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OBSERVATIONS OF ROOT SYSTEM DEVELOPMENT AND DYNAMICS OF ROOT:SHOOT RATIO OF SELECTED TURF GRASS VARIETIES AND BREEDING LINES GROWN IN DIFFERENT SOIL CONDITIONS

ABSTRACT

Twelve varieties and breeding lines from three turf grass species, grown in pots in three different soil mixtures were first tested in glasshouse for drought resistance. Further, turf in pots was allowed to regenerate and root and shoot dry weight was measured after one (in April) and two (in May, August and October) years from seed sowing. Turf grass regeneration after simulated drought was different accordingly to soil mixtures used. In peaty mixture regeneration was good and similar to all species, but in proportional mixture it was better for Kentucky bluegrass and in sandy mixture – for perennial ryegrass than for other species, respectively. Regeneration of turf grass after drought in different soil conditions was mainly affected by the ability to develop specific root system. The growth dynamic of tested varieties and breeding lines depends on physical and chemical soil properties. Despite soil mixture, red fescue and Kentucky bluegrass developed root system of high dry weight values along with low values of shoot dry weight, as contrary to perennial ryegrass, which developed root system of low dry weight along with high shoot dry weight values.

Key words: *Festuca rubra, Lolium perenne, Poa pratensis*, turf, root, root:shoot ratio

INTRODUCTION

The main factors that affect plant development dynamics are of environmental (temperature, soil moisture, mineral elements, acidity and structure of soil, availability of water and nutrients) and anthropogenic (fertilization, irrigation, mowing etc.) origin. Mutual relations between mentioned factors are responsible not only for seasonal development of plants but also for different physiological, morphological and anatomical adaptations. It refer both to above and below ground parts of plants. The latter are important elements of plants copying strategies against unfavorable environment conditions (Carrow 1996, Stetson and Sullivan 1999, Chaves 2003, Janicka 2004). Plant adaptations to seasonal soil water deficits and regeneration abilities are of particular importance. Soil drought is responsible for reduction of dimensions of particular root system traits (i.e. reduction of root

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weight growth and length of lateral roots) as well as less favorable root:shoot ratio (Kukielska 1974, Grzesiak 2002). Root system is therefore significant element of plant defense strategy against drought. One of important adaptations is the increase in root:shoot ratio with decreasing soil water availability (Huang and Fry, 1998; Kemp and Cluvenor, 1994; Brarr and Palazzo, 1995; Chaves *et al.* 2003). It is claimed that the role of root system in resistance mechanisms is minor as compared to aboveground parts of plant, however structural changes in root systems were not yet clearly described.

The aim of our work was to describe dynamics of changes in root system development and root:shoot ratio of selected varieties and breeding lines from three major turf grass species grown in different soil media.

MATERIAL AND METHODS

Twelve turf grass varieties and breeding lines were selected for above experiment from three major cool-season turf grass species: perennial ryegrass (*Lolium perenne* L.), Kentucky bluegrass (*Poa pratensis L.*) and red fescue (*Festuca rubra* L.). 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. Mixtures were than analyzed for chemical, structural and water properties (Table 1). Metal pots (5000 cm^3, 20 cm in diameter, with

Table 1

Chemical, physical and water properties of soil mixtures

Parametrs	Type of soil mixture:		
	Peaty	Proporcjonal	Sandy
Soil parameters			
pH	7.3	7.6	7.7
Corg. [%]	9.59	3.20	0.88
N total [%]	0.55	0.28	0.06
C/N	18÷1	11÷1	15÷1
Water properties [% of volumetric moisture content]			
Full water capacity (pF = 0.0)	70.7	52.4	42.8
Field water camacity (pF = 2.0)	47.7	31.4	16.4
Permanent wilting point (pF = 4.2)	13.9	9.0	6.2
Bulk density of soil [g × cm3]	0.715	1.193	1.477
Texture [%]			
1÷0.1 mm	90	61	84
0.1÷0.02 mm	6	22	7
< 0.02 mm	4	17	9

drainage hole) 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 (314 cm^2). 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 (15^{th} - 19^{th} April 2004), pots were covered with 0.5 cm of 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 3 cm height. 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 oraz 5.3 kg Mg.

