PLANT BREEDING AND SEED SCIENCE
Volume 78 2018

DOI: 10.1515/plass-2018-0010

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EFFECT OF DROUGHT ON THE PERFORMANCE OF THREETURF GRASS SPECIES

ABSTRACT

Drought is the main environmental factor hampering world agriculture production. In the face of warming climate and reduced fresh water resources it become obvious that search for any factors decreasing water use is strongly recommended. Turf grasses able to withstand drought period longer could be recommended for turf areas as parks, lawns, home gardens etc. and relatively lower amounts of water should ensure satisfactory turf quality. Therefore, twelve turf varieties from three major cool-season turf grass species: perennial ryegrass (*Lolium perenne* L.), Kentucky bluegrass (*Poa pratensis* L.) and red fescue (*Festuca rubra* L.) were tested in glasshouse pot experiment and in the laboratory for determination of their relative ability to withstand green longer in the face of water deficit.

The different response of the examined forms to drought was noted. Conditions that favor fast water depletion were the most suitable for the expression of water deficit-related traits. Therefore, sandy mixture of 16% volumetric moisture content at field water capacity was mostly suitable for observation of the variation of tested forms. Turf condition of Kentucky bluegrass, as contrary to red fescue, was strongly connected with the soil moisture. Different manifestation of drought resistance was observed in tested species. Kentucky bluegrass, as rather no resistant to drought, exposed low level of drought avoidance. Red fescue was able to survive drought mainly due to leaf blades resistant to desiccation. In perennial ryegrass some other mechanisms evolved to survive drought. Early leaf wilting and senescence contributes to nutrient remobilization during drought and avoids large water loses during the transpiration. Therefore, perennial ryegrass turf was able to regenerate better after drought, as compared to the other tested grass species.

Search for new turf forms should focus on searching for ability to maintain acceptable conditions longer in a presence of increasing water deficit. It will then reduce the duration of period of poor turf conditions and further, turf water demands.

Key words: drought, grasses, turf, cell membrane stability, *Lolium perenne, Festuca rubra, Poa pratensis.*

Communicated by Dariusz Mańkowski

INTRODUCTION.

Drought, a period of abnormally dry weather, results in the soil-water deficit and subsequently – plant-water deficit. Arising from the moisture deficit in the soil and air, the drought interfere in the water balance of a given area (Bąk, Łabędzki, 2002). Water deficit in plant disrupts many cellular and whole plant functions, having a negative impact on the plant growth and reproduction. Crop yields are reduced by 69% on average when plants are exposed to unfavorable conditions in the field (Bray, 2001). In 2018 drought has affected a third of Poland's crop. Farmers across northern and central Europe are currently facing crop failure and bankruptcy as a consequence of the most intense regional droughts in recent memory (Nelsen, 2018).

In nature, certain species are adapted to the water deficits, exposing some resistance mechanisms and strategies. In case of grasses drought resistance is the ability to produce the desired product (herbage or green lawn) during slight, temporary or early drought; survive severe drought; and finally, having survived, respond rapidly to renewed water supply (Humphreys, 2001).

Cool-season turf grasses often suffer from extended periods of drought during the summer but water supplies used to irrigate turf are limited and are in competition for use by agriculture, recreation etc. It is in the best interest of turf managers to conserve water and to design both irrigation and turf which provide the quality of the grass with minimum water use (Hull, 1997). One of the frequently stated *turf disadvantages* is that it needs lots of water. But this is only a public perception, not scientifically accepted truth. High water use from turf areas is mostly related to human decision to irrigate the grass, not to the grass itself. Moreover, without a drop of water during drought periods, most of the currently used turf grass species survive (Żurek, 2006).

Although irrigation may be costly, a green and growing turf improves environmental conditions better than a brown turf. The main benefits of a healthy turf are water and wind erosion control. Actively growing turf may have a surface temperature that is 20 degrees cooler than a dormant turf during the summer (Hull, 1997).

Drought stress affects the turf quality, growth rate, evapotranspiration and recuperative potential (Ebdon and Kopp, 2004). Turf quality decline is an effect of reduction of root growth, leaf water potential, cell membrane stability, photosynthetic rate, photochemical efficiency and carbohydrate accumulation (Carrow, 1996 a, b; Huang and Gao, 1999; Jiang and Huang, 2001 a, b).

One from many important factors that determine the drought resistance of plants is the ability of leaf cell membranes to keep its function and integrity as long as possible during water deficit stress (Huang *et al.* 1997c). Membranes play a central role in various cellular functions, in particular those membranes with embedded enzymes and water/ion transporters. Drought leads to severe membrane damage. Efflux of water from the cells results in shrinkage of cell walls and plasma membrane, and eventually to collapse of cells (Svensson, 2001). Therefore, the strain on membranes is one of the most important effects of drought and survival (Chaves and Oliveira, 2004). It is also closely linked with the plant recovery after drought, which is a function of plant capacity to avoid or to repair membrane damage. Grass dehydration tolerance is affected by cell membrane stability. On the basis of cell membrane stability selection for drought resistant turf grasses was suggested (Zhao *et al.*, 1994). In some experiments Kentucky bluegrass (*Poa pratensis* L.) ecotypes of higher cell membrane stability were also resistant to simulated drought conditions (Abraham *et al.*, 2003, 2004; Wang and Huang, 2004).

Numbers of experiments were described to examine different aspects of the turf grass performance during drought. Generally, turf performance, which is a complex feature combined from the sward density during growing season, turf color, texture etc. declines as drought stress increase. However, the range of decline and final regrowth after drought are strongly dependent on numerous factors as for example: genetic properties of plant, plant age, soil type, management intensity, drought duration etc.

Pot experiments in glasshouse or controlled environment are quite suitable and widely used. Despite of some disadvantages due to the age of plants (too young), unreal high transpiration rate and unrealistic fast root growth, it is still very convenient tool to examine the stress resistance of plants (Humphreys, 2001). Different pot dimensions and treatments were presented in numerous works, however various soil conditions in pots were not discussed intensively, including sandy soil structures usually found on well projected football pitches.

