The effect of light availability on leaf area index, biomass production and plant species composition of park grasslands in Warsaw

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ABSTRACT

How light conditions affect development of park grasslands is a question that has not been satisfactory addressed. The aim of this study was therefore determination of the level to which unfavorable light conditions influence grassy parks area and relationships between parameters which determine state of turf grasses. Researches were conducted in two parks in Warsaw, in various light conditions and included measurement of: leaf density, sward height, leaf area index (LAI), and botanical composition of the communities. The leaf density of shaded areas did not exceed 70%. LAI value varied from 0.5 to 0.9-fold lower than in the areas in half-shade and in sun. The participation of basic lawn species at Skaryszewski Park was higher under shade, while at Łazienki Królewskie was higher in full-sunlight areas. The state of tested grassy areas in limited solar radiation does not satisfy the requirements of recreational and representational functions. The development processes of vegetation coverage were inhibited at the sites of lower solar radiation. LAI was influenced by both leaf coverage and sward height. *Agrostis stolonifera* and *Poa trivialis* may be recommended to create grass areas under limited solar radiation.

Keywords: green infrastructure; park habitat conditions; urban green area; environmental improvement; leaf density of sward

Park grass communities have many functions in urban areas (Potchter et al. 2006, Tlustoš et al. 2006, Godefroid et al. 2007). To obtain park areas with high quality is particularly difficult task, mainly due to the variation in light conditions. One of the main responses of plant growing in limited access to light is to create the elongated tills and less leaf coverage and amount of shoots per area (Cavagnaro et al. 2007). Leaf area index (LAI) is one of the most important of plant canopy parameters (Yang et al. 2012). Unfortunately, at the moment there is no literature for the use of LAI ratio as an indicator for assessing the degradation degree of grassland in urban parks. There are also no studies considering relationships of this parameter with others and also defining state of park grasslands, such as leaf density per area or shoot high. So far, park lawns were rarely studied ecosystems (Bertoncini et al. 2012). The aim of this study was to answer following research questions: (1) How do unfavorable light conditions influence the development of the grassy parks area with decorative and recreational functions?; (2) Is there any correlation between LAI and leaf coverage and sward height?, and (3) Which species could be most recommended for renovation of grassy areas?

MATERIAL AND METHODS

The grassy areas located in Museum Łazienki Królewskie (52°12'N, 21°1'E) and Skaryszewski

Park (52°25'N, 21°15'E) was the chosen location for this study. The research was conducted in period 2010–2012 in 3 research sites: shaded by trees, half shade, and in sun. Single plot area was equal to 1 m^2 (Table 1). The total incoming radiation to the surface of grass communities was measured by use of the solar meter TM 206 device (Tenmars, Inc. Taipei, Taiwan). Measurements were made 3 times a day, once a month throughout growth season. Soil moisture was defined by a time domine reflectometry (TDR) technique; in each plot 3 measurements were made. Chemical soil properties were performed according to standards (PN-R-04031). Plant available P and K concentrations were performed by the Egner-Riehm method. The results were assessed on the basis of the numbers contained in Polish standards for mineral soils (PN-R-04022, PN-R-04023). All plots characterized with a neutral or slightly acidic reaction. Soil characterized with high abundance of digestible form for plant of potassium but low abundance of digestible form of phosphorus. Total nitrogen content was within the norms prescribed for minerals soils.

The following measurement were performed periodically (every month during growth season): leaf coverage of sward area (percentage cover of leaves, three replicates per treatment were made), sward height (main from 3 points of the plot before cut), leaf area index (measured in 5 replicates by use of the SunScan analysis system (Delta-T Device, Ltd. Cambridge, UK) with light sensitive 'wand'), the surface weight of cut sward dry matter (over 3 cm) and its botanical composition by botanical-weight analyses performed three times during growing seasons: May, July and September.

Collected data were evaluated by the ANOVA model and by the Fischer' test as a post hoc at a 0.05 confidence level. All analyses were performed in Statistica 10.0 program (StatSoft, Inc. Tulsa, USA).

