Experimental studies on plant stress responses to atmospheric changes in Northern Finland

Kari Taulavuori[1 *], Erja Taulavuori[1] and Kari Laine[2],
[1]University of Oulu, Department of Biology, FI-90014 University of Oulu, P.O. Box 3000, [2]University of Oulu, Thule Institute, FI-90014 University of Oulu, P.O. Box 7300

1 Introduction

Stress is a significant deviation from the conditions optimal for life, and elicits changes and responses at all functional levels of organisms and, although first reversible, it may become permanent (Larcher 1995). Winter is usually the most stressful season for plants in northern hemisphere. Many species are subjected to very low temperatures and variations between temperature extremes. By definition, plant frost hardiness refers to an ability to withstand temperatures below 0°C (e.g. Sakai and Larcher 1987; Taulavuori et al. 2003). The major environmental factors controlling frost hardiness are temperature and daylength. Geographic origin of the plant and thus the genetic background provide limits for the range and timing of plant frost hardiness. In northern high latitudes, the development of adequate frost hardiness is an essential factor to survive over winter-time. All the environmental changes that could affect plant frost hardiness determine thus the survival over a seasonal cycle. According to the results of ultrastructural needle studies, acid rain delays the development of winter hardening process of conifer trees (Reinikainen and Huttunen 1989, Bäck and Huttunen 1992). In addition to structural information, quantitative methods were needed to assess the level of frost hardiness under experimental manipulations. For this purpose, the available methodology was carefully reviewed (Taulavuori 1996a), and equipment for rate-controlled freezer was developed (Taulavuori et al. 1996b). In this article we review the results mainly from the plant frost hardiness – atmospheric changes point of view, but also some other responses (e.g. growth, biochemistry) are included.

2 Studies on elevated O_3 and CO_2 gases and warming winter

At the beginning of 1990's, the Department of Botany (later fused with the Department of Biology) established experimental fields for testing plant stress responses under controlled environment mimicking many atmospheric changes, including gas fumigations and temperature elevations. Our group focused especially on responses in plant cold hardiness and defence against oxidative stress. Elevated levels of either O_3 or CO_2 did not markedly affect these processes (E. Taulavuori et al. 1997; K. Taulavuori et al. 2001). Elevated winter temperatures, however, indicated that warming climate could reduce the frost hardiness of dwarf shrub bilberry (K. Taulavuori et al. 1997). The same result was obtained later in experiment with mountain birch performed in cooperation with Norwegian colleagues (Taulavuori et al. 2004; Skre et al. 2008).

3 Studies on other pollutants

Impacts of other contaminants from anthropogenic origin were also studied. During the 1990's, the effects of nitrogen overload were assessed in the context of gas (i.e. O_3 and CO_2) fumigations (E. Taulavuori et al. 1997; K. Taulavuori 2001). Until then, the anecdotal evidence was that nitrogen supply always reduces plant frost hardiness. However, our studies indicated that nitrogen supply may also improve the development of plant frost hardiness, especially in species adapted to nutrient deficits in soils (Taulavuori et al. 2001).

Only few articles had reported that trace or heavy metals could cause forest injuries through reduced frost hardiness (Sutinen et al. 1996; Kukkola et al. 1997). The literature was reviewed and a hypothesis was

*Correspoding author, E-mail: kari.taulavuori@oulu.fi

constructed to test the effect of trace metals on plant frost hardiness (Taulavuori et al. 2005a). However, the uptake and translocation occurred only in below-ground stems of bilberry *(Vaccinium myrtillus)*, and no translocation to aerial parts occurred (Tahkokorpi et al. 2010). Therefore it is understandable that no differences in frost hardiness of bilberry stems appeared, as indicated by Figure 1. Based on the above, the experimental manipulation of plants with heavy (or trace) metals was not continued for the following reasons: (1) the manipulation of plants may require several growing seasons due to slow mobilization and further accumulation in studied tissue. (2) The use of toxic contaminants is always a risk for environment and health. Therefore, experimental studies testing the presented hypothesis were decided to be substituted rather with testing material from contaminated environments (vicinity of smelters etc.).

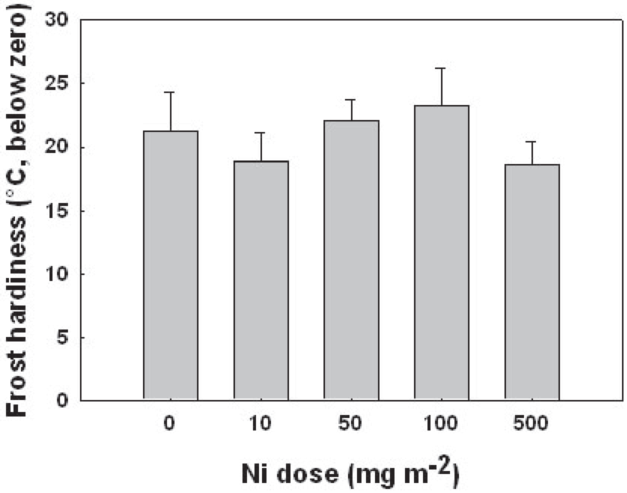

Figure 1 *Frost hardiness of Vaccinium myrtillus stems at the beginning of October 2006 after one growing season manipulation with Ni exposure by doses in a range from 0 to 500 mg m^{-2} (Turunen et al. 1995, Figure 1).*

4 Studies on UV-radiation

During the 2000's, responses to UV-radiation were studied in FUVIRC experiment in Sodankylä, Northern Finland. The preliminary results indicated that plant frost hardiness could be reduced under elevated UV-B radiation, and a hypothesis according to which there is a trade-off between UV-defence mechanism and development of frost hardiness was published (Taulavuori et al. 2005b). Data was collected yearly and there are currently 3-4 (unpublished) manuscripts under preparation. The results are partly consistent with the presented hypothesis, although the responses were not as significant as expected. The major finding is that the plant frost hardiness response varies between plant species. The results suggest that the evergreen species are more vulnerable to UV-radiation.

5 Studies on drought

While precipitation may be increased in northern areas as a consequence of changing climate, the probability of local and temporal summer droughts will increase (ACIA 2005). For example, in 2006 in northern Finland, the late summer was very hot and dry and water deficit resulted to premature leaf dropping or browning in August. A comparison of evergreