the means for main effects (factors), while confidence intervals for the means of Fisher's least significant difference (LSD) test ($\alpha = 0.05$) were used to compare the means from the subclasses (interactions).

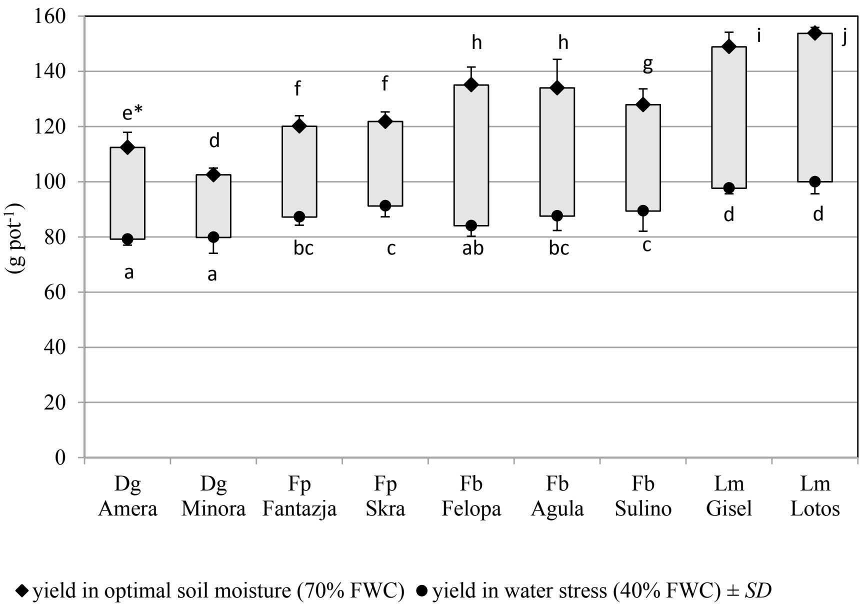

Fig. 1 Decrease of dry matter yield (sum of three cuts) of selected forage grasses under conditions of drought stress in the first year. * Different letters on bars represent significant differences among treatments (LSD test, $p < 0.05$).

Tab. 1 Relative dry matter yield of grass species and cultivars in relations to control object in the first year (%).

Species	Cultivar	Regrowth I	II	III	Sum
Dactylis glomerata	'Amera'	75.6	68.0	63.8	70.4
	'Minora'	70.6	88.4	80.0	77.9
Festuca pratensis	'Fantazja'	79.0	71.1	67.0	72.6
	'Skra'	82.0	72.7	69.7	74.9
Festulolium braunii	'Felopa'	77.7	57.5	49.8	62.2
	'Agula'	76.4	57.4	63.3	65.5
	'Sulino'	85.3	58.7	67.1	69.9
Lolium multiflorum	'Gisel'	77.3	52.5	67.6	65.6
	'Lotos'	73.0	55.8	66.0	65.0
Average		77.3	64.7	66.0	69.3

Results

Soil moisture was an important factor affecting the dry matter yield of the species and cultivars of forage grasses. Under optimum soil moisture, the best yields were obtained for *L. multiflorum* 'Gisel' and 'Lotos' (Fig. 1). A significantly lower total yield of dry matter was obtained for hybrid *F. braunii*, but a greater efficiency was found for 'Felopa' and 'Agula' cultivars as compared to cultivar 'Sulino'. *Festuca pratensis* 'Fantazja' and 'Skra' yielded at a similar, average level. *Dactilis glomerata* 'Minor' was found to have the lowest efficiency. Grass cultivars reacted with a significant yield decrease to the limited soil moisture (average by 31.1%). The smallest decrease of the total yield was recorded for *D. glomerata* 'Minor', while the biggest – for *F. braunii* 'Felopa' and 'Agula' (accordingly by 37.8 and 34.5%) and for *L. multiflorum* 'Lotos' and 'Gisel' (accordingly by 35.0 and 34.4%). Analyzing individual regrowths, it was found that the stress caused by the shortage of water in the soil limited the yield of grasses in the first regrowth the least (average by 22.7%), while significantly more in the second and third regrowth (accordingly by 35.3 and 34.4%) compared to the optimally moisturized treatments (Tab. 1).

The reaction of grasses to the stress caused by water deficits in the soil was dependent on the species and cultivar. The group resistant to drought (DSI < 1) included *D. glomerata* and *F. pratensis*, while the sensitive group

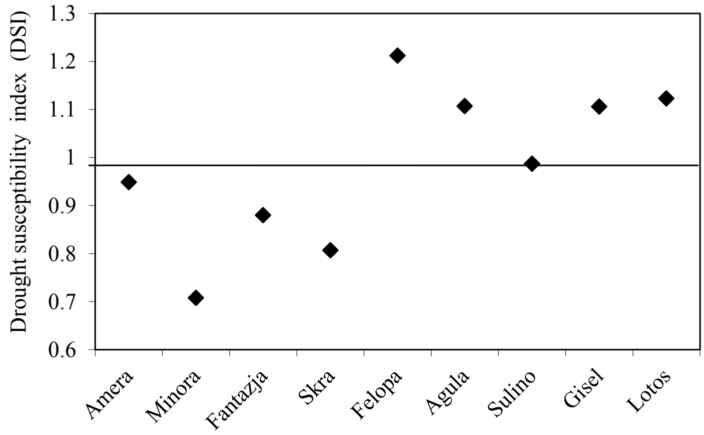

Fig. 2 Drought susceptibility index (DSI) for grass cultivars under conditions of water deficit.

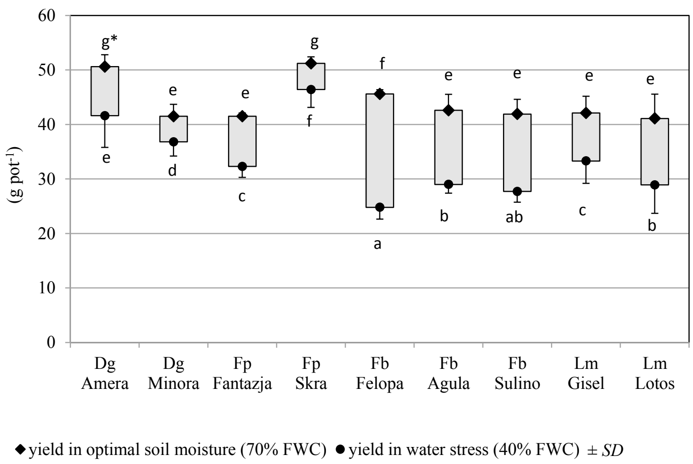

Fig. 3 Decrease of dry matter yield of selected forage grasses after drying-up period in the first regrowth in the second year. * Different letters on bars represent significant differences among treatments (LSD test, $p < 0.05$).

– *L. multiflorum* and *F. braunii* (Fig. 2). Among the tested *D. glomerata* cultivars, 'Minora' was more stress-resistant than 'Amera'. Among the *F. pratensis* cultivars, 'Skra' was more resistant than 'Fantazja'. *Festulolium braunii* hybrid showed a diverse sensitivity to drought. The cultivar 'Sulino' was the least sensitive to stress, while 'Felopa' – the most. *Lolium multiflorum* cultivars had a similar resistance to drought. Taking into account the values of the DSI index, the tested cultivars can be ranked in accordance with their sensitivity to drought in the first year of utilization, starting from the most resistant cultivar: 'Minora', 'Skra', 'Fantazja', 'Amera', 'Sulino', 'Agula', 'Gisel', 'Lotos', and 'Felopa'.

Regenerative capacities of the tested species and cultivars of grasses were investigated in the second year of growing in the first regrowth after a 10-day period of drying. Dry matter yields were calculated in absolute values (Fig. 3) and in relative values, as a percentage of the dry matter yield of the tested plants as compared to the control (Tab. 2). The yielding ability of grasses after a period of complete abandonment of watering was the highest in the case of *F. pratensis* 'Skra', followed by *D. glomerata* 'Minora', while in the case of the other grasses, it was significantly lower. Hybrid *F. braunii* 'Felopa' showed the lowest regeneration capabilities. The highest values of the coefficient of variation were recorded for *L. multiflorum* cultivars 'Gisel' and 'Lotos', while the lowest for *F. braunii* 'Agula' and 'Sulino'. None of the tested cultivars was able to recreate the conditions to the level of the plants not subjected to stress.