The aim of above work was to analyze the effect of different soil conditions, including general turf performance during a simulated drought with relation to the leaf cell membrane stability of three major turf grass species.

MATERIALS AND METHODS.

Twelve turf grass varieties and breeding lines (further referred to as objects) of major European turf grass species were selected for above experiment: perennial ryegrass (*Lolium perenne* L.): Stadion, Stoper, Nira and breeding strain - KRH-22, Kentucky bluegrass (*Poa pratensis* L.): Alicja, Ani and breeding strains: Dresa and Chałupy, red fescue (*Festuca rubra* L.): Adio, Bargena, Nimba and Leo. Seed was kindly provided by breeders or breeding companies. Three different soil mixtures were prepared from peat, river sand and compost soil as follows: ‘peaty’ mixture - 1 part of compost soil and 2 parts of peat; ‘proportional’ mixture – 1 part of compost soil, 1 part of sand and 1 part of peat; ‘sandy’ mixture - 1 part of compost soil, 1 part of peat and 4 parts of sand. Soil mixtures were than analyzed for the chemical, structural and water properties (Table 1).

Table 1

Chemical, physical and water properties of soil mixtures

Soil parameter:	Type of soil mixture:		
	Peaty	Proportional	Sandy
Chemical analysis results (in mg per 100g of soil)			
pH	7.3	7.6	7.7
Na	7.7	3.8	3.2
K	45.6	24.2	8.0
Ca	488.1	287.5	226.1
Mg	27.1	11.1	5.6
P	5.9	4.7	3.1
Salinity [g/100 g of soil]	0.17	0.07	0.05
$C_{organic}$ [g/1 kg of soil]	95.9	32.0	8.8
N_{total} [g/1 kg of soil]	5.5	2.8	0.6
C / N	18 : 1	11 : 1	15 : 1
Soil texture (share in %)			
< 0.02 mm	4	15.2	0.5
0.02 – 0.05 mm	6.3	22.4	6.2
0.05 – 0.1 mm	15.4	14.2	15.9
0.1 – 0.25 mm	16.5	12.2	34.1
0.25 – 0.5 mm	35.7	30.4	31.9
0.5 – 1.0 mm	22.1	5.6	11.4
Bulk density of soil [$g \times cm^3$]	0.715	1.193	1.477
Water properties (in % of volumetric moisture content)			
Full water capacity (pf = 0.0)	70.7	52.4	42.8
Field water capacity (pf = 2.0)	47.7	31.4	16.4
Permanent wilting point (pf = 4.2)	13.9	9.0	6.2

Test procedures:

Pot experiment

Metal pots (6 per one object, 5000 cm^3, 20 cm in diameter, with drainage hole in the bottom) were filled with soil mixtures: 3.6 kg of peaty mixture, 6.0 kg of proportional mixture and 7.4 kg of sandy mixture per pot. On the basis of standard germination test results, sowing quantities were calculated to equalize seedling amount per pot area. Sowing quantities (in grams per pot) were as follows: Kentucky bluegrass: Dresa – 0.52, Chałupy – 0.54, Ani – 0.55, Alicja – 0.60; red fescue – Adio – 0.64, Leo – 0.67, Bargena and Nimba – 0.70; perennial ryegrass: Stadion – 0.94, Stoper – 0.96, Nira – 0.96 and KRH-22 – 1.01.

After sowing, pots were covered with 0,5 cm of the sand, well-watered and placed in the field. From seed sowing until seedling emergence pots were covered with white polypropylene non-woven cover and watered daily. During further vegetation in the field, pots were watered 3 – 4 times a week and grass was cut 3 times with hand mower at height of 3 cm. Mineral fertilizer was added once: 1.06 g per pot, and it equals (in kg per 1 ha): 30.9 kg N, 16.7 kg P, 49.6 kg K and 5.3 kg Mg.

Mean air temperature during grass vegetation in field (April, May and June) was 13.3°C and total rainfall – 149 mm.

After 80 days in the field, pots were moved to the unheated glasshouse, well-watered, weighed (W_1) and soil volumetric moisture content (VMC) was measured with *ThetaProbe* (*ThetaMeter* HH1, manufactured by Eijkelkamp Agrisearch Equipment, The Netherlands) at depth 0 – 6 cm.

Three pots per object in each of three soil mixtures were further kept without watering (drought conditions) and next three pots in each soil mixture were watered once a week with 0.5 l of tap water per pot (control conditions). VMC was measured two times per week and following traits were also evaluated:

- sward density (SD) was evaluated at the beginning and at the end of test, using 1-9 scale, where 1 is bare ground, no plants; 9 is complete turf cover (Prończuk, 1993; Prończuk *et al.* 1997),
- turf condition (TC), in 1 – 9 scale: 1 – completely dead plants, no green tissue visible, even when tillers dissected, 3 – trace of green tissue, usually at base of the youngest leaves, 5 – approx. half of plants with appreciable amounts of green leaves, 7 – most or all of leaves alive, but with the most of them scorched, permanently wilted, 9 – all leaves alive without symptoms of scorching (Humphreys and Thomas 1993, Minner and Butler 1985).

During vegetation in glasshouse pots were cut 6 times at 3 cm with hand mower. End of the drying phase was noted when VMC dropped to 0% and TC to 1. Regeneration started after pots weighed for the second time (W_2), and submerged in water for initial weight (W_1) recovery (ca. 24 hours). Further treatment for the test pots was the same as for control pots. VMC and TC were further measured and observed during regeneration. At the end of experiment (81 days after pots replacement to glasshouse, 161 days after sowing) SD was evaluated.

The total amount of available water for the test turf grown in pots was estimated on the basis of pots weights before and after drought ($W_1 – W_2$).

Mean air temperature during glasshouse test was 20.6°C, with optimum between fourth and sixth week (from 20.0 to 30.3°C, mean 24.9°C). Humidity ranges from 55.4 to 98.5%, with mean value at 75.7%. The highest humidity values were noted at the end of the test and lowest values – between eight and eleventh week.