RESULTS AND DISCUSSION

The light conditions significantly affected leaves coverage of lawns in analyzed parks (Table 2). The leaves coverage in shady conditions was similar during the whole study period and was equal to 63% in Łazienki Królewskie and 71% in Skaryszewski Park. This parameter was much higher under partial shading conditions (82–88%). Even better leaves coverage (95–98%) was found on the lawn in full sun. Many authors reported that plant growing in a limited access to light formed longer but

Table 1. Characteristics of the habitat research sites

	Łazienki Królewskie			Skaryszewski Park		
	shade	half-shade	sun	shade	half-shade	sun
GPS localization	35.8099''N, 16.3472''E	29.3795''N, 39.2822''E	28,4748''N, 38.8090''E	35.8099''N, 16.8493''E	36.6678''N, 15.6327''E	59687''N, 34721''E
Total irradiance (W/m^2)						
Spring	163	230	507	171	373	499
Summer	127	199	564	137	149	530
Autumn	62	99	371	64	127	325
Soil moisture (%)						
Spring	25	27	28	25	28	32
Summer	24	35	29	23	27	29
Autumn	18	25	26	15	24	26
Chemical properties of soils						
pH_{KCL}	7.2	7.3	7.4	6.4	6.4	6.3
N (%)	0.339	0.441	0.460	0.281	0.297	0.310
P (mg × 100 g DM)	4.7	4.3	4.7	3.9	4.6	3.7
K (mg × 100 g DM)	25.7	12.0	12.1	18.8	24.7	25.2

Table 2. The leaves coverage and sward height at research areas ± SD

	Łazienki Królewskie			Skaryszewski Park		
	shade	half-shade	sun	shade	half-shade	sun
Leaves coverage on research areas (%)						
Spring	62 ± 8^{a}	86 ± 5^{b}	98 ± 2^{c}	69 ± 4^{a}	86 ± 4^{b}	97 ± 2^{c}
Summer	63 ± 8^{a}	87 ± 5^{b}	98 ± 2^{c}	68 ± 2^{a}	87 ± 4^{b}	97 ± 2^{c}
Fall	63 ± 2^{a}	85 ± 3^{b}	95 ± 2^{c}	72 ± 3^{a}	87 ± 4^{b}	98 ± 2^{c}
Sward height (mm)						
May	73 ± 9^{a}	107 ± 9^{b}	113 ± 6^{b}	83 ± 7^{a}	117 ± 6^{b}	136 ± 8^{c}
June	102 ± 8^{a}	116 ± 8^{a}	120 ± 7^{b}	102 ± 9^{a}	124 ± 5^{b}	144 ± 4^{c}
July	102 ± 5^{a}	117 ± 8^{b}	126 ± 7^{c}	105 ± 7^{a}	134 ± 5^{b}	153 ± 6^{c}
August	95 ± 10^{a}	120 ± 7^{b}	119 ± 9^{b}	105 ± 9	142 ± 8^{b}	144 ± 6^{b}
September	94 ± 6^{a}	104 ± 5^{b}	108 ± 8^{b}	102 ± 5^{a}	124 ± 5^{b}	137 ± 5^{c}
October	93 ± 10^{a}	98 ± 9^{ab}	104 ± 5^{b}	93 ± 10^{a}	116 ± 5^{b}	126 ± 6^{c}

The average for the 2010–2012 period. The means for each park in a season marked by the same letter do not differ significantly

fewer shoots and had less developed root systems (Repková et al. 2009, Xu et al. 2010).

In May, plant regrowth was considerably slower in shaded areas than in partial shade and in sun. The range of sward height in shade was on average by 30% lower than in half shade and by 37% lower than in full sun. In the next part of growth season, differences between height of sward growing in shade and in sunlight were lower. In Skaryszewski Park, height of sward amounted to respectively 21% and 28%, and in Łazienki Królewskie – to 13% and 25%. In Skaryszewski Park significant differences in sward height in half shade and in full sun throughout the growing season were also found, while in Łazienki Królewskie they were observed only in June and July (Table 2). These results support those obtained by Vargas et al. (2002).

In Łazienki Królewskie, under shade, LAI values varied from 0.6 to 0.9 (Figure 1); in half-shade they varied from 1.2 to 1.9; LAI highest values were found under sun (2 to 2.8). Significant differences between sun and half-shade were observed from July and between sun and shade were throughout the season. Trend of variability was well accentuated within the growing season under sun. In Skaryszewski Park it was also found that the lowest