Nutrients content in dry matter yield of first regrowth was dependent on the soil moisture and the species of the grass (Tab. 3). The level of total protein of all treatments increased under lower soil moisture. A higher increase was recorded with young plants in the first year (average by 50.9%), than with older plants in the second year (average by 33.1%). Regardless of the level of soil moisture, in the first year, the least total protein was accumulated by *L. multiflorum* due to its large number of generative shoots, while the most – by *F. pratensis*. Under stress conditions, the content of crude fiber in dry matter of grass significantly decreased, on average by 9.1% in the first, and by 17.0% in the second year of

Tab. 2 Yielding capacity of grasses species and cultivars after drying-up period.

Species	Cultivar	Mean	Standard deviation	Coefficient of variation (%)
Dactylis glomerata	'Amera'	82.0 bcd	8.65	10.55
	'Minora'	89.1 cd	11.42	12.82
Festuca pratensis	'Fantazja'	77.7 bcd	4.84	6.23
	'Skra'	90.8 d	7.79	8.59
Festulolium braunii	'Felopa'	54.3 a	4.82	8.88
	'Agula'	68.1 ab	2.28	3.34
	'Sulino'	66.2 ab	3.07	4.64
Lolium multiflorum	'Gisel'	79.7 bcd	13.25	16.62
	'Lotos'	70.8 abc	10.43	14.73

Tab. 3 Content of total protein, crude fiber and digestibility of dry matter of grass cultivars depending on the soil moisture in the first cut.

Species	Cultivar	Soil moisture (% ppw)	Total protein (g kg^{-1})		Crude fiber (g kg^{-1})		DM digestibility (%)	
			1 year	2 year	1 year	2 year	1 year	2 year
Dactylis glomerata	'Amera'	70	99	140	301	285	68.8	69.6
		40	134	176	282	251	74.5	73.2
	'Minora'	70	87	162	344	293	65.3	68.0
		40	148	192	300	258	70.6	75.4
Festuca pratensis	'Fantazja'	70	114	169	296	210	73.9	75.2
		40	162	188	263	214	79.2	79.5
	'Skra'	70	114	146	286	277	74.6	73.4
		40	166	188	259	217	79.3	79.2
Festulolium braunii	'Felopa'	70	100	145	232	249	79.5	78.1
		40	144	213	212	197	81.7	80.2
	'Agula'	70	101	146	230	224	80.5	78.5
		40	154	209	209	199	81.7	80.8
	'Sulino'	70	104	152	237	244	81.4	78.1
		40	149	208	209	190	81.5	80.4
Lolium multiflorum	'Gisel'	70	78	142	220	263	81.1	74.6
		40	129	218	208	215	82.2	77.6
	'Lotos'	70	80	152	220	238	81.1	75.9
		40	134	211	210	221	82.4	78.3
Mean for the cultivar								
'Amera'			116 ab	158 a	291 b	268 bc	71.6 ab	71.4 a
'Minora'			118 abc	177 a	322 c	276 c	67.9 a	71.7 a
'Fantazja'			138 c	178 a	279 b	252 abc	76.5 bc	77.3 b
'Skra'			140 c	167 a	272 b	247 abc	77.0 bc	76.3 ab
'Felopa'			122 abc	179 a	222 a	223 abc	80.6 c	79.2 b
'Agula'			128 bc	177 a	219 a	211 a	81.1 c	79.6 b
'Sulino'			126 bc	180 a	223 a	217 ab	81.5 c	79.2 b
'Gisel'			103 a	180 a	214 a	239 abc	81.7 c	76.1 ab
'Lotos'			107 ab	182 a	215 a	229 abc	81.8 c	77.1 b
Mean for level of soil moisture								
70			97 a	150 a	263 b	262 b	76.2 a	74.6 a
40			147 b	200 b	239 a	218 a	79.2 b	78.3 b

growing, as compared to the control. A large variation in the content of this component was recorded also between species of the grass. Under the optimal soil moisture and under stress, the largest amount of crude fiber was found for *D. glomerata*, and the lowest for *L. multiflorum* and *F. braunii* hybrid, which were similar in this aspect. In the second year of growing, more crude fiber was recorded for *D. glomerata*, followed by *F. pratensis* and *L. multiflorum*, while the least for *F. braunii*. The level of soil moisture affected also the digestibility of grass dry matter. Under drought stress, the value of this indicator was significantly higher, in the first year on average by 3.9%, while in the second on average by 5.0% compared to the optimally moisturized objects. Moreover, this feature was also more closely related to species than to cultivars. Regardless of the level of soil moisture, in the first year of growing, the highest, similar digestibility was recorded for *L. multiflorum* and *F. braunii*, while significantly lower – for *D. glomerata*. *Festuca pratensis* had a medium value of this ratio. In the second year of growing, a significantly higher dry matter digestibility was found for *L. multiflorum*, *F. braunii*, and *F. pratensis* than for *D. glomerata*.

