The effect of UV-B radiation on plant growth and development

K. Zuk-Golaszewska[1], M.K. Upadhyaya[2], J. Golaszewski[1]

[1]University of Warmia and Mazury in Olsztyn, Poland
[2]University of British Columbia in Vancouver, Canada

ABSTRACT

In the experiment conducted in the greenhouse, the different doses of UV-B radiation applied to the two species *Avena fatua* and *Setaria viridis* induced changes in leaf and plant morphology. It was a decrease of plant height, fresh mass of leaves, shoots and roots as well as leaf area. Besides, it caused the leaf curling in both of the species. The significant differences between *Avena fatua* and *Setaria viridis* in the studied traits were mainly due to the tillering ability of the species. The content of chlorophyll varied considerably. The average values of leaf greenness (SPAD units) for oats were about 43 while for green foxtail 32, respectively. U-VB did not reduce leaf weight ratio, shoot dry matter, shoot to root ratio and leaf area ratio.

Keywords: UV-B radiation; *Avena fatua*, *Setaria viridis*

Different species have different response to the level of UV-B irradiation (Matthew et al. 1996, Skorska 1996a, b). In the study of Furness et al. (1999) vertical leaf orientation and a concealed terminal bud may protect *Tragopogon pratensis* dicot from UV-B radiation. On the other hand, in the case of *Cynoglossum officinale* with the creeping leaves habit and exposure of shoot terminals to radiation resulted in higher susceptibility to UV-B radiation. Cline and Salisbury (1966) proposed that monocots might be less affected by UV-C radiation than dicots because of their vertical leaf orientation, protective basal sheath, and concealed apical meristem.

The changes in plants morphology induced by UV-B may affect competition for light (Barnes et al. 1988). The negative effects of UV-B radiation results in deformed morphological parameters. Exposure to UV-B decreased plant height, leaf area and plant dry weight increased auxiliary branching and leaf curling (Dai et al. 1995, Greenberg et al.1997, Furness et al. 1999). Dai et al. (1995) reports that after a few weeks of UV-B exposure, leaf area and plant dry weight of rice were significantly reduced.

Weigh et al. (1998) stated that enhanced UV-A decreased leaf area per unit plant biomass (leaf area ratio) but increased biomass productivity both per unit leaf area (leaf area productivity) and per unit leaf nitrogen (leaf nitrogen productivity). High levels of UV-B clearly decreased the relative growth rate and nitrogen productivity, as leaf area ratio, leaf area productivity and leaf nitrogen productivity were all decreased.

The purpose of our study is (1) to assess the effect of UV-B radiation on some morphological and physiological traits of two different species *Avena fatua* and *Setaria viridis* and (2) to estimate the interaction species × different levels of UV-B radiation.

MATERIAL AND METHODS

This study consisted of two series of experiment with wild oats (*Avena fatua*) and green foxtail (*Setaria viridis*) separated in time. The experiments were carried out in a greenhouse at the University of British Columbia in Vancouver, Canada.

The factors of the experiment were two species of common weeds (factor I) – wild oats and green foxtail and different level of ultraviolet radiation (factor II): 0 UV-B (control), 4, 8, 12 kJ/m^2/d UV-B. The experiment was established by a random sub-blocks method at six replications (according to the methods proposed by Furness et al. 1999). Plants were grown in the UV-B chambers. The chambers (3) were constructed of metal frames. The frames were covered by sheets of Mylar film (Type D, O127 mm thin)[1], which prevent any UV-B radiation from escaping. At the top of each frame, six a bank of UV-B 313 40W fluorescent tubes[2] were installed. For each experiment, three doses of UV-B were administered to different groups of plants within each chamber. One, two and three layers of cellulose acetate film were placed over each flat of plants to control the amount of UV-B radiation reaching the plants. Cellulose acetate film absorbs all UV radiation below 320 and 290 nm, respectively (Barnes et al. 1988). UV-B radiation was measured using an International Light IL 1700 Radiometer[3]. An IL782A double-slit monochromator[3] was used to measure radiation at single-nanometer intervals between 290 and 350 nm. Biologically effective UV-B was calculated from these readings based on Caldwell's generalized plant damage action spectrum normalized to 300 nm. Integrated estimate of UV-B between 290 and 315 nm were measured with an International Light SED 240 Bulk Sensor[3]. Three layers were used to approxi-