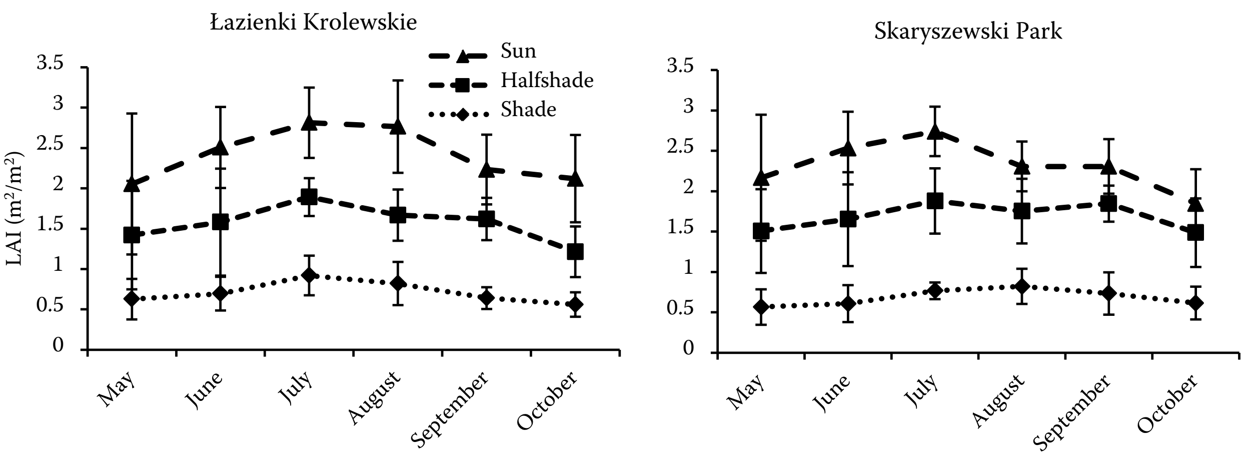

Figure 1. The relationship between the leaf area index (LAI) ratio and the light conditions during the growing season. The averages for 2010–2011 period

Table 3. The botanical composition and aboveground biomass of sward (% dry matter) ± SD

Species	Łazienki Królewskie Park								
	shade			half-shade			sun		
	spring	summer	autumn	spring	summer	autumn	spring	summer	autumn
Lolium perenne	13.9 ± 4.1[a]	0.7 ± 0.1[a]	22.8 ± 6.1[a]	0	0	0.6 ± 0.1[b]	0.1 ± 0[b]	0.3 ± 0[b]	0
Festuca rubra	4.2 ± 1.6[a]	1.4 ± 0.3[a]	11.1 ± 2.8[a]	0	0	1.1 ± 0.3[b]	0	0.1 ± 0[b]	0
Poa pratensis	5.3 ± 0.8[a]	4.0 ± 0.5[a]	4.3 ± 1.0[a]	10.0 ± 4.2[b]	5.5 ± 2.3[a]	1.0 ± 0.3[b]	20.9 ± 5.8[c]	3.3 ± 0.2[a]	24.9 ± 6.1[c]
Poa trivialis	23.1 ± 6.1[a]	20.1 ± 4.3[a]	36 ± 8.1[a]	15.6 ± 4.2[b]	46.3 ± 10.8[b]	12.5 ± 10.2[b]	5.1 ± 0.7[c]	1.5 ± 0.4[c]	5.6 ± 1.2[b]
Poa annua	4.3 ± 0.3[a]	0	0.9 ± 0.1[a]	1.1 ± 0.2[b]	6.1 ± 0.7[b]	3.6 ± 0.7[b]	13.8 ± 4.7[c]	2.4 ± 0.2[c]	16.0 ± 3.9[c]
Agrostis stolonifera	2.4 ± 1.2[a]	55.3 ± 10.6[a]	0.3 ± 0.1[a]	27.2 ± 8.4[b]	12.3 ± 3.2[b]	53.2 ± 12.9[b]	5.0 ± 2.4[a]	70.1 ± 20.1[c]	8.0 ± 1.9[c]
Grasses total	53.2	81.5	75.4	53.9	70.2	72	44.9	77.7	54.5
Taraxacum officin.	16.1 ± 2.8[a]	1.9 ± 0.3[a]	0.7 ± 0.4	2.3 ± 0.4[b]	1.9 ± 0.2[a]	3.7 ± 0.6	0.3 ± 0.1[c]	0[b]	+
Bellis perennis	3.9 ± 0.8[a]	0.3 ± 0.1[a]	12.7 ± 3.6[a]	35.2 ± 8.1[b]	3.6 ± 0.6[a]	1.1 ± 0.2[b]	1.7 ± 0.4[a]	0.9 ± 0.5[a]	18.3 ± 7.3[c]
Plantago major	0	0	0	0.4 ± 0.1	15.1 ± 2.8[a]	0	0	3.8 ± 0.5[b]	0.4 ± 0.1
Forbs total	20.0	1.2	13.4	37.9	20.6	4.8	2.0	4.7	18.7
Trifolium repens	0	3.6 ± 1.0[a]	9.0 ± 3.8[a]	1.4 ± 0.5[a]	2.4 ± 0.8[a]	9.8 ± 3.1[a]	42.7 ± 16.7[b]	14.2 ± 5.1[b]	23.7 ± 8.3[b]
Others less than 5%	26.8 ± 10.1	12.7 ± 3.1	2.2 ± 0.4	6.8 ± 0.3	6.8 ± 0.5	13.4 ± 5.6	10.4 ± 3.9	3.4 ± 0.7	3.1 ± 0.8
Total	100	100	100	100	100	100	100	100	100
Aboveground biomass (g DM/m^2)	11.2 ± 2.4[a]	12 ± 11.2[a]	7.7 ± 2.7[a]	14.5 ± 5.7[a]	27.3 ± 7.9[b]	17.5 ± 0.8[a]	27.1 ± 8.1[b]	20.2 ± 3.9[b]	26.6 ± 8.8[b]