Membrane stability

Cell membrane stability (CMS) was assessed according to Amin and Thomas (1996). Samples of ca. 80 mg of fully emerged, healthy and undamaged leaf lamina were collected from each tested object from control conditions grown in proportional mixture. Leaf samples were further incubated over silica gel for 24 h (drought simulation) or over water in humid chamber at 25°C for 30 minutes (control). Samples were than leached in 150 cm^3 of deionized water for 24 h on the laboratory shaker, and electrical conductance was measured (C_1). Samples were than autoclaved for 40 minutes, allowed to cool, and conductance was measured again (C_2). Membrane stability was calculated both for dried and control samples as :

$$CMS = 100 \times \frac{1 - C_1}{C_2}$$

CMS of dried leaves was expressed as a percentage of control samples.

Statistical analysis

All statistical calculations were made with STATISTCA ver. 12.0 PL. Significance of differences were accepted with 95% of probability. Lest significant differences (LSD) were calculated according to Fisher test and values were shown only if statistically significant with accepted probability.

For visual presentation of relations between VMC and TC, the best fitted equation were plotted, using the highest value of coefficient of determiantion (R^2). For all species and mixture types rule as:

$$y = a \times ln(x) + b$$

was used, where dependent variable is VMC and independent variable – TC).

RESULTS

Soil VMC changes during drying.

As it has been proved by regression analysis, soil moisture decrease during drying was linear in the case of all species and all used soil mixtures (Table 2). It is also evident from above that mean VMC of soil under sward dropped to 0% after 22 – 24 days in sandy mixture, from 28 to 29 days in proportional mixture and from 44 to 46 days in peaty mixture of drying. In each of applied soil mixtures, perennial ryegrass was the fastest soil-drying species, as contrary to Kentucky bluegrass.

Table 2

Results of the linear regression analysis with VMC as dependent variable and number of days since water withheld (drying) as independent variable.

Soil mixture	Species	Model	Unstandardized coefficients		Standardized coefficients	t	Sign.	Dependent variable value
			B	Std.Error	Beta			For indepen-dent = 0 (VMC = 0%)
Peaty	*Festuca rubra*	Constant	41.04	1.38		29.70	0.000	45.0
		No. of days	-0.91	0.05	-0.983	-19.90	0.000	
	Lolium perenne	Constant	40.25	1.60		25.14	0.000	44.3
		No. of days	-0.91	0.05	-0.977	-17.10	0.000	
	Poa pratensis	Constant	41.86	1.36		30.78	0.000	45.8
		No. of days	-0.91	0.05	-0.983	-20.24	0.000	
Propor-tional	*Festuca rubra*	Constant	26.96	0.89		30.37	0.000	28.9
		No. of days	-0.93	0.05	-0.989	-18.56	0.000	
	Lolium perenne	Constant	25.57	1.02		24.99	0.000	28.1
		No. of days	-0.91	0.06	-0.984	-15.76	0.000	
	Poa pratensis	Constant	29.72	1.12		26.60	0.000	29.5
		No. of days	-1.01	0.06	-0.985	-15.97	0.000	
Sandy	*Festuca rubra*	Constant	17.04	0.90		18.857	0.000	23.7
		No. of days	-0.72	0.07	-0.975	-10.677	0.000	
	Lolium perenne	Constant	16.14	0.78		20.604	0.000	22.1
		No. of days	-0.73	0.06	-0.981	-12.514	0.000	
	Poa pratensis	Constant	18.00	0.55		32.567	0.000	23.9
		No. of days	-0.75	0.04	-0.991	-18.233	0.000	

No statistical differences between grass species and objects were found for the amount of water available for plants during drying. It ranges from 2.217 kg H_2O per pot for peaty mixture, 1.355 kg H_2O per pot for proportional mixture to 0.915 kg H_2O per pot for sandy mixture.

Turf performance

As soil VMC declined from the field water capacity (pF = 2.0) to permanent wilting point (PWP, pF = 4.2), condition of turf (TC) was rather stable. First visible symptoms of the permanent water deficit on the turf was leaf wilting i.e. TC decrease to score 7. It includes a blue-green color and leaf rolling or folding (Carrow, 1996). In our experiment, perennial ryegrass varieties wilted first, in sandy mixture some varieties wilted half a day after VMC dropped to PWP (Table 3). As contrary to above, the longest delay of wilting was noted for Kentucky bluegrass 'Dresa' in peaty and proportional mixtures. Generally, if VMC reached PWP, turf become wilted after 3.3 – 5.4 days in peaty and proportional mixture but 0.4 – 4.1 days in a sandy mixture. As soil VMC decreased below PWP, TC also decreased and finally dropped to 1, after 27 days in sandy mixture, 35 days in proportional mixture and

53 days in a peaty mixture. Only in sandy mixture intra-specific variation was noted for perennial ryegrass and red fescue.

Table 3

Number of days from the beginning of drying to: decrease of soil moisture content to the permanent wilting point (pF=4.2); wilting of turf (TC=7) and its total dry-out (TC=1)