The nutritional value of roughage in the diet of ruminants is determined by, besides digestibility, its protein and energy value (Tab. 4, Tab. 5). The protein value expressed in PDIN, PDIE, and PDIF was higher under reduced soil moisture, whereas significant differences occurred mainly in the first year of growing. In contrast, the energy value of the studied grasses expressed in nutrient units of milk (UFL) and livestock production (UFV) had higher values under stress conditions, but statistically significant differences were not proven. The nutritional value of biomass was also more dependent on a species than on a cultivar. In the first year of growing, the highest protein value was recorded for *F. pratensis* and *F. braunii*, and energy value for *F. braunii* and *L. multiflorum*, while in the second year, *F. pratensis*, *L. multiflorum*, and *F. braunii* had a similar PDIN, PDIE, and PDIF values, while UFL and UFV values were the highest with *F. braunii*. The lowest nutritional value in both years of vegetation was recorded for *D. glomerata*.

Discussion

Fodder grasses reacted to stress conditions caused by a moisture deficiency in the soil with the reduction of their yields, due to inhibition of the processes of plant development and growth. The results of the research have confirmed that *D. glomerata*, *F. pratensis*, *F. braunii*, and *L. multiflorum* had significantly lower dry matter yields (average by 31%) in condition of water stress. The smallest reduction in dry matter yield under stress was recorded for *D. glomerata* and *F. pratensis*, while significantly higher for *F. braunii* and *L. multiflorum*. Using the yield reduction as the criterion for measuring the level of stress resistance, it was assessed that *D. glomerata* was the most resistant to long-term drought, followed by *F. pratensis*. The resistance of *F. braunii* and *L. multiflorum* was much smaller and similar. It showed that, in terms of sensitivity to water deficits in the soil, the hybrid *F. braunii* was more similar to *L. multiflorum* than *F. pratensis*. Olszewska et al. [18] showed that a long-term water stress (35% FWC) caused a significant reduction in the yield of the three species of grass. The smallest reduction of dry matter yield was recorded for *Lolium perenne* (46%), higher for *D. glomerata* (57%), and the highest for *F. pratensis* (68%). Madziar and Latanowicz [11] found, however, that regardless of soil moisture, *D. glomerata* yielded the best, *Phleum pratense* worse, while *F. pratensis* the least. In field conditions, irrigation of forage grasses significantly increases yields in dry years. According to Rumasz-Rudnicka [19], irrigation of *Lolium westerwoldicum* increased its green matter yield by 17%. According to Norris and Thomas [20], withholding the irrigation of *Lolium* sp. for 10 days before mowing, reduced its yield by 20%, while the abandonment of irrigation for 6 weeks – by 45%. The current results have conformed previous observations of low drought resistance of *F. braunii* hybrid [21]. It was observed that limited rainfall in May resulted in the reduction of annual yields of *F. braunii* 'Felopa' by 15% in relation to the achievement in the optimal previous year. The sensitivity of this hybrid to the lack of moisture in the soil has also been reported by Wilman [22], Łyszczarz et al. [23], Borowiecki [24], as well as Gutmane and Adamovich [25]. However, there was

Tab. 4 Dry matter digestibility and energy and protein value of grass cultivars depending on soil moisture in the first cut in the first year of vegetation.