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

One half of pots was further kept without watering (drought conditions) and second half was watered once a week with 0.5 l of tap water per pot (control conditions). VMC was measured two times per week. Sward density (SD) was evaluated at the beginning of test, using 1-9 scale, where 1 is bare ground, no plants; 9 is complete turf cover (Prończuk, 1993; Prończuk *et al.* 1997).

Drying phase ended when VMC in upper soil layer (0-6 cm) dropped to 0% and when there was no visible green tissues in sward (condition of turf equals 1°, according to Humphreys and Thomas 1993, Minner and Butler 1985, Żurek 2004, 2006). At this moment pots were immersed in water to VMC increase up to initial value, same as before drying test. Glasshouse phase of experiment was finished after 81 days (161 days from seed sowing). Pots were further moved outside glasshouse and put into the ground for l' of height.

Further observations and measurements were taken only on drought stressed pots. Sward was allowed to regenerate during whole vegetation period of 2005. VMC was near filed capacity, grass was mown and fertilized two times in same quantity as given above. One year after seed was sown, SD was evaluated and shoots (S) and roots (R) dry weight was measured. Roots were washed in water on sieves according to Böhm (1985) and Smit *et al.* 2000. After washing, roots were oven dried in 60^o per 16 hours and weighed. Root volume was measured while submerging them in distilled water for 2 minutes and measuring volume of stuffed water. Dry weight of shoots was also measured after drying as described above.

In 2006 soil moisture was also kept near field water capacity, turf was fertilized (3 times) and mowed (5 times). Turf in pots maintained condition from 5° (approx. half of plants with appreciable amounts of green leaves, all leaves permanently wilted) to 8° (the great majority of leaves alive, only few at the wilting phase) during whole season (Humphreys and Thomas 1993, Minner and Butler 1985, Żurek 2004, 2006). During 2006 further root and shoot dry weight measurements were taken in three seasons: at the beginning of vegetation (May), at the full vegetation (August) and at the end of vegetation (October).

Results were analyzed with SAS® statistical package: three-way ANOVA were performed and LSD values were calculated using Tukey test (HSD) with probability of 95% (SAS Institute, 2004 a, b).

Climatic conditions

Mean air temperature during vegetation if the field in 2004 were 13.3°C, total natural rainfall was 149 mm. During glasshouse test mean air temperature was 20.6°C and ranged from 20.0° to 30.3°C in 4th and 6th week of test period, respectively. Mean air humidity was 60%.

The beginning of 2005 vegetation season was cold, and precipitation was similar to normal value. Spring was 0.7 – 1.2°C warmer than normal and wet. Summer and autumn were dry. Especially dry months were July (+2.2°C greater then normal) and September (+2.6°C greater then normal). Precipitation in vegetation season 2005 was 81.2% of normal and temperature – 104.9% of normal.

Winter of 2005/2006 was dry and cold. However, form April up to October mean air temperatures were higher than normal from 0.8°C (May and June) to 5.1°C (July). April, May and August were rather wet, while rest of months in vegetative season 2005 were dry. Mean monthly precipitation in June and July was 40 mm lower than normal.

RESULTS AND DISCUSSION

On the basis of VMC changes during drying phase, it was calculated that permanent wilting point (pF = 4.2) followed after 20 days of drying in sandy mixture, after 27 days in proportional mixture and after 35 days in peaty mixture.

For majority of varieties and breeding lines subjected to drought in glasshouse test, statistically significant decrease of sward density was observed in all soil mixtures, as compared to control conditions (Table 2). Perennial ryegrass varieties and breeding lines were the most resistant for artificial drought conditions in respect of sward density stability. Depending on soil mixture, perennial ryegrass maintained from 61 to 96% of initial sward density. The least drought resistant sward density was observed for red fescue and Kentucky bluegrass. The latter regenerated in soil conditions only 29 to 31% of initial sward density. Sward density decrease depend not only on species examined but also on varieties and breeding lines.