Name of object	Soil mixtures:								
	Peaty			Proportional			Sandy		
	pF=4.2	Wilting	Dry-out	pF=4.2	Wilting	Dry-out	pF=4.2	Wilting	Dry-out
Mean for									
P. pratensis	29.6	35.0	54.1	18.6	24.0	35.3	13.7	17.8	28.9
Alicja	29.7	35.7	54.0	18.9	24.3	34.8	14.2	20.0	29.1
Ani	30.6	36.0	54.6	19.2	24.0	36.6	15.3	20.7	29.2
Chałupy	30.4	33.7	55.5	19.0	23.5	35.5	12.8	14.7	30.1
Dresa	27.5	34.7	52.4	17.4	24.0	34.4	12.5	16.0	27.2
Mean for									
L. perenne	26.9	30.3	51.2	16.9	20.2	33.4	12.4	12.8	24.2
KRH-22	27.9	32.7	54.1	16.5	18.7	33.8	12.4	13.5	25.8
Nira	27.5	26.3	49.4	16.6	18.7	33.9	14.1	13.5	26.2
Stadion	27.0	32.3	52.3	17.2	20.3	33.5	11.6	12.0	23.2
Stoper	25.2	29.7	49.1	17.2	23.0	32.4	11.5	12.0	21.6
Mean for									
F. rubra	28.1	31.8	54.2	18.6	23.6	35.7	13.0	16.3	28.2
Adio	27.4	26.3	56.8	18.1	23.0	34.0	9.8	13.0	24.1
Bargena	28.4	33.0	55.5	19.1	24.0	35.7	12.9	17.0	28.5
Leo	27.3	32.0	54.4	18.8	22.3	37.2	13.8	16.0	29.3
Nimba	29.1	35.7	50.0	18.3	25.0	35.7	15.4	19.0	31.0
Mean for objects:	28.2	32.3	53.2	18.0	22.6	34.8	13.0	15.6	27.1
LSD for objects	-	-	-	-	3.6 **	-	3.46 **	6.1 **	5.3 **
LSD for species	2.2**	3.8***	-	1.25***	1.8***	-	-	3.17*	2.8 **

Levels of significance: ** p < 0.05. *** - p < 0.01

Moisture decrease was not related to tested objects, however TC decrease to wilting (7.0) and total leaf dry out (1.0) was not only related to the soil mixtures but also to tested objects (Table 4).

Table 4

Two-way ANOVA results for moisture and condition decrease (mean squares).

Source of variation	VMC decrease to permanent wilting point	Decrease of turf condition to:	
		7.0	1.0
Soil mixtures	2038.0 **	2451.0 *	5977.5 **
Objects	8.35	70.9 **	26.7 *
Soil mixtures x objects	4.2	12.6	10.1

Statistical significance at: * -p < 0.05; ** - p < 0.01

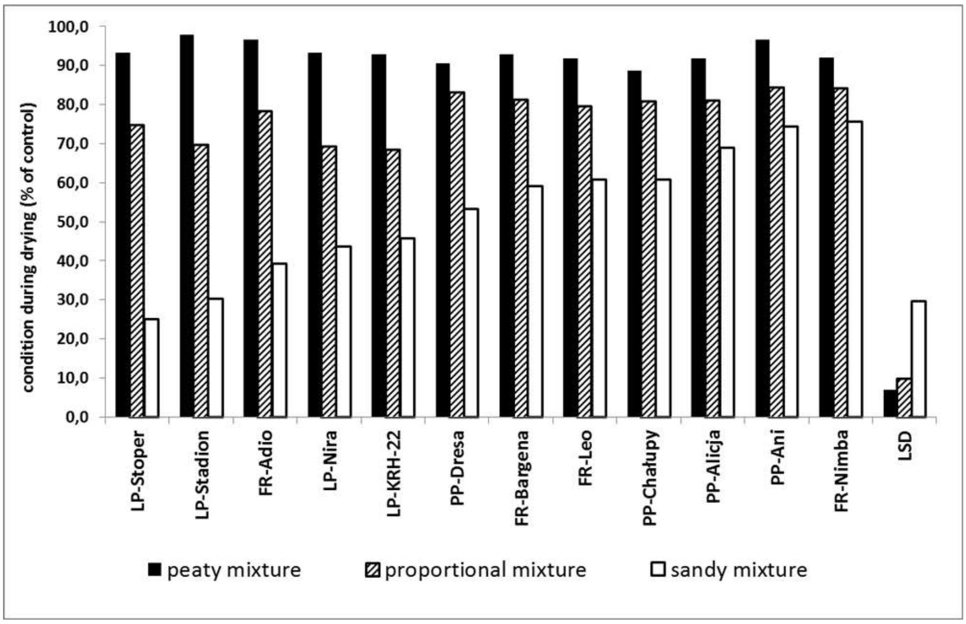

Fig. 1. Turf condition during drying (% of control pots, objects ordered with increasing values in a sandy mixture)

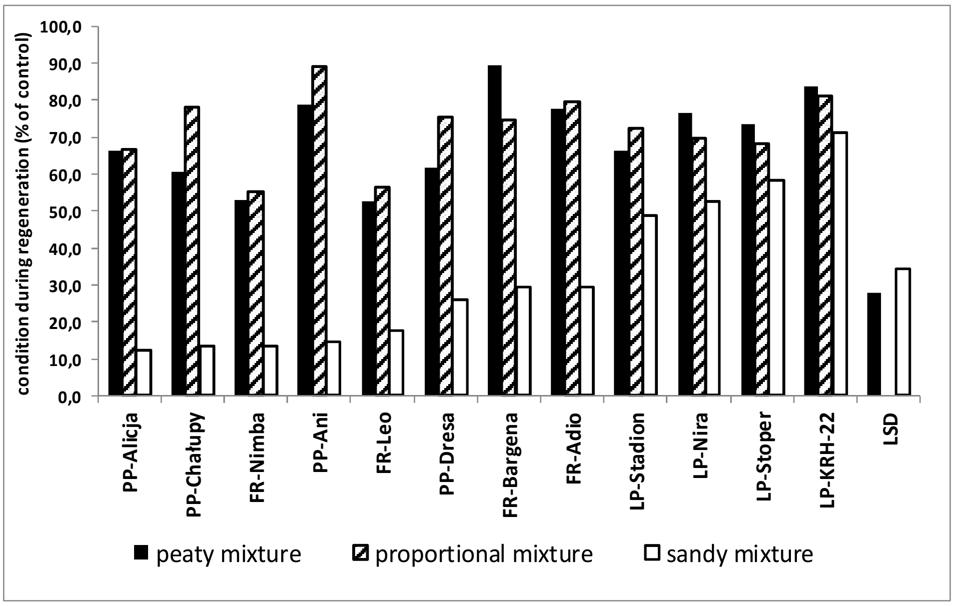

Fig. 2. Turf condition during regeneration (% of control pots, objects ordered with increasing values in sandy mixture). Abbreviations: LP – *Lolium perenne*. FR – *Festuca rubra*. PP – *Poa pratensis*

Mean values of TC during drying were strongly reduced in a sandy mixture, and difference between objects were also noted in a proportional mixture (Fig. 1).