Species	Cultivar	Soil moisture (% ppw)	PDIN	PDIE	PDIF	UFL	UFV
Dactylis glomerata	'Amera'	70	62.0	74.3	22.2	0.82	0.75
		40	84.0	86.2	30.1	0.91	0.85
	'Minora'	70	54.6	69.3	19.5	0.76	0.68
		40	93.0	85.1	33.3	0.84	0.77
Festuca pratensis	'Fantazja'	70	71.8	81.8	25.7	0.89	0.83
		40	102.0	94.5	36.5	0.98	0.93
	'Skra'	70	71.5	82.0	25.6	0.90	0.85
		40	104.4	95.6	37.4	0.97	0.92
Festulolium braunii	'Felopa'	70	62.8	83.5	22.5	0.99	0.95
		40	90.3	92.5	32.3	1.02	0.98
	'Agula'	70	63.6	84.9	22.8	1.01	0.97
		40	96.6	93.8	34.6	1.01	0.98
	'Sulino'	70	64.7	85.5	23.2	1.02	0.98
		40	93.4	92.5	33.4	1.00	0.97
Lolium multiflorum	'Gisel'	70	48.7	82.2	17.4	1.03	1.00
		40	81.3	90.7	29.9	1.03	1.00
	'Lotos'	70	50.2	82.6	18.0	1.03	1.00
		40	84.4	91.7	30.2	1.03	1.00
Mean for the cultivar							
'Amera'			73.0 b	80.2 b	26.1 b	0.86 b	0.80 b
'Minora'			73.8 bc	77.2 a	26.4 b	0.80 a	0.72 a
'Fantazja'			86.9 e	88.1 cd	31.1 d	0.94 c	0.88 c
'Skra'			87.9 e	88.8 d	31.5 d	0.94 c	0.88 c
'Felopa'			76.6 cd	88.0 cd	27.4 bc	1.00 d	0.96 d
'Agula'			80.1 d	89.4 d	28.7 c	1.01 d	0.98 de
'Sulino'			79.1 d	89.0 d	28.3 c	1.01 d	0.98 de
'Gisel'			65.0 a	86.4 c	23.7 a	1.03 d	1.00 e
'Lotos'			67.3 a	87.2 cd	24.1 a	1.03 d	1.00 e
Mean for level of soil moisture							
70			61.1 a	80.7 a	21.9 a	0.94 a	0.89 a
40			92.2 b	91.4 b	33.1 b	0.98 a	0.93 a

Explanations: PDIN – protein digested in the small intestine supplied by rumen-undegraded dietary protein plus protein digested in the small intestine supplied by microbial protein from rumen-degraded protein; PDIE – protein digested in the small intestine supplied by rumen-undegraded dietary protein plus protein digested in the small intestine supplied by microbial protein from rumen-fermented organic matter; PDIF – protein digested in the small intestine; UFL – feed unit for lactation; UFV – feed unit for maintenance and meat production.

Tab. 5 Dry matter digestibility and energy and protein value of grass cultivars depending on soil moisture in the first cut in the second year of vegetation.

Species	Cultivar	Soil moisture (% ppw)	PDIN	PDIE	PDIF	UFL	UFV
Dactylis glomerata	'Amera'	70	87.9	84.8	31.5	0.85	0.78
		40	110.3	94.0	39.5	0.90	0.83
	'Minora'	70	101.7	87.2	36.4	0.82	0.74
		40	120.9	97.5	43.3	0.93	0.87
Festuca pratensis	'Fantazja'	70	106.6	94.5	38.1	0.91	0.86
		40	117.8	100.1	42.2	0.99	0.95
	'Skra'	70	91.9	87.6	32.9	0.90	0.84
		40	118.1	100.0	42.3	0.99	0.94
Festulolium braunii	'Felopa'	70	91.1	90.9	32.6	0.97	0.93
		40	133.8	104.4	47.9	0.99	0.95
	'Agula'	70	91.4	90.3	32.7	0.98	0.93
		40	131.1	103.6	46.9	1.00	0.95
	'Sulino'	70	95.4	90.9	34.1	0.96	0.92
		40	130.3	103.0	46.6	0.99	0.95
Lolium multiflorum	'Gisel'	70	89.1	87.7	31.9	0.91	0.85
		40	136.6	104.1	48.9	0.94	0.89
	'Lotos'	70	95.4	90.0	34.1	0.93	0.88
		40	132.7	103.2	47.5	0.94	0.89
Mean for the cultivar							
'Amera'			99.1 a	89.4 a	35.5 a	0.88 a	0.80 a
'Minora'			111.3 b	92.3 b	39.8 b	0.88 a	0.80 a
'Fantazja'			112.2 b	97.3 d	40.1 b	0.95 c	0.90 b
'Skra'			105.0 ab	93.8 bc	37.6 ab	0.94 bc	0.89 b
'Felopa'			112.4 b	97.7 d	40.2 b	0.98 c	0.94 c
'Agula'			111.3 b	97.0 d	39.8 b	0.99 c	0.94 c
'Sulino'			112.8 b	97.0 d	40.4 b	0.98 c	0.94 c
'Gisel'			112.9 b	95.9 cd	40.4 b	0.92 b	0.87 b
'Lotos'			114.0 b	96.6 d	40.8 b	0.94 bc	0.88 b
Mean for level of soil moisture							
70			94.5 a	89.3 a	33.8 a	0.91 a	0.86 a
40			125.7 a	101.1 b	45.0 a	0.96 a	0.91 a