Table 2

Results of estimation of sward density and shoot and root parameters for evaluated turf varieties and breeding lines after one year of regeneration in different soil conditions

Species (B)	Variety or strain (C)	Sward density [% of initial value]	Shoot dry weight [g per pot] — S	Root dry weight [g per pot] — R	Root volume (cm^3 per pot)	R÷S
Peaty mixture (A)						
Festuca rubra	Adio	100.8	2.4	22.2	140.0	9.2
	Bergena	82.9	3.1	22.6	225.0	7.2
	Leo	95.2	3.7	22.0	185.0	5.9
	Nimba	87.9	4.0	28.6	270.0	7.1
	Mean	91.7	3.3	23.9	205.0	7.3
Poa pratensis	Alicja	98.4	6.1	33.8	260.0	5.5
	Ani	95.2	7.6	46.0	375.0	6.0
	Chałupy	100.2	4.6	32.5	256.0	7.1
	Dresa	98.0	6.1	22.2	142.0	3.6
	Mean	97.8	6.1	33.6	258.3	5.5
Lolium perenne	KRH-22	93.3	2.8	14.7	195.0	5.2
	Nira	95.0	2.8	13.6	215.0	4.8
	Stadion	95.5	4.0	12.3	125.0	3.0
	Stoper	89.1	2.8	12.4	160.0	4.4
	Mean	93.2	3.1	13.3	173.8	4.3
Proportional mixture (A)						
Festuca rubra	Adio	67.5	4.1	26.5	195.0	6.5
	Bergena	82.1	4.4	24.2	255.0	5.5
	Leo	58.6	4.1	23.5	167.0	5.7
	Nimba	63.2	4.0	36.7	355.0	9.2
	Mean	67.9	4.1	27.7	243.0	6.7
Poa pratensis	Alicja	84.1	4.9	23.5	177.0	4.8
	Ani	93.7	5.4	48.6	282.0	9.0
	Chałupy	93.3	7.9	51.5	290.0	6.5
	Dresa	91.7	6.8	34.1	208.0	5.0
	Mean	90.7	6.3	39.4	239.3	6.3
Lolium perenne	KRH-22	84.8	3.0	10.1	205.0	3.3
	Nira	87.5	4.8	15.7	200.0	3.2
	Stadion	78.0	2.6	13.0	175.0	4.9
	Stoper	80.0	2.3	14.1	190.0	6.1
	Mean	82.6	3.1	13.3	192.5	4.3

Table 2

continued

Species (B)	Variety or strain (C)	Sward density [% of initial value]	Shoot dry weight [g per pot] — S	Root dry weight [g per pot] — R	Root volume (cm^3 per pot)	R : S
Sandy mixture (A)						
Festuca rubra	Adio	36.0	1.8	12.9	115.0	7.1
	Bergena	40.7	4.3	23.6	217.0	5.5
	Leo	25.1	1.8	9.9	135.0	5.5
	Nimba	23.8	2.1	9.5	105.0	4.5
	Mean	31.4	2.5	14.0	143.0	5.6
Poa pratensis	Alicja	29.5	3.8	27.0	175.0	7.1
	Ani	29.5	4.2	16.7	105.0	4.0
	Chałupy	24.8	3.0	7.2	70.0	2.4
	Dresa	30.9	3.8	29.0	530.0	7.6
	Mean	28.7	3.7	19.9	220.0	5.3
Lolium perenne	KRH-22	85.7	9.9	23.6	250.0	2.3
	Nira	66.1	4.6	24.6	330.0	5.4
	Stadion	60.8	11.2	26.2	260.0	2.2
	Stoper	68.3	4.3	7.0	95.0	1.6
	Mean	70.2	7.5	20.4	233.8	2.8
ANOVA results						
	A	***	—	**	—	—
	B	**	**	***	—	**
	C	—	—	—	—	—
	A × B	**	***	***	—	—
	A × C	—	—	—	—	—
	B × C	—	—	—	—	—
	A × B × C	—	—	—	—	—

significant: *** - p<0.01, ** - p<0.05, — no significance

Analysis of shoot and root dry weight taken after one year from seed sowing indicated significant effect of species and variety on shoot dry weight (Table 2). Soil mixture had no significant effect on both traits analyzed. In peaty and proportional mixture Kentucky bluegrass yielded higher while on sandy mixture – perennial ryegrass, especially 'Stadion' variety (11.2 g per pot). The lowest shoot dry weigh was noted for red fescue on sandy mixture. It is possible that results were also strongly affected by specific morphological traits of grasses, differentiated in respect on leaf blades dimensions as well as on the rate of it's lignifications (Falkowski 1982).