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Figure 1. Effect of radiation on the plants of *Avena fatua* (from the left 0, 4, 8 and 12 kJ/m^2/d UV-B, respectively)

mate an ambient UV-B level (4 kJ/m^2/d) for outdoor growth, two layers gave a low dose (8 kJ/m^2/d) and one layer gave a high dose (12 kJ/m^2/d) above ambient level.

Temperature and humidity inside the greenhouse were partially controlled using computer system. The temperature averaged 22.6°C in March (20.3–24.4), 23.1°C in April (22.0–25.2), 24.4°C in May (22.2–24.4). Relative humidity averaged 38.7% in March (3.7–71.9), 23.1% in April (4.8–69.0), 37.6% in May (2.6–55.0). The seeds of *Avena fatua* and *Setaria viridis* were sown into the pots containing 70% peat moss – 20% perlite and 10% pasteurised mineral soil mixture and fertilizer added was osmocote 13-13-13 (slow release) + micronutrients. Pots were placed under different levels UV-B: 0 (control), 4, 8, 12 kJ/m^2/d UV-B, respectively, applied for 6 hours per day. After thinning, only the one healthy and most vigorous plant was left per pot (one plant in one pot). The plants received natural sunlight without any supplemental lighting and six hours UV-B radiation. The plants were watered every day. Against aphids, 5 mg Pirimor per 10 l of water per week was used.

In both experimental series the following observations were determined: number of leaves, tillering of plants recorded after three weeks and before harvest plant height, biomass of plants, specific leaf weights (leaf dry weight, leaf: shoot dry ratio, shoot dry matter), leaf area and content of chlorophyll. Leaf area was measured using a LI COR LI-3000[4] portable leaf area meter and the content of total chlorophyll was measured with a Minolta SPAD-502 meter[5]. The total chlorophyll content was measured every five days, beginning a week after germination until plant final harvest.

The results were statistically analysed with the use of the ANOVA method.

Figure 2. Effect of radiation on the plants *Setaria viridis* (from the left 0, 4, 8 and 12 kJ/m^2/d UV-B, respectively)

Table 1. Effect of UV-B radiation on development of *Avena fatua* and *Setaria viridis*

UV-B level	High of plant before harvest		Number of leaves per plant	
	I	II	I	II
		Avena fatua		
0	19.9	19.3	15.3	14.0
4	16.4	18.6	11.3	12.0
8	17.4	18.8	12.7	12.5
12	16.2	16.9	11.33	13.2
		Setaria viridis		
0	21.1	17.6	62.3	63.0
4	19.0	15.0	62.0	69.5
8	20.7	12.8	68.5	61.3
12	13.1	11.8	53.0	58.8
$LSD_{0.01}$ for species × UV-B	ns	2.84	ns	ns
		Mean for species		
Avena fatua	17.5	18.4	12.6	12.9
Setaria viridis	18.5	14.3	61.4	63.1
LSD for species	ns	1.42	7.89	11.32
		Mean for UV-B level		
0	20.5	18.4	38.8	38.5
4	17.7	16.8	36.6	40.7
8	19.0	15.8	40.6	36.9
12	14.6	14.3	32.1	36.0
LSD for UV-B	3.14	2.01	ns	ns

RESULTS AND DISCUSSION

The species *Avena fatua* and *Setaria viridis* grown in the greenhouse under the UV-B radiation had different growth habit and different reaction to UV-B radiation. The high level of irradiation caused leaf curling, especially at the *Setaria viridis* (Figures 1 and 2).