For explanations see Tab. 4.

no confirmation for the research results of Thomas and Humphreys [26], who claimed that this hybrid was as draught resistant as *F. pratensis* or Domański and Jokś [27] who showed that under soil moisture deficits, *F. braunii* hybrid yielded at a similar level to *Festuca arundinacea*. Growth inhibition under drought is a typical defense reaction among plants. Water deficit in the soil leads primarily to the reduction of water potential of plant shoots and to the stimulation of the growth of the root system. A direct reaction of plants is to change the method of distribution of assimilates, which in turn lowers the yields of biomass [28,29].

The selection of proper cultivars is, besides habitat and agrotechnical conditions, one of the yield determining factors [30]. The obtained results showed that the tested cultivars responded differently to the shortage of water in the soil. *Dactylis glomerata* 'Minora' was more resistant to stress than 'Amera', *F. pratensis* 'Skra' – than 'Fantazja', and *F. braunii* 'Sulino' – than 'Felopa' and 'Agula'. The reaction of *L. multiflorum* 'Gisel' and 'Lotos' was similar. The studies conducted by Szoszkiewicz et al. [31] also showed a different reaction of grass cultivars to water stress. Under optimal soil moisture, the highest yields were obtained from late cultivars of *D. glomerata* 'Satra' and *F. pratensis* 'Westa', while under water stress (40% FWC) – from semi-early cultivar of *D. glomerata* 'Amera' and early cultivar of *F. pratensis*. According to Olszewska [32], among the tested *F. pratensis* cultivars, 'Skra' had a better efficiency both under optimal soil moisture and water scarcity, compared to 'Skawa', but significant differences under stress conditions have not been proven. In other studies, the same author recorded a higher yield of *D. glomerata* 'Dala' compared to 'Areda', regardless of the level of soil moisture [33]. According to Kochanowska-Bukowska [34], among the cultivars of *D. glomerata*, 'Astera' yielded the highest, 'Amera' and 'Bepro' significantly lower, while 'Potomac' the lowest. Our results have confirmed prior literature reports concerning different reactions of individual cultivars to water stress. Dziadczyk [9] suggested that this difference results from genetic conditioning of the cultivars of a given species to a particular stress.

The cease of drought, usually after soil hydration, leads to the start of plant regeneration process. According to Kemp and Culvenor [35], it is more important to plants than maintaining growth during drought. In this study, after a 10-day period of a complete abandonment of watering, there was no complete regeneration of grasses, i.e., restoration of their prior-drought state. *Festuca pratensis* 'Skra' and *D. glomerata* 'Minora' regenerated the best (fielding abilities after stress – accordingly 91 and 89%), while *F. braunii* 'Felopa' – the worst (54%). According to Żurek [36], *L. perenne* is a species capable of relatively high recovery after the most stressful conditions. After a complete dryout, the cultivars of this species regenerated achieving approximately 59% of the total health of plants grown under control conditions. Withering of leaves during the prolonged lack of water is very important for plants, as it allows for the transfer of proteins, fats and other macromolecules to other organs, such as the buds of young leaves, flowers or seeds, from which the plant will be able to renew itself after the cease of drought [37,38]. According to Volaire and Leliévre [39], grass regeneration process depends largely on the density and the degree of the regrowth of the shoots subjected to long-term water shortages and on the growth of new shoots. Leaf buds are the key organs which determine the survival of grasses of water shortage periods. They can tolerate much lower values of osmotic potential than fully developed leaf blade, and they initiate subsequent regrowth of plants. In fact, the hydration of young tissues and elongating leaf blades and sheaths occurs the fastest, while in the case of mature leaves, it is much slower [37]. According to Carrow [40,41], withering of grass leaves, which is a symptom of the gradual degradation of chlorophyll, is considered a good indicator plant resistance to drought conditions. A diversified drying out and regeneration are also crucial for the evaluation of breeding lines because of the great diversity of genotypes.