Averages for the 2011–2012 period. The means (within each light condition) marked by the same letter do not differ significantly

LAI values were measured in the shade (0.6 to 0.8), additionally in this positions seasonal changes were not observed. In half-shade they ranged from 0.8 to 1.9. The significantly highest values of LAI were measured in full light conditions (1.8 to 2.8). The changes of LAI during the growing season were also observed by many authors. Vargas et al. (2002) concluded that the reduction of LAI was observed at the end of August. Li et al. (2010) concluded that LAI initially increased with increasing shading, but decreased rapidly with time. Research conducted by Lambert et al. (1999) showed a significant increase in LAI grassland during one spring month. Authors correlated this phenomenon with nutrient level and water supply (in spring time, they were close to optimum), but our research shown that biomass did not developed properly in unfavorable light conditions.

In Łazienki Królewskie the correlation coefficient between LAI and leaves coverage was 0.91, and between LAI and sward height it was equal to 0.84. In Skaryszewski Park the correlation coefficient between LAI and leaves coverage was equal to 0.94 and, between LAI and sward height it was equal to 0.95. According to Lambert et al. (1999) and Ramirez-Garcia et al. (2012) LAI value for vascular plant species could be affected by: number of tillers, number of leaves per tiller and average area of leaves.

The impact of the solar radiation incoming to grass communities depends on the part of season (Tables 3 and 4). In Łazienki Królewskie in spring the masses of sward growing under shade and half-shade were similar, but in full sun it was twice higher. The largest biomass of sward in summer was in half-shade. It was twice as high as in the shade and full sun. In autumn, most sunny surfaces characterized themselves by higher biomass, but mass growing in partial shade was significantly higher than in the shade. In Skaryszewski Park,

Table 4. The botanical composition and aboveground mass of sward (% dry matter) ± SD

Species	Skaryszewski Park								
	shade			half-shade			sun		
	spring	summer	autumn	spring	summer	autumn	spring	summer	autumn
Lolium perenne	0	3.7 ± 1.6[a]	0	9.2 ± 2.6[b]	7.5 ± 3.8[a]	16.5 ± 4.3[a]	16.1 ± 4.9[c]	15.3 ± 6.8[b]	12.9 ± 4.7[a]
Festuca rubra	0	0	0	0	0.1 ± 0[a]	0	0.5 ± 0.2	0.2 ± 0.1[a]	12.0 ± 5.5
Poa pratensis	22.1 ± 8.6[a]	43.2 ± 20.1[a]	31.4 ± 10.6[a]	3.2 ± 1.5[b]	2.0 ± 0.4[b]	4.2 ± 2.8[b]	2.4 ± 1.8[b]	5.7 ± 1.4[c]	1.8 ± 0.4[b]
Poa trivialis	26.9 ± 11.8[a]	13.4 ± 3.1[a]	35.1 ± 5.7[a]	9.3 ± 3.7[b]	13.4 ± 4.5[a]	17.2 ± 6.2[b]	28.8 ± 9.8[a]	13.4 ± 2.3[a]	16.2 ± 4.2[b]
Poa annua	11.7 ± 5.6[a]	1.9 ± 0.1[a]	2.2 ± 0.8[a]	56.7 ± 15.6[b]	13.3 ± 5.2[b]	0.7 ± 0.3[a]	3.6 ± 0.5[c]	0.1 ± 0[c]	+
Agrostis stolonifera	14.9 ± 4.2	18.0 ± 6.1	27.6 ± 4.8	3.3 ± 2.1	11.5 ± 4.3	23.9 ± 7.8	19.0 ± 13.8	31.7 ± 14.2	28.2 ± 13.3
Grasses total	77.6	80.2	96.3	81.7	45.8	46.0	70.4	31.7	42.9
Ranunculus repens	2.0 ± 0.4[a]	0	0.1 ± 0	2.9 ± 1.8[a]	14.4 ± 8[a]	6.2 ± 5.9	1.7 ± 0.8[a]	1.1 ± 0.5[b]	6.3 ± 2.8
Glechoma hederacea	4.5 ± 1.5[a]	10.9 ± 2.3[a]	0.8 ± 0.2[a]	1.9 ± 0.4[b]	1.5 ± 0.3[b]	0.3 ± 0.1[a]	0.6 ± 0.2[c]	0.2 ± 0.1[c]	0.5 ± 0.1[a]
Plantago major	1.3 ± 0.9[a]	0.6 ± 0.1[a]	0.2 ± 0.1[a]	3.1 ± 1.1[b]	12.2 ± 1.6[b]	8.6 ± 3.1[b]	4.4 ± 1.2[b]	0	1.1 ± 0.6[a]
Forbs total	7.8	11.5	1.1	7.2	28.1	15.1	6.7	1.3	7.9
Trifolium repens	0	0.2 ± 0.1[a]	0.2 ± 0.1[a]	+	12.1 ± 5.8[b]	11.8 ± 3.8[b]	4.7 ± 3.1	19.9 ± 7.4[b]	6.8 ± 2.4[c]
Others less than 5%	14.6 ± 4.2	8.1 ± 3.2	2.4 ± 0.5	10.4 ± 4.8	12 ± 2.4	10.6 ± 2.8	18.2 ± 6.8	12.4 ± 5.3	14.2 ± 8.8
Total	100	100	100	100	100	100	100	100	100
Aboveground biomass (g DM/m^2)	12.9 ± 3.9[a]	17.6 ± 11.1[a]	15.7 ± 14.3[a]	13.1 ± 3.4[a]	18.6 ± 10.3[a]	15.6 ± 8.6[a]	18.61 ± 6.2[a]	43.9 ± 12.3[b]	18.2 ± 10.4[a]