The mean plant height of *Avena fatua* and *Setaria viridis* was similar in the first experiment and in the second experiment the plants of *Avena fatua* were significantly higher than the plants of *Setaria viridis* (Table 1). It can be explained by different sunlight conditions in the two series of the experiment. Generally the subsequent levels of increased UV-B radiation delayed plant growth, at the same time in experiment I the differences in mean plant height at the 0, 4, 8 kJ/m^2/d UV-B radiation were non-significant (ns) and only for 12 kJ/m^2/d significant plant height reduction was noted. In the second experiment, harmful impact of UV-B radiation started at the lower level of UV-B radiation at 8 kJ/m^2/d.

The mean plant height of *Avena fatua* was the same irrespective of the UV-B radiation level while the plants of *Setaria viridis* were much more susceptible than *Avena fatua* to the UV-B radiation. It resulted in shorter plants at the levels of 8 and 12 kJ/m^2/d UV-B radiation. The species were also different in the number of leaves but this can be explained by natural interspecies differences. For that trait only a tendency of the number of

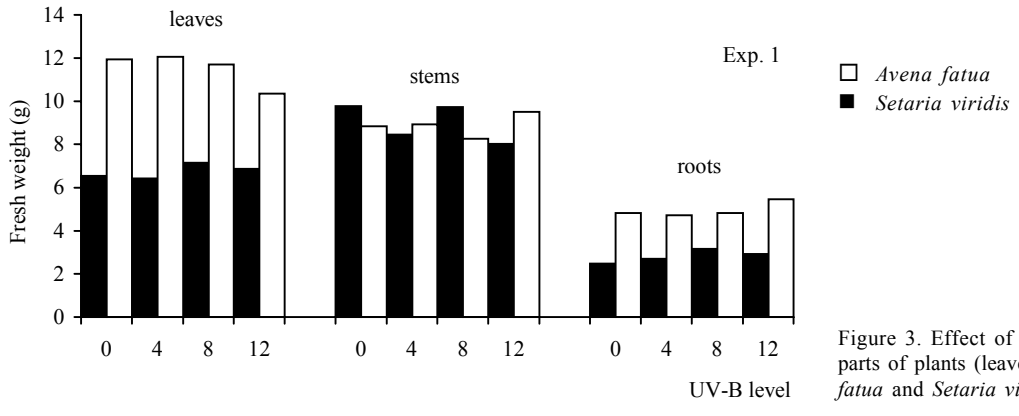

Figure 3. Effect of UV-B radiation on fresh parts of plants (leaves, stem and roots) *Avena fatua* and *Setaria viridis* (experiment I)

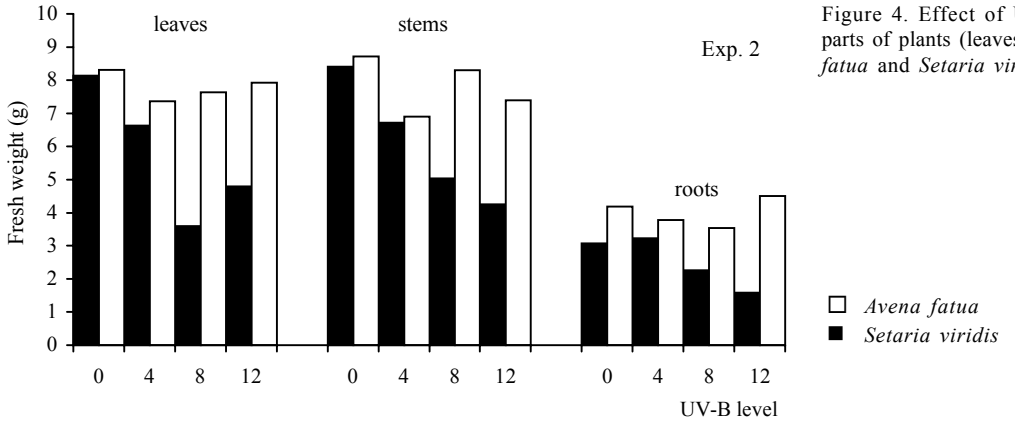

Figure 4. Effect of UV-B radiation on fresh parts of plants (leaves, stems and roots) A*vena fatua* and *Setaria viridis* (experiment II)

leaves reduction at the levels of 8, 12 kJ/m^2/d UV-B radiation was observed.