Significant differentiation of shoots dry weight was reflected in development of root dry weight. Statistical analysis on root dry weight made one year after seed sowing indicated the species effect on mentioned trait. The root dry weight ranged from the highest values recorded in peaty and proportional mixture for Kentucky bluegrass (33.6 and 39.4 grams per pot, respectively) to lowest values recorded for perennial ryegrass grown in peaty and proportional mixture (13.3 and 14.0 grams per pot, respectively) and for red fescue grown in sandy mixture (14.0 grams per pot).

It is also possible that dry weight of root system could be affected by the ability of tested species to soil penetration. As it was stated in literature, perennial ryegrass usually developed shallow root system (80% of root weight to 10 cm depth) and is therefore described as drought sensitive species. However, the major part of its root system may be developed in lower soil layers, which promotes grass regeneration especially in light soils (Jurek 1987, 1994, Rutkowska and Stypiński 2003). For comparison, Kentucky bluegrass and red fescue usually develop root system in upper soil layers (95% of root weight in 0-30 cm soil layer). Mentioned species are also able to develop rhizomes and stolons to distribute over space and to store nutrient reserves (DaCosta *et al.* 2004, Stewart *et al.* 2004). Above statement may explain obtained differences in root system dry weight. No significant differences for all tested varieties and breeding lines were noted for root volume and root :shoot ratio.

Analysis of grass growth during second year of vegetation indicated that aboveground weight growth proceed along with seasonal temperature changes, irrespective soil mixture type (Table 3). The highest, but not statistically significant, shoot dry weights were noted in peaty and proportional mixtures, while the lowest was for Kentucky bluegrass grown in sandy mixture. It has also been estimated that highest values of shoot dry weight were observed during full vegetation, except red fescue grown in peaty mixture. Values of shoot dry weight obtained at the beginning and at the end of vegetation were mostly similar or higher at the end of vegetation. Above results were similar to Rutkowska and Hempel (1986) statement that grass growth is higher when air temperature ranges from 15 to 25°C, provided the optimal soil moisture and fertility levels. However, it should be also noted for few of tested varieties and breeding lines (e.g. red fescue variety Leo) the continuous increase of shoot dry weight during vegetation season, irrespective soil mixture type.

Root dry weight analysis indicated that it was significantly affected by soil mixture type at spring (Table 4). The highest values of root dry weight were noted for red fescue and Kentucky bluegrass grown in peaty and proportional mixtures and for perennial ryegrass grown in proportional and sandy mixtures. On the basis of measurements taken in May, August and October the highest values of root dry weight were noted in May. It was than significantly lowered in August and turn back to value similar to spring in October. Above relations were frequently divergent that shows it, that at each of soil mixture same species and varieties or breeding lines may develop different root systems. Such root systems may adopt in its specific way to changing climatic and soil conditions. Similar relations were also noted for root volume.

Table 3

Shoot dry weight (gram per pot) and root: shoot ratio for grass varieties and breeding lines grown in different soil mixtures collected in different parts of vegetation period