The sensitivity of plants to environmental stress is determined by the value of drought sensitivity index (DSI). Determination of DSI index allows for the comparison of sensitivity to water stress of different grass genotypes for the selection of the most valuable ones, e.g., for further breeding works and introduction of new, improved cultivars into practice. This method of estimating the quantitative indicator of drought tolerance is simplified, because it does not take into account the interaction of the drought conditions with the development stages or important physiological aspects of plants, especially transpiration. It provides, however, the general information on the basis of which it is possible to rank the cultivars in terms of their yields under limited water supply. *Dactylis glomerata* 'Minora' was the most resistant to drought, while *F. braunii* 'Felopa' – the least. The evaluation of drought resistance of spring wheat cultivars has been performed by, among others, Grudkowska et al. [42] and also Bahar and Yildirim [43].

The factors included in our studies differentiated organic nutrients content and nutritional value of grass. Soil moisture had a greater impact on crude protein and crude fiber than the grass cultivar. Under drought stress, all the species had more total protein, but less crude fiber in comparison to the optimally moisturized treatments. These results are consistent with the results of other researchers who found an increase in protein content and a reduction in crude fiber content of *D. glomerata*, *F. pratensis*, and *P. pratense* under water deficit in the soil [11,31,32]. Also in the study of Trzaskoś et al. [44], there was an increase in total protein content in dry matter of grass sward under dry conditions. According to Zimont and Pawlak [45], water stress contributed to the reduction of dry matter yield and the increase of total protein content of *L. multiflorum*, while it did not initially affect the protein yield. Yet, after further drying of the soil, protein yields rapidly decreased, which indicated the deterioration of animal feed under drought.

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Wpływ stresu suszy na plonowanie i wartość pokarmową wybranych traw pastewnych

Streszczenie

Celem badań było porównanie plonowania oraz wartości pokarmowej wybranych gatunków i odmian traw pastewnych w optymalnych warunkach wilgotnościowych i podczas długotrwałego stresu suszy. Oceniano również zdolność regeneracji roślin po odwodnieniu. Doświadczenie wazonowe przeprowadzono w latach 2009–2010 w szklarni IUNG – PIB w Puławach (Polska). W badaniach uwzględniono dziewięć odmian należących do czterech gatunków traw: *Dactylis glomerata* ('Amera', 'Minora'), *Festuca pratensis* ('Skra', 'Fantazja'), *Festulolium braunii* ('Felopa', 'Agula', 'Sulino') i *Lolium multiflorum* ('Gisel', 'Lotos'). Zastosowano dwa poziomy wilgotności gleby: 70% ppw (wilgotność optymalna) i 40% ppw (długotrwały stres suszy).
Badania wykazały, że stres wywołany niedoborem wilgoci w glebie istotnie ogranicza plony *D. glomerata*, *F. pratensis*, *F. braunii* i *L. multiflorum*. Łączny plon suchej masy traw w warunkach stresu był średnio o 31% mniejszy w porównaniu do wydajności osiągniętej na obiektach optymalnie uwilgotnionych. Najmniejszą redukcją plonu suchej masy w warunkach niedoboru wody w glebie, a tym samym, największą odpornością na stres posiada *D. glomerata*. W niewielkim stopniu ustępowała jej *F. pratensis*. Odporność *L. multiflorum* i *F. braunii* na stres była podobna i istotnie mniejsza niż pozostałych gatunków. Wykazano zróżnicowanie odmianowe traw w reakcji na niedobór wody w glebie. Na podstawie wartości wskaźnika DSI (drought susceptibility index) uszeregowano badane odmiany pod kątem wrażliwości na suszę, poczynając od odmiany najbardziej odpornej: 'Minora', 'Skra', 'Fantazja', 'Amera', 'Sulino', 'Agula', 'Gisel', 'Lotos' i 'Felopa'. Strawność suchej masy i wartość pokarmowa roślin uzależniona była od poziomu wilgotności gleby oraz gatunku trawy. W warunkach stresu wodnego strawność oraz wartość białkowa przyjmowały wyższe wartości, w porównaniu do obiektów kontrolnych. Najlepszą wartością pokarmową cechowały się *L. multiflorum* i *F. braunii*, natomiast najsłabszą – *D. glomerata*.