The differentiated levels of UV-B affected on fresh weight of leaves and stems (Figures 3 and 4). In experiment I, only the difference between them was highly significant. Fresh weight of leaves for *Avena fatua* was 11.51 g and 6.74 g for *Setaria viridis*, respectively. On the other hand, in experiment II the species showed a stronger reaction to increasing levels of UV-B radiation. A very distinguished tendency to the decrease of leaves fresh weight for the following levels of UV-B radiation. In comparison with the control, the fresh mass reduction was 15% at the 4 kJ/m^2/d, 31.4% at the 8 kJ/m^2/d and 22.6% for 12 kJ/m^2/d. Similar reaction of plants as for leaves fresh weight was observed for shoot fresh weight. In experiment I, the level of UV-B radiation did not differentiate that trait whereas in experiment II the species were strongly affected by UV-B radiation. For the highest level the shoot, fresh weight reduction was 32.1% as against the control. The different effects in the fresh weight of leaves and shoots for the subsequent experiments were affected ambient by isolation, generally higher in the experiment I. The fresh weight of roots though varied between species and showed no reaction to UV-B radiation. Tillering of plants measured periodically was closely connected with the interspecies differences (Figure 5). The tillering value for *Avena fatua* ranged between 1.7% and 9.3% for *Setaria viridis*, respectively. The results confirmed the earlier studies by Barness et al. (1988), Greenberg et al. (1997) and Furness et al. (1999). They reported the distinguished changes in the morphological traits such as the plant height and the leaf area reduction and the curling of leaves.