Species (B)	Variety or strain (C)	Shoot dry weight [g/pot]				R÷S			
		Collecting time – stage of vegetation							
		Start	Full	End	Mean	Start	Ful	End	Mean
Peaty mixture (A)									
Festuca rubra	Adio	6.9	11.7	9.3	9.3	5.5	1.7	1.7	3.0
	Bergena	6.9	9.4	11.0	9.1	4.9	2.3	3.6	3.6
	Leo	5.7	7.3	16.2	9.7	4.6	1.5	2.3	2.8
	Nimba	6.9	10.5	13.9	10.4	4.1	2.0	1.6	2.6
	Mean	6.6	9.7	12.6	9.6	4.8	1.9	2.3	3.0
Poa pratensis	Alicja	6.1	8.0	5.5	6.5	3.6	2.7	4.7	3.7
	Ani	7.0	9.5	5.9	7.5	4.9	1.5	4.0	3.5
	Chałupy	6.5	15.1	11.3	11.0	5.9	2.0	2.2	3.4
	Dresa	8.2	12.5	8.4	9.7	5.4	2.1	2.8	3.4
	Mean	7.0	11.3	7.8	8.7	5.0	2.1	3.4	3.5
Lolium perenne	KRH-22	3.9	15.4	8.6	9.3	1.8	0.6	1.7	1.4
	Nira	4.1	14.4	5.8	8.1	1.6	1.2	2.1	1.6
	Stadion	4.6	11.9	8.1	8.2	1.4	0.5	1.2	1.0
	Stoper	4.9	11.6	9.2	8.6	2.0	0.8	1.3	1.4
	Mean	4.4	13.3	7.9	8.5	1.7	0.8	1.6	1.4
Proporcjonal mixture (A)									
Festuca rubra	Adio	4.5	6.5	6.6	5.8	8.2	1.3	2.3	3.9
	Bergena	5.5	10.9	10.0	8.8	3.5	3.0	2.9	3.1
	Leo	5.4	6.5	7.0	6.3	4.5	1.7	2.1	2.8
	Nimba	4.6	11.9	10.3	8.9	4.0	2.6	1.9	2.8
	Mean	5.0	8.9	8.5	7.5	5.0	2.2	2.3	3.2
Poa pratensis	Alicja	7.6	9.7	3.4	6.9	3.2	4.8	8.0	5.3
	Ani	6.3	9.4	10.3	8.6	7.6	2.9	5.0	5.2
	Chałupy	4.0	16.1	7.0	9.0	8.5	1.7	4.9	5.0
	Dresa	7.5	7.7	6.6	7.3	7.5	2.0	5.2	4.9
	Mean	6.4	10.7	6.8	8.0	6.7	2.8	5.8	5.1
Lolium perenne	KRH-22	11.7	7.9	2.7	7.4	2.3	0.5	1.9	1.6
	Nira	8.3	14.4	5.8	9.5	1.5	0.9	3.3	1.9
	Stadion	9.8	10.0	9.3	9.7	1.8	0.9	0.9	1.2
	Stoper	5.1	13.4	4.1	7.5	3.0	0.7	1.9	1.9
	Mean	8.7	11.4	5.5	8.5	2.1	0.8	2.0	1.6

Table 3

continued

Species (B)	Variety or strain (C)	Shoot dry weight [g/pot]				R : S			
		Collecting time – stage of vegetation							
		Start	Full	End	Mean	Start	Full	End	Mean
Sandy mixture (A)									
Festuca rubra	Adio	3.0	11.5	9.5	8.0	8.5	2.0	1.4	4.0
	Bergena	5.8	10.4	6.1	7.4	2.9	4.8	2.9	3.5
	Leo	5.4	9.8	10.1	8.5	2.6	2.4	1.4	2.1
	Nimba	4.1	10.4	7.3	7.2	3.3	2.5	2.4	2.7
	Mean	4.6	10.5	8.2	7.8	4.3	2.9	2.0	3.1
Poa pratensis	Alicja	2.5	5.6	2.9	3.7	2.3	1.7	11.3	5.1
	Ani	2.5	6.1	2.4	3.7	7.3	2.1	13.8	7.7
	Chałupy	3.5	8.4	4.8	5.6	1.5	1.5	2.6	1.9
	Dresa	4.8	7.8	3.2	5.3	4.1	1.6	2.3	2.6
	Mean	3.3	7.0	3.3	4.6	3.8	1.7	7.5	4.3
Lolium perenne	KRH-22	14.3	11.5	2.5	9.4	0.8	0.7	3.1	1.5
	Nira	4.5	16.2	4.3	8.3	2.3	1.1	3.4	2.3
	Stadion	5.1	13.3	8.2	8.9	1.3	1.0	1.0	1.1
	Stoper	5.4	7.7	3.6	5.6	2.4	0.2	2.0	1.5
	Mean	7.3	12.2	4.6	8.0	1.7	0.8	2.4	1.6
ANOVA results									
	A	—	—	***	***	—	—	—	—
	B	—	**	***	**	**	**	**	**
	C	—	—	—	**	—	—	—	—
	A × B	**	—	—	**	—	—	—	—
	B × C	—	—	—	—	—	—	—	—
	A × C	—	—	—	—	—	—	—	—
	A × B × C	—	—	—	—	—	—	—	—

significant: *** - p<0.01, ** - p<0.05, — no significance

Table 4

Root dry weight and volume for grass varieties and breeding lines in different soil mixtures collected in different parts of vegetation period