The strongest effect of water deficit was noted in perennial ryegrass, where average TC was only 5.7% of control conditions for the grass grown in a peaty mixture, 29.4% in a proportional mixture and 63.9% in a sandy mixture. Condition of perennial ryegrass variety Stoper dropped to 25% of control in a sandy mixture, as compared to red fescue Nimba (75.6%) and Kentucky bluegrass Ani (74.4%).

Most of the tested objects were not able to regenerate to the values of control turf (Fig.2). In the case of Kentucky bluegrass and red fescue very low values of TC (from 1.1 to 2.4) were observed. It means that only few green plants per pot regenerated. As contrary to above, the quality of perennial ryegrass after regeneration was more than 50% of control. For example, perennial ryegrass KRH-22 regenerated in all soil mixtures to the level of control conditions. Kentucky bluegrass regenerated better in a proportional mixture, than in a peaty and sandy. For red fescue (exc. Bargena) there was no difference between regeneration in a peaty and proportional mixtures.

Reduction of SD was the highest for Kentucky bluegrass varieties grown in sandy mixture where it decreased to 25% (Chałupy) and 31% (Dresa) of its initial value. As contrary, the best SD after drought and regeneration was noted for perennial ryegrass: from 70% (in a sandy mixture) to 93% (in a peaty mixture) of initial density. For perennial ryegrass KRH-22 no statistical difference between all mixtures used was found (Fig. 3).

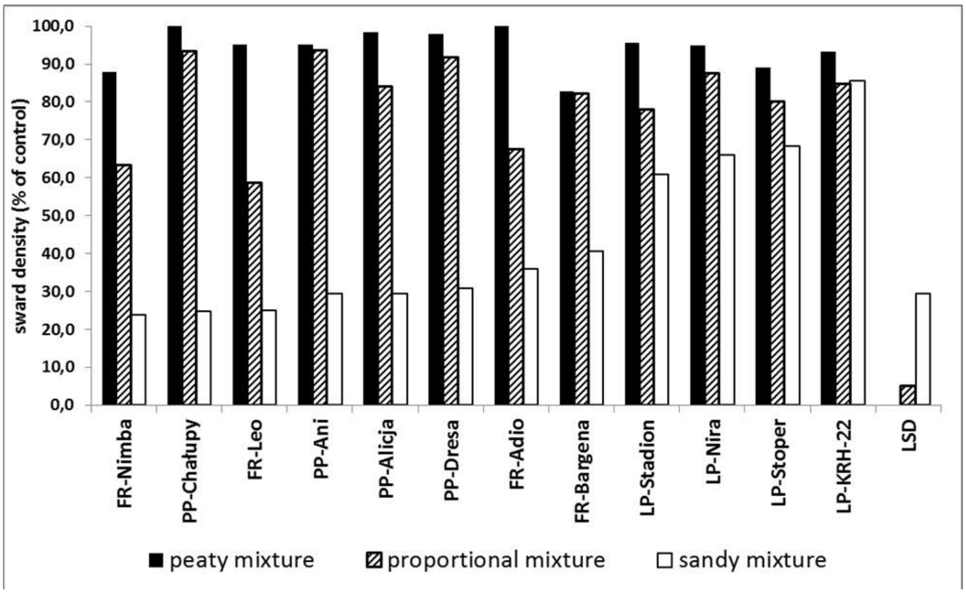

Fig. 3. Sward density at the end of test (% of initial value, objects ordered with increasing values in sandy mixture). Abbreviations: LP – *Lolium perenne*. FR – *Festuca rubra*. PP – *Poa pratensis*

Reduction of the sward density after drought and recovery in all soil mixtures was noted for red fescues. It ranged from 23.8% of initial SD in a sandy mixture (Nimba), 58.2% in a proportional (Leo) to 83.0% in a peaty mixture (Bargena). No SD reduction was noted for Adio in peaty mixture.