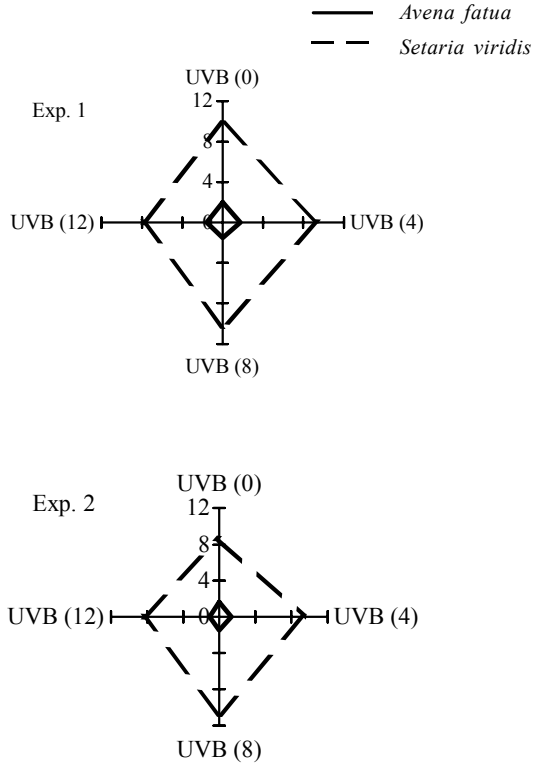

Figure 5. Effect of UV-B radiation on plant tillering

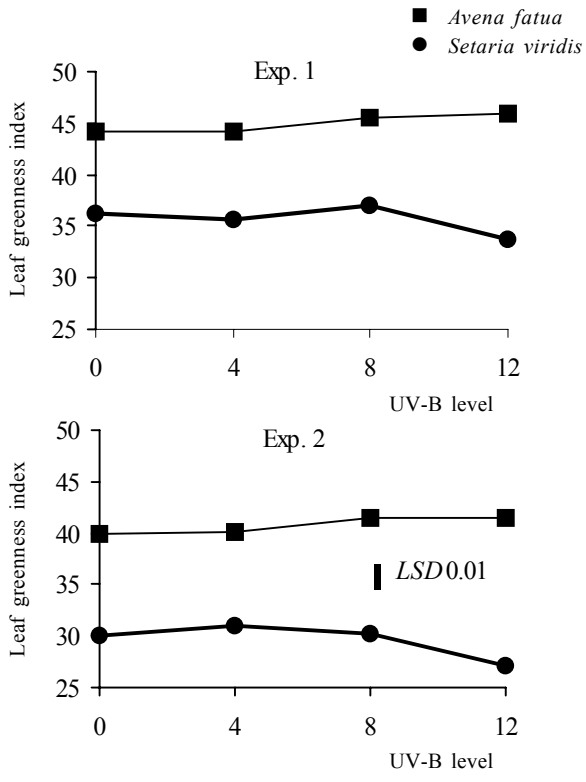

Figure 6. Effect of UV-B radiation to leaf greenness index

Table 2. Effect of UV-B radiation on some physiological indices

UV-B level	SLW (g/m^2)		LA (per cm^2)		LWR		SDM (%)		SRR		LAR	
	I	II	I	II	I	II	I	II	I	II	I	II
						Avena fatua						
0	28.9	30.0	483.0	348.7	0.67	0.48	8.61	10.51	1.56	1.87	710.40	418.31
4	26.9	30.1	429.1	315.3	0.60	0.51	7.83	10.90	1.43	1.80	651.12	493.67
8	29.9	30.8	450.4	338.7	0.68	0.48	7.55	10.60	1.80	1.95	737.17	446.50
12	28.7	31.8	484.2	334.8	0.52	0.51	7.56	10.70	1.54	1.49	706.97	474.83
						Setaria viridis						
0	19.9	18.5	427.8	535.0	0.39	0.48	14.06	10.68	5.58	2.66	394.15	679.34
4	18.0	19.0	475.1	456.8	0.46	0.48	10.89	9.75	3.60	1.79	479.36	673.22
8	20.0	19.6	461.0	309.3	0.43	0.48	14.11	9.25	5.44	2.49	409.44	575.43
12	19.5	19.8	399.6	245.5	0.43	0.56	12.29	7.88	5.43	3.01	490.21	404.46
$LSD_{0.01}$ for species × UV-B	ns	ns	ns	157.97	ns	ns	ns	ns	ns	0.89	ns	ns
						Mean for species						
Avena fatua	28.6	30.7	461.7	334.4	0.62	0.49	7.89	10.69	1.43	1.78	701.42	458.33
Setaria viridis	19.3	19.2	440.9	386.6	0.43	0.47	12.84	9.39	5.01	2.49	443.29	583.11
LSD for species	1.64	2.44	ns	ns	0.09	ns	1.87	1.25	1.18	0.45	130.29	140.95
						Mean for UV-B level						
0	24.4	24.2	455.4	441.8	0.53	0.48	11.34	10.59	3.57	2.27	552.28	548.83
4	22.5	24.5	452.1	386.0	0.53	0.49	9.36	10.33	2.51	1.80	565.24	583.44
8	24.9	25.2	455.7	324.0	0.55	0.48	10.83	9.92	3.31	2.22	573.41	510.96
12	24.1	25.8	441.9	290.1	0.48	0.48	9.93	9.29	3.49	2.25	598.59	439.64
LSD for UV-B	2.32	ns	ns	111.70	ns	ns	ns	ns	ns	ns	ns	ns

SLW = specific leaf weight, LA = leaf area, LWR = leaf weight ratio, SDM = shoot dry matter content, SRR = shoot :root ratio, LAR = leaf area ratio