Species (B)	Variety or strain (C)	Root dry weight [g per pot]				Root volume [cm^3 per pot]			
		Collecting time - vegetation stage							
		Start	Full	End	Mean	Start	Full	End	Mean
Peaty mixture (A)									
Festuca rubra	Adio	38.1	19.9	16.2	24.7	235.0	123.0	100.0	152.7
	Bergena	33.3	21.6	39.2	31.4	327.0	212.0	385.0	308.0
	Leo	26.5	10.6	36.7	24.6	225.0	90.0	310.0	208.3
	Nimba	28.3	21.4	22.4	24.0	265.0	201.0	210.0	225.3
	Mean	31.5	18.4	28.6	26.2	263.0	156.5	251.3	223.6
Poa pratensis	Alicja	22.2	21.4	26.0	23.2	170.0	165.0	200.0	178.3
	Ani	34.4	13.9	23.5	23.9	280.0	115.0	192.0	195.7
	Chałupy	38.4	29.8	25.3	31.2	305.0	235.0	200.0	246.7
	Dresa	44.1	26.8	23.4	31.4	280.0	172.0	150.0	200.7
	Mean	34.8	23.0	24.6	27.4	258.8	171.8	185.5	205.3
Lolium perenne	KRH-22	7.2	9.8	15.1	10.7	95.0	130.0	200.0	141.7
	Nira	6.8	17.3	11.4	11.8	106.0	270.0	180.0	185.3
	Stadion	6.2	6.3	10.0	7.5	56.0	145.0	100.0	100.3
	Stoper	9.7	9.4	11.8	10.3	125.0	120.0	150.0	131.7
	Mean	7.5	10.7	12.1	10.1	95.5	166.3	157.5	139.8
Proporcjonal mixture (A)									
Festuca rubra	Adio	37.1	8.5	15.0	20.2	272.0	62.0	110.0	148.0
	Bergena	19.0	32.7	29.5	27.1	200.0	345.0	310.0	285.0
	Leo	24.1	11.5	14.8	16.8	170.0	80.0	105.0	118.3
	Nimba	18.4	31.1	20.2	23.2	177.0	300.0	195.0	224.0
	Mean	24.7	20.9	19.9	21.8	204.8	196.8	180.0	193.8
Poa pratensis	Alicja	24.4	46.2	27.4	32.7	182.0	345.0	205.0	244.0
	Ani	47.9	27.0	51.7	42.2	280.0	160.0	300.0	246.7
	Chałupy	33.9	26.7	36.4	32.4	190.0	150.0	205.0	181.7
	Dresa	56.7	15.6	34.4	35.6	345.0	95.0	210.0	216.7
	Mean	40.7	28.9	37.5	35.7	249.3	187.5	230.0	222.3
Lolium perenne	KRH-22	27.0	4.2	5.3	12.2	530.0	85.0	105.0	240.0
	Nira	12.0	12.3	19.5	14.6	150.0	155.0	245.0	183.3
	Stadion	18.1	8.6	8.2	11.6	242.0	115.0	110.0	155.7
	Stoper	15.1	9.9	7.6	10.9	204.0	135.0	102.0	147.0
	Mean	18.0	8.8	10.2	12.3	281.5	122.5	140.5	181.5