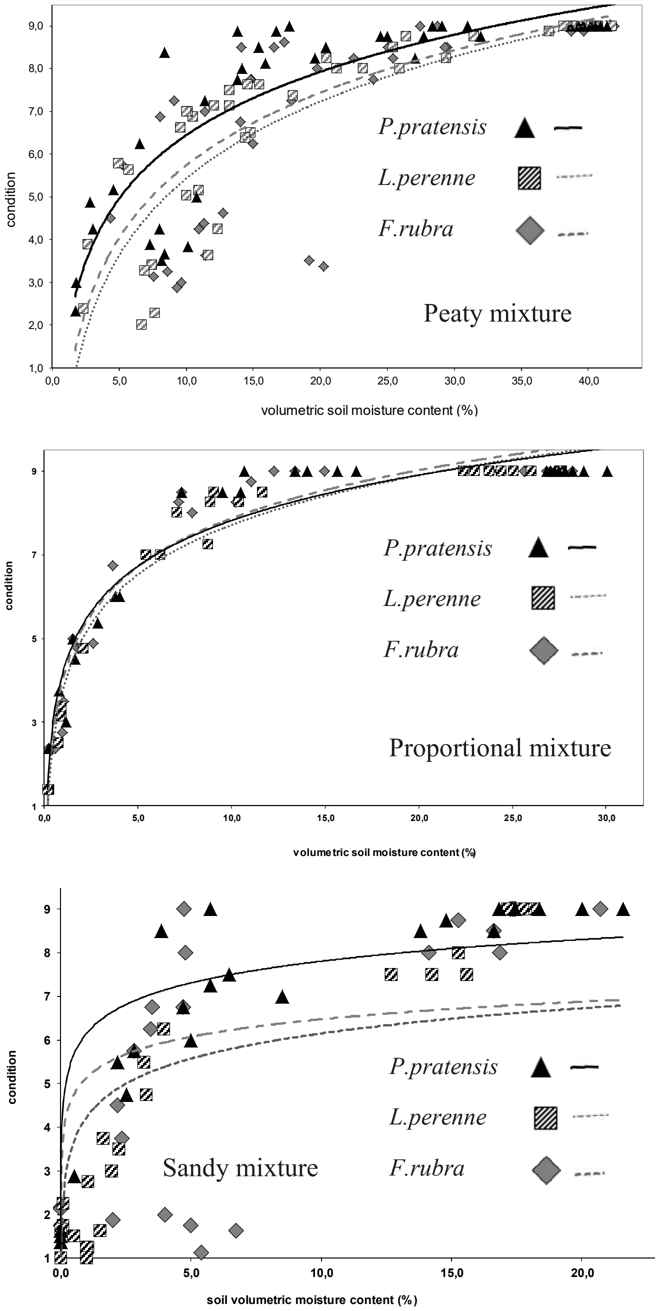

Fig. 4. Relation between VMC (volumetric soil moisture content) and TC (turf condition) in different soil mixtures

It is evident from above that turf condition during drying is close related to VMC of soil. When plotting all TC data from different soil mixtures against

VMC (Fig. 4) it can be concluded that condition of Kentucky bluegrass is mostly related to the soil moisture during drying and regeneration. Variation of TC is described by VMC from 74% in a peaty mixture to 92% in a proportional mixture. As contrary, TC of red fescue was the least related to VMC. Generally, TC during drying and regeneration was mostly dependent on VMC in a proportional mixture: from 92% for Kentucky bluegrass to 97% for perennial ryegrass.

Cell membrane stability (CMS)

Stability of the leaf cell membranes of tested objects was the highest for red fescue: from 45.5% for Nimba to 19.3% for Bargena (Fig. 5). No significant difference was noted for perennial ryegrass entries (CMS from 10.6 to 9.2%). Significantly lower CMS value were noted for strain Chałupy of Kentucky bluegrass (7.2%), while for the rest of objects from the same species it raged 17.2 (Alicja) to 13.5 (Dresa).

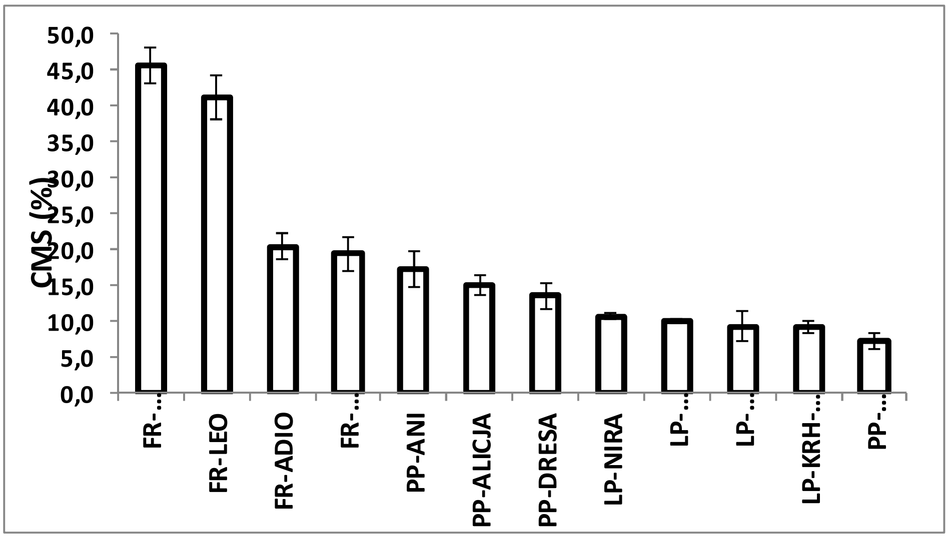

Fig. 5. Leaf cell membrane stability of tested objects – expressed as a % of control (non-dried leaves) LSD = 5.48, Abbreviations: LP – *Lolium perenne*. FR – *Festuca rubra*. PP – *Poa pratensis*

Relations between CMS and TC during drought were different for the tested species (Table 5). For Kentucky bluegrass SD after drought and number of days from water withheld to wilting were positively correlated with CMS. However, for red fescue and perennial ryegrass only few correlations were significant and all of them negative, mostly for the turf grown in sandy mixture. Above relation seems to be 'species-specific' and therefore general conclusion is not quite clear. We can only suppose that during fast drying in our experimental conditions higher membrane stability was not the main factor that determined post-drought performance for red fescue and perennial ryegrass

Table 5

Correlation coefficients for traits observed on turf and cell membrane stability (only statistically significant coefficients were given).

Traits	Soil mixture	*Poa pratensis*	*Lolium perenne*	*Festuca rubra*
Mean turf condition during drying (% of control pots)	Peaty	-	-	-
	Proportional	-	-	-
	Sandy	-	-	-
Mean turf condition during regeneration (% of control)	Peaty	-	-	-
	Proportional	-	-	-
	Sandy	-	-0.90*	-0.93*
Sward density after drought & regeneration (% of initial value)	Peaty	-	-	-
	Proportional	-	-	-
	Sandy	0.99*	-	-0.90*
Soil moisture decrease to permanent wilting point	Peaty	-	-	-
	Proportional	-	-	-
	Sandy	-	-	-
Number of days from water withheld to wilting start	Peaty	-	-	-
	Proportional	0.90[a]	-	-
	Sandy	-	-	-
Number of days from water withheld to total dry out	Peaty	-	-	-0.91*
	Proportional	-	-	-
	Sandy	-	-	-

Significance levels: a – $p < 0.1$; * - $p < 0.05$

DISCUSSION.