The measurements of leaf greenness made in the five terms of plant growth started from the phase of three leaves and finished at the beginning of shooting. The leaf greenness index of *Avena fatua* and *Setaria viridis* as well as the reaction of the trait to UV-B radiation in the following plant growth stages were similar. It was only for the experiment II where significant interaction species × UV-B radiation was proved (Figure 6). In *Setaria viridis* the leaf greenness index was lower for the highest level of UV-B radiation. In the study by Robakowski (1999), the high level of UV-B radiation (22.64 kJ/m^2/d) reduced chlorophyll content by 20% in comparison to the control. On the other hand, in the study by Skorska (2000) effect of the high UV-B radiation reduced chlorophyll content to 50% of the control. The greenness index can facilitate some decisions in practice in the stress of nitrogen lack in cereals information on greenness index an additional dose of nitrogen fertilization can be suggested. In the study of Hoffman (1999) on ornamental plants the high level of radiation caused chlorophyll degradation but has no impact on quality of the plants.

Among the physiological indices measured were SLW, LAI, LWR, SDM, SPR and LAR (Table 2). The UV-B radiation had no significant effect to the most of them, but LAI and SRR. In the experiment II, the two species had specific reaction to UV-B radiation. Leaf area index for *Avena fatua* did not change with the change of the level of UV-B while in the case *of Setaria viridis* successive levels of UV-B radiation, caused successive reduction of leaf area from 12.7% (4 UV-B), 26.7% (8 UV-B) to 34.3% (12 UV-B). These results are in accordance with the results reported by Dai et al. (1995) and Furness et al. (1999). Dai et al. (1995) have stated that rice plants did not reduce the leaf area as well as the dry matter of plants. In the study by Furness et al. (1999) (*Cynoglossum officinale*, *Centaura diffusa* and *Tragopogon pratensis*), the UV-B radiation decreased leaf area in all weeds while the most susceptible was *Cynoglossum officinale*.

Sources of materials

[1]UVB-313 40W fluorescent tubes, Q-Panel,Westlake, OH 44145

[2]Mylar film (Type D, 0.127 mm thick) and cellulose acetate film (diacetate type, 0.127 mm) Cadillac Plastic Canada, Inc., Burnaby, B.C., Canada V5A 1V3

[3]International Light ILI1700 Radiometer, IL 782 Amonochromatot and SED240 Bulk Sensor. International Light, Inc., Newburyport, MA 01950

[4]LI-COR LI-3000 portable leaf area meter, LI-COR, Inc., Lincoln, NE 68504

[5]SPAD-502 meter, Minolta Corp., Ossaka, Japan

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ABSTRAKT

Vliv záření UV-B na růst a vývoj rostlin

Ve skleníkovém pokusu jsme aplikací rozdílných dávek záření UV-B na dva rostlinné druhy *Avena fatua* a *Setaria viridis* navodili změny v morfologii listů a rostlin. Došlo ke snížení výšky rostlin, zelené hmoty listů, nadzemních a podzemních částí a ke zmenšení listové plochy. Kromě toho záření způsobilo u obou druhů kadeřavost listů. Významné rozdíly ve sledovaných znacích mezi *Avena fatua* a *Setaria viridis* vyplývaly z odnožovací schopnosti obou druhů. Zaznamenali jsme značné kolísání obsahu chlorofylu. Průměrná vitalita listů (vyjádřená v jednotkách SPAD) se u ovsa pohybovala kolem hodnoty 43, zatímco u béru zeleného dosahovala hodnoty 32. Záření UV-B nesnížilo poměrnou hmotnost listů, sušinu nadzemních částí, poměr nadzemních a podzemních částí a poměrnou listovou plochu.

Klíčová slova: záření UV-B; *Avena fatua*; *Setaria viridis*

Corresponding author:

Dr. Krystyna Zuk-Golaszewska, University of Warmia and Mazury in Olsztyn, Department of Crop Production, 10-718 Olsztyn, Poland
tel.: + 48 895 234 713, e-mail: kzg@moskit.uwm.edu.pl