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UV-B Radiation - How Burning is It for Plants?

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Summary

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In the last twenty years a bulk of papers studying the influence of UV-B radiation on plants was published. The majority of them are the reports on short term experiments, performed mainly under controlled indoor environment; in laboratories, greenhouses and growth chambers. The comparison with outdoor experiments revealed that the damage caused by UV-B appeared to be much higher under indoor conditions, than in field studies. The main reason is that under natural environment all acclimations e.i. changed optical properties of the leaves, accumulation of UV-B absorbing compounds, repair of DNA damage and ability of scavenging of radicals are much more expressed than in indoor experiments. Different authors claim that above all PAR/UV-A/UV-B ratio is of major importance, not only because of photorepair mechanisms, but also because of the costs of other protective mechanisms including synthesis of secondary substances. UV-B radiation will affect the structure and function of the ecosystems. Reliable estimation of the influence of UV-B radiation on ecosystems must base on the long-term outdoor experiments. Agricultural plants appears to be more sensitive since in the past breeding efforts were directed mainly into an increase of the yield of certain cultivar. The potential of these plants to cope with elevated UV-B radiation is still unclear.

Introduction

Only 1.5% of the total solar energy reaching the Earth is within UV-B region (FREDERICK & al. 1989), but it has significant influence on organisms. That is why the thinning of the stratospheric ozone layer and consequently enhanced UV-B radiation presents a topic, which has been intensively researched and discussed during last twenty years (ROZEMA & al. 1997a). Until now the majority of the studies were planned as a short term experiments, performed mainly under controlled indoor environment; in laboratories, greenhouses and growth chambers

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(CALDWELL & FLINT 1994, ROZEMA & al. 1997a, JOHANSON 1997) under relatively modest light conditions. Only about 15% of the researches has been performed under natural conditions (CALDWELL & al. 1995). The main targets are DNA (MITCHELL & KARENTZ 1993), photosystem II (JANSEN & al. 1996) and membranes (BORNMAN 1989). Plant reactions to avoid harmful effect of UV-B are different. They evolve several mechanisms which mitigate potential damage caused by UV-B. All mechanisms demand additional metabolic energy and some of them directly depend on light. But indoor radiation conditions, above all the UV-A/UV-B/PAR ratio usually differs from those in the field. Comparative outdoor studies showed that the damage obtained under indoor conditions could be overestimated (ROZEMA & al. 1997a). The following contribution summarises the effects of enhanced UV-B radiation on plants, the mechanisms which prevent or mitigate the damage and its influence on the ecosystem level.

The Effects of UV-B Radiation on Plants

UV-B radiation has a strong influence on macromolecules and through this it influences gene activity, photosynthesis and metabolism of the plants what could disturb plant growth as a whole and consequently the interrelations in the ecosystems. The main target of UV-B radiation is DNA (PEAK & al. 1984, QUAITE & al. 1992). Different lesions of DNA influence the synthesis of proteins. The damaged sites could be repaired by photolyase in the presence of the UV-A and PAR photons (MITCHELL & KARENTZ 1993). Besides direct effects UV-B also influences DNA indirectly, by formation of free radicals. Proteins could also be damaged, because they absorb light in the UV-B region. The investigations revealed the disturbance in the synthesis of ribulose-1,5-biphosphate carboxylase/oxydase (GREENBERG & al. 1996, BAKER & al. 1996) and also the enzymes of nitrogen metabolism in nitrogen fixing algae (KUMAR & al. 1996). Another sensitive target is the photosynthetic apparatus. UV-B radiation is known to damage the protein subunits D1 and D2 of photosystem II (PSII) (JANSEN & al. 1996) and PSII grana and stroma lamellae (YU & BJÖRN 1996, 1997). UV-B radiation also influences the permeability of membranes and disturbs the transport of potassium into the guard cells (CALDWELL & al. 1995). The main reason is peroxidation of non saturated fatty acids and consequently changes in lipid structure.

Protective Effects and Repair Mechanisms

Protection includes modification on a biochemical and a morphological level in order to influence penetration of UV-B radiation into plant tissue. UV-B stimulates the production of some enzymes of the phenylpropanoid pathway. Synthesis of UV-B absorbing substances like flavonoids and anthocyanins, morphological changes of the leaf surface and changed mesophyll structure protect the inner tissue (CALDWELL & al. 1995). In many plants the increased level of flavonoids in the epidermis significantly reduces the damage of the leaf's tissue (TEVINI & al. 1991). Scavengers of free radicals and active oxygen also prevent the harmful effects. Damaged DNA is effectively repaired by DNA-photolyase (BUCHHOLZ & al. 1995). This process is light dependent. Another mechanism is production of polyamins which mitigate the damage of membranes. Metabolic costs for activation of this mechanisms have not been evaluated yet.

Multiple Stressors

Another aspect which needs a special attention is multiple stress. Researchers who studying the influence of UV-B radiation in combination with other stressors found out that the effects of UV-B under stress conditions could be even more harmful. The results of DECKMAN & IMPENS 1997 who studied the cultivars of rye showed that the production of UV-B protective substances is depressed under the shortage of soil nitrogen. The question of the interaction of UV-B radiation with a CO_2-enriched atmosphere is also very important. Some experiments have already been performed by SULLIVAN 1997. It is known that enhanced UV-B could decrease primary production and on the other hand elevated CO_2 concentrations increases the productivity of C_3 plants. It seems that UV-B radiation could diminish the beneficial effects of higher CO_2 concentrations.

Effects on Ecosystems

The researches of the influence of UV-B on the ecosystem level are scarce (CALDWELL & al., 1995, JOHANSON & al. 1995, JOHANSON 1997, TOSSERAMS & al. 1997). The field studies revealed mainly morphological changes and little direct disturbance. The effects of UV-B radiation on single organisms could alter the relations in the ecosystems. The differences among species, their protective and adaptive responses influence the success of certain species. The influence on growth and phenology (SAILE-MARK & TEVINI 1997), growth form and formation of secondary substances affect the competitive relationships within the ecosystem. When studying subarctic vegetation BJÖRN & al. 1996 found little effect of UV-B. For estimation of trends under enhanced UV-B radiation, long-term observations of the ecosystems are necessary.

The effects on relations within the ecosystem could be also due to the increased synthesis of tannins and lignins what could affect herbivory and decomposition and through that cycling of nutrients and biogeochemical cycles (ROZEMA & al. 1997c). The final result could be changed biodiversity and species composition. The harmful effects have already be detected in some agricultural plants since in the past breeding efforts were directed mainly to increase the yield of certain cultivar. The potential of these plants to cope elevated UV-B radiation is still unclear (ROZEMA & al. 1995, 1997b). The genetic variability within the species offers the possibility to breed UV-B resistant cultivars.

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