Water availability is one of the major factors that determine seed germination and further plant development in the regions of seasonal or permanent water deficits (Dodd and Donovan, 1999; Sharma, 1973). The rate of the water uptake is crucial for the plant competitive ability (Wilman *et al.*, 1998). Soil moisture changes observed in our work were quite similar to described by Jiang and Huang (2000) for Kentucky bluegrass and Volaire and Leliévre (2001) for the orchard grass and tall fescue. In our experiment we have noticed that soil moisture content in pots with perennial ryegrass decreased faster then in pots with Kentucky bluegrass or red fescue. Wilman and co-authors (1998) suggested that at spring, perennial ryegrass absorbed water slower than tall fescue or Italian ryegrass, but from May to October it was similar for all species, even with advantage to perennial ryegrass. Such relation is due to intensive growth of perennial ryegrass green mass, especially during the second part of growing season (Falkowski, 1982; Elberse and Berendse, 1993).

Rate of the soil moisture decrease to the level of permanent wilting point (in our experiment between 10 to 30 days of drying) was similar to results obtained in pot experiment made by Karsten and Mac Adam (2001) with perennial ryegrass and tall fescue. They noted permanent wilting point between 10 and 20 days of drying.

Soil moisture changes are strongly connected with the changes in plants. Plants cope with soil moisture decrease to level close to permanent wilting point. Below this level some reversible changes (e.g. desiccation of leaf bases) may first occur, and further, irreversible changes (e.g. total dry-out) will affect plant (Chaves *et al.*, 2002; 2003; Chaves and Oliveira, 2004). At the beginning of soil moisture decrease the plants are usually able to keep tissue water potential at unchanged level, but if drought still progresses, rapid decrease of tissue water potential appears (Amiard *et al.*, 2003).

First, reversible change associated with the water deficit is leaf wilting. Wilt symptoms include a blue-green color and leaf rolling or folding (Carrow, 1996a, b). When wilted, the plants may reduce transpiration and therefore, total water loss. According to Thomas and Evans (1989) wilting intensity is close connected with leaf water potential. It has been proved for Kentucky bluegrass by Ebdon and Koop (2004) that degree of wilting was connected both with the ability to extract water from deeper soil layers and higher evapotranspiration. Observations on tall fescue leaf folding during the water deficit were more suitable for the estimation of plant water status than laboratory measures of leaf osmotic potential (White *et al.*, 1992).

Concerning fast wilting of perennial ryegrass, as was noted in our experiment, it could be the element of plant strategy for copying with drought. Jones (1990, after Milnes *et al.*, 1998) claims that the optimum drought copying strategy of plants is based on fast uptake and spending of water, provided that plant is able to survive water deficit due to special mechanisms. Such reactions has been noted for junegrass or orchard grass from South of Europe (Volaire, 1995; Milnes *et al.*, 1998). Very fast wilting of perennial ryegrass during drought was also probably due to the low root weight and low root:shoot ratio, as compared to Kentucky bluegrass and red fescue (Dziamski *et al.* 2007). Differences in the root distribution during drought stress may be due to carbon relocation from the shoots to roots for formation of a more extensive root system into deep soil (Mc Cann and Bingru Huang, 2008).

The main factor that determined wilting speed was the amount of water available for plants. The phenomenon of fast wilting on the light, sandy soils as contrary to a peaty soils, was observed during spring drought 2000 in the upper Noteć valley (Łabędzki, 2000). Different speed of wilting and dry-out was observed also by Carrow (1996 a) for tall fescue turf varieties.

It is possible that wilting was assisted by leaf cell membrane stability (CMS). We have noticed close relation between CMS and wilting for red fescue and Kentucky bluegrass. Red fescue Nimba of the highest CMS (45.5%) wilted after 36 days of drought in a peaty mixture while red fescue Adio, of low CMS (20.3%) wilted 10 days earlier. Kentucky bluegrass Alicja (high CMS = 15%) wilted 2 days later than Kentucky bluegrass Chałupy, of the lowest CMS = 7.2%. Such relation is rather easy to explain and has been proved in some other experiments, where Kentucky bluegrass ecotypes of higher cell membrane stability were also resistant to simulated drought conditions (Abraham *et al.*, 2003, 2004; Wang and Huang, 2004).

Some authors suggested that cell membrane stability during dehydratation was a measure of dehydratation tolerance of whole plants (Huang *et al.*, 1997 b). It was true for spring wheat (Zagdańska and Pacanowska, 1979). However, according to our results, high cell membrane stability seems not to be the good measure of turf quality after drought. In perennial ryegrass we have noticed small variation of CMS while in red fescue rather high. The manifestation of CMS is probably due to the general genotype drought resistance strategy and is close related to the share of other parts of plant in general drought resistance.

Next visible step in turf grass reaction to the permanent water deficit was leaf yellowing and finally, senescence and total plant dry-out. Leaf yellowing is the result of chlorophyll degradation in senescing leaves, which unmasks the presence of carotenoids (Munne-Bosch and Alegre, 2004). Drought-induced leaf senescence contributes to the plant survival under drought, since it allows an early diversion of resources from vegetative to reproductive development, remobilization of nutrients from drying leaves to the young parts of plant (thus contributing to plant survival) and reduction in water loss from the whole plant (Munne-Bosch and Alegre, 2004; Volaire *et al.* 2005). Leaf yellowing and senescence is normally considered a measure of drought tolerance in the field conditions (Beard, 1989; Carrow, 1996a,b; Huang *et al.*, 1997 a; Minner and Butler, 1995).

Different leaf senescence and further regeneration are of the key role for breeding lines evaluation because of high level of differentiation between genotypes (Thomas, 1990; Carrow, 1996a). However, for Kentucky bluegrass there was no close relation between the water use efficiency and leaf wilting and senescence (Ebdon and Kopp, 2004).

Soil water abundance was crucial for the plant condition during drying. In a soil mixture of the poorest water retention (sandy mixture), the lowest condition was noted. The differentiation of both species and varieties increased along with the decrease of water retention of soil mixtures. The most drought susceptible species was perennial ryegrass. It was the consequence of fast soil drying, as it was mentioned above. However, if plant reduces its foliage fast, shorter is the period of exposition of living, aboveground parts of plants to drought conditions, and therefore, less is the damage of leaf bases and tillers. Plants may therefore regenerate faster after the drought is over (Munne-Bosch and Alegre, 2004). One of the major factors that determine plant survival during drought is the effective water use. Higher water use efficiency for perennial ryegrass as compared to tall fescue and orchard grass was observed in pot experiment made by Johnson and Basset (1991, after Thomas, 1994). It was true for drought test conditions as well as for watered control pots. Competitive ability of perennial ryegrass in comparison with orchard grass, meadow fescue or timothy decreased in the wet conditions while with increasing site moisture, sugars content in dry matter decreased (Falkowski *et al.*, 1986; Baryła and Warda, 1999).