Table 4

continued

Species (B)	Variety or strain (C)	Root dry weight [g per pot]				Root volume [cm^3 per pot]			
		Collecting time - vegetation stage							
		Start	Full	End	Mean	Start	Full	End	Mean
		Sandy mixture (A)							
Festuca rubra	Adio	25.4	23.4	13.5	20.8	225.0	207.0	120.0	184.0
	Bergena	16.6	49.7	17.4	27.9	152.0	460.0	160.0	257.3
	Leo	13.9	23.6	14.1	17.2	188.0	320.0	190.0	232.7
	Nimba	13.5	25.5	17.8	18.9	150.0	280.0	195.0	208.3
	Mean	17.3	30.6	15.7	21.2	178.8	316.8	166.3	220.6
Poa pratensis	Alicja	5.6	9.8	33.0	16.1	40.0	65.0	215.0	106.7
	Ani	18.5	12.6	33.1	21.4	115.0	80.0	205.0	133.3
	Chałupy	5.2	12.3	12.5	10.0	47.0	113.0	115.0	91.7
	Dresa	19.6	12.1	7.5	13.1	355.0	220.0	135.0	236.7
	Mean	12.2	11.7	21.5	15.1	139.3	119.5	167.5	142.1
Lolium perenne	KRH-22	10.9	8.4	7.6	9.0	115.0	90.0	80.0	95.0
	Nira	10.3	18.3	14.6	14.4	137.0	245.0	195.0	192.3
	Stadion	6.8	13.6	8.1	9.5	67.0	135.0	80.0	94.0
	Stoper	13.0	12.0	7.2	10.7	172.0	160.0	95.0	142.3
	Mean	10.3	10.6	9.4	10.1	122.8	157.5	112.5	130.9
		ANOVA results							
	A	***	—	—	***	**	—	—	—
	B	***	***	***	***	—	—	—	**
	C	—	—	—	***	—	—	—	—
	A × B	**	**	**	***	—	—	—	—
	B × C	—	—	—	—	—	—	—	—
	A × C	—	—	—	—	—	—	—	—
	A × B × C	—	—	—	—	—	—	—	—

significant: *** - p<0.01, ** - p<0.05, — no significance

Mutual dependences of grass root system growth and shoot regrowth were well illustrated by root:shoot ratio on Fig. 1. Above ratio subjected seasonal fluctuations with highest values noted at spring. High spring root **:** shoot value could be an effect of autumn and winter root growth, when usually no or only minor aboveground growth activity is noted.

According to our observations, root:shoot ratio changed from high spring value, low summer value to high autumn value. The highest seasonal differentiation of root:shoot ratio was noted for Kentucky bluegrass grown in peaty and proportional mixtures, but no differences were found for tested species in sandy mixture. Therefore it can be concluded that seasonal changes in root:shoot ration values were mostly dependent on changes in shoot dry weight.