Averages for 2011–2012 period. The mean (within each light condition) marked by the same letter do not differ significantly

significant differences between the mass of the sward on areas with different treatment were observed only during the summer.

In Łazienki Królewskie the grasses of the great influence on sward were creeping species, such as: *Agrostis stolonifera* L., *Poa trivialis* L., *Poa pratensis* L., and *Lolium perenne* L. (Table 3). *Poa trivialis* grew most efficiently under full shade and half-shade. During spring and autumn, participation of this species on shaded areas was the greatest of all grasses – 26% on average. In half-shade *Poa trivialis* was the dominant species in summer. *Agrostis stolonifera* expanded most efficiently under half-shade and full sun. On half-shaded areas this species had the largest share in sward in spring (27%) and autumn (53%). *Agrostis stolonifera* greatest growth was noted under full sun conditions during summer time (70%) and shade (55%). *Poa pratensis* and *Poa annua* during spring and autumn grew best under full sun conditions. In the summer the shares of these species were low and did not depend on light conditions. *Lolium perenne* expanded the best in the shade during spring and autumn.

In Skaryszewski Park *Poa trivialis*, *Poa pratensis* and *Agrostis stolonifera* grew best under shade, especially during spring and autumn (Table 4). The share of these species was equal to almost 80% of sward. In half-shade in spring *Poa annua* dominated, but in the summer and autumn *Agrostis stolonifera* and *Poa trivialis* dominated. In full sun *Agrostis stolonifera* dominated in summer. *Poa trivialis* and *Lolium perenne* were also the species well developing in those conditions. On the shaded areas smaller density of leaves and the presence of species undesirable in recreation lawns were observed (Bertoncini et al. 2012). Research conducted at Warsaw lawns by Wysocki (1998) confirmed a significant share of monocotyledonous plants. *Festuca rubra*, *Lolium perenne* and *Poa pratensis* are characterized by high sward coverage. The share of *Poa trivialis* was insignificant.

In conclusion, the state of tested grassy areas under limited solar radiation in both parks does not satisfy the requirements of recreation and representational functions, mainly due to insufficient soil cover and small participation of mains species, such as *Lolium perenne*, *Poa pratensis* and *Festuca rubra.* There is a lot of factors, which can influence on grassy areas, such as fertilizer application (Hejcman et al. 2007). However, the nutrient content in the soil at all positions was similar. The development processes of vegetation coverage were stopped at the sites of lower solar radiation, which are evidenced by a decreasing in the LAI values and aboveground biomass. The high correlation coefficient between LAI and leaves coverage and between LAI and sward height were found in both parks. However, future researches should be extended to find out which of parameters of aboveground biomass affects value of the LAI. *Agrostis stolonifera* and *Poa travilis* may be recommended to create grass areas under limited solar radiation because of large participation of that species in sward under limited solar radiation.

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