When the drought ends, after natural rain or artificial watering, the regeneration begins. It is of the major importance for perennial grasses, especially regeneration from existing plants rather than requiring establishment of new plants (Kemp and Kluvenor, 1994). Good regeneration after drought may be more important than plant growth during the dry season. Above process is linked with the ability to reduce cell membrane damages during desiccation or fast repairing of membranes (Chavez and Olivera, 2004). Regeneration is also dependent on

the density of tillers surviving prolonged water deficit, its regrowth and growth of new tillers (Volaire *et al.*, 1998). Water content in young plant tissues of leaves and sheets increase along with increasing soil moisture content (Amiard *et al.*, 2003). During the same time, water content in mature leaf blades increased rather slow, and in roots no increase was noted.
In our experiment none of tested objects regenerated to 100% of initial value, as it was noted in the previous field experiment on turf grasses (Żurek, 2000). Apart from obvious differences between pot experiment and field drought, perennial ryegrass was selected as the best regenerating species in the most stressful conditions (i.e. sandy mixture). Perennial ryegrass varieties regenerated its condition to 59% of control pots, while red fescue only 22% and Kentucky bluegrass – 16%. Fast regrowth of perennial ryegrass tillers after drought was also observed by Volaire and co-authors (1998). It was ascribed to greater availability of carbohydrates and proline at the end of drying phase (Volaire *et al.*, 1998).

One from many important factors that determine the quality of turf varieties is sward density (Diesburg *et al.*, 1997). Value of sward density at the end of the drying period was claimed to be a turf quality index (Qian and Engelke, 1999). Once more, perennial ryegrass seems to be a species of the highest sward density after drought and regeneration. Sward density of ryegrass was 70% in a sandy mixture, while for red fescue – 31% and for Kentucky bluegrass – 29%. Low sward density of red fescue turf after drought was also observed by Minner and Butler (1985).

Red fescue indicate some evolutionary developed adaptive mechanisms similar to f.e. *Trichloris crinita*, Argentinian pasture grass (Greco and Cavagnaro, 2003). Along with the increasing temperature and increasing probability of summer drought occurrence, red fescue plants decrease aboveground weight together with an increase of root growth production (Dziamski *et al.*, 2007). That is probably the reason why condition of red fescue sward was the least dependent on the soil moisture, as compared to Kentucky bluegrass and perennial ryegrass. An increase of root:shoot ratio is an element of the plant drought resistance strategy known as *drought avoidance* (Beard 1989; Chaves *et al.*, 2003). However, usually it is not in line with turf user expectations. Creeping red fescue and sheep fescue are commonly used for low maintenance turf (Dernoeden *et al.*, 1994, 1998, Diesburg *et al.*, 1997, Harkot and Czarnecki, 1999, Lutyńska, 1993). However, along with increasing drought, turf from above species usually display a brown patchy appearance, rather than uniform dormancy as for the perennial ryegrass and Kentucky bluegrass. Mulch, provided by dead leaves or dormant turf is difficult to mow. Finally, the dead areas on turf of creeping red fescue or sheep fescue never fill in with new growth and that is why above species were recorded to be less drought resistant than perennial ryegrass and Kentucky bluegrass (Minner and Butler, 1985).

Drought tolerant cultivars of the major amenity grasses were always very important for breeders and managers. But it is still not clear that any drought tolerant cultivars exist, even in large turf trails in USA (Thorogood 2003). On the other hand it is quite easy to find significant differences between commercial cultivars, on the single trait basis (Żurek, unpublished data). What is probably of the major interest, is that drought tolerance is species-dependent. In few cases species with genetically enhanced drought tolerance were used for the improvement of other species. One good example is hybridization between Texas bluegrass (*Poa arachnifera* Torr.) and *Poa pratensis*. A few of the resulting cultivars demonstrated enhanced drought tolerance (Read and Anderson, 2003).

However, considering the world-wide water problems, probably the best way is to look for 'water-saving' cultivars rather than for better drought tolerance. Presently the modern cultivars with improved drought resistance retain proper turgor in stress conditions by more intense transpiration. Unfortunately, more intense transpiration during the drought period is compatible with higher transpiration rate under the optimal weather conditions, which results in larger amount of water evapotranspiration from the soil (Rybka and Żurek, 2010). Nothing is currently known about the possibility of producing 'water-saving' amenity grass cultivars. Another option for the water problems is to use municipal water, wastewater, storm water or other types of water not suitable for people or animals. The idea is to have more than one water source available for use on a single turf site (Duncan *et al.* 2009).

CONCLUSIONS

1. The expression of natural variation, connected with the water deficit is much more visible in conditions that favor faster water loss. Environmental conditions have much stronger effect on the water loss than morphological and physiological properties of grass plants. Soil mixture, which was the most suitable for estimation of the grass reaction to the water deficit was a sandy mixture, of relatively low water capacity (ca. 16% of field water capacity). While testing in such conditions, differences between tested varieties were clearly manifested.
2. Key traits in the evaluation of turf grass in drought conditions seems to be regeneration and sward density maintenance after drought. Other biochemical and physiological parameters (e.g. leaf cell membrane stability) of great value for the general understanding of plant reaction to the stress, should be treated as additional determinants of potential quality of tested varieties.
3. Suggestions for the practice resulting from above publication and concerning turf surfaces quality during prolonged water deficits are that we should use grass mixtures with high perennial ryegrass contents to ensure relatively high turf regeneration after drought if watering is not possible or not recommended. In case of no problems with watering turf quality could be increased with higher share of Kentucky bluegrass in the mixtures.

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