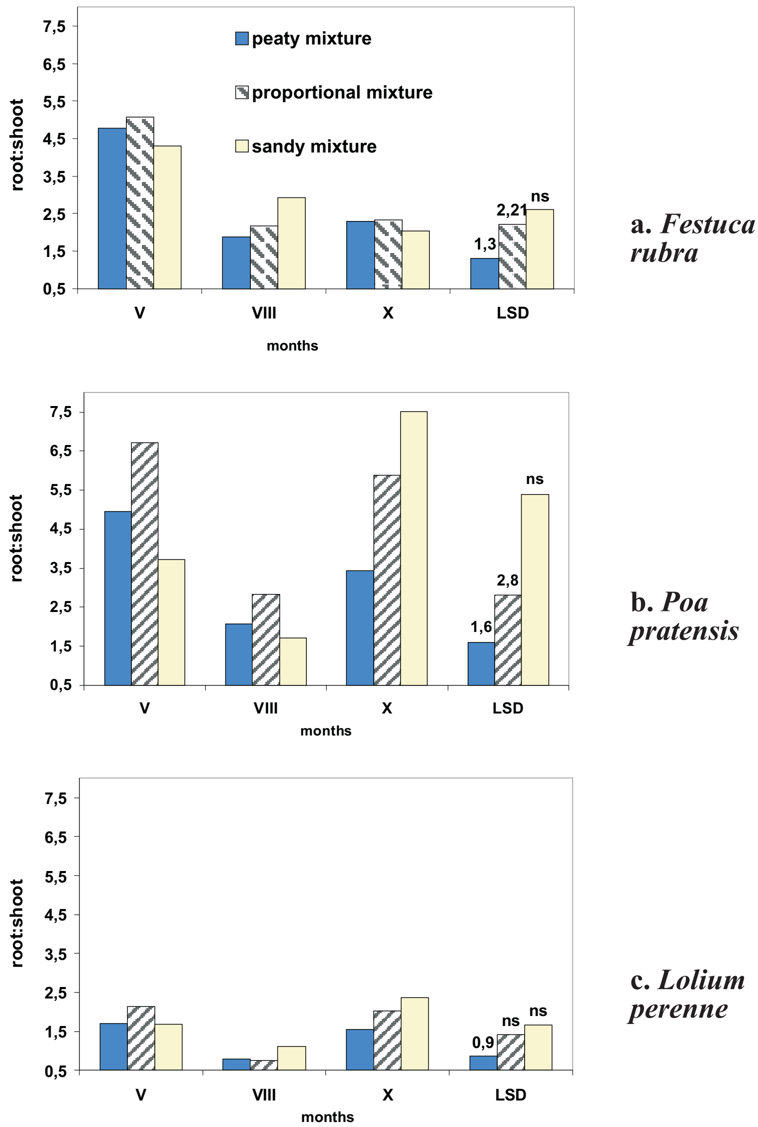

Fig. 1. Seasonal changes of root **:** shoot ratio in different soil mixtures

It is claimed that seasonal variations in root system development are derivatives of seasonal changes in soil moisture in moderate climate (Petrovic, 1995; Stetson and Sullivan 1999). That is probably the reason why only small changes of seasonal root:shoot ratio were noted in soil mixture of poor moisture capacity (i.e. sandy mixture). Despite of additional watering, total volume of water available for plants was low, and therefore the period when plants suffer from water deficit was extended, as compared to other mixtures used.

Very fast wilting of perennial ryegrass during simulated drought was probably due to low root weight and low root:shoot ratio, as compared to Kentucky bluegrass and red fescue (Żurek 2006).

When taking soil moisture into account, growth of root:shoot ratio values along with decreasing soil moisture could be noticed in August (for red fescue) and in October (for Kentucky bluegrass and perennial ryegrass). Such reaction indicate some evolutionary developed adaptive mechanisms in red fescue, similar to f.e. *Trichloris crinita*, Argentinian pasture grass (Greco and Cavagnaro, 2003). Along with increasing temperature and increasing probability of summer drought occurrence, red fescue plants decrease aboveground weight together with an increase of root growth production. That is probably the reason why condition of red fescue sward was the least dependent on soil moisture, as compared to Kentucky bluegrass and perennial ryegrass (Żurek 2006). An increase of root:shoot ratio is an element of plant drought resistance strategy known as *drought avoidance* (Beard 1989; Chaves *et al.* 2003). The effects of root:shoot ratio decrease are: reduction of water loose from plant (by closing of stomata, old leaves shedding, growth reduction etc.) and increase of water absorbing root area (Chaves *et al.* 2003). It is explained through different shoot and root sensitivity to ABA acid and better osmotic adjustment in roots than in shoots (Huang and Fry 1998). Root:shoot ratio is also affected by soil type, competitive ability of other plants or water availability (Dittmer 1973).

Root:shoot ratio increase along with decrease of soil moisture availability was noted for Kentucky bluegrass and perennial ryegrass in October. As it was explained by Żurek (2006) sward condition of mentioned species is related much stronger to soil moisture than of red fescue. Autumn root:shoot ratio increase along with soil moisture decrease is probably due to intensive belowground growth with reduced aboveground growth.

CONCLUSIONS

The growth dynamic of turf grass varieties and breeding lines used in above experiment depends on physical and chemical soil properties.

Turf grass regeneration after simulated drought was different accordingly to soil mixtures used. In peaty mixture regeneration was good and similar to all species, but in proportional mixture it was better for Kentucky bluegrass and in sandy mixture – for perennial ryegrass than for other species, respectively.

Turf grass regeneration after drought in different soil conditions was affected by the ability to develop specific root system.

Despite the soil mixture, red fescue and Kentucky bluegrass developed root system of high dry weight values along with low values of shoot dry weight, as contrary to perennial ryegrass, which developed root system of low dry weight along with high shoot dry weight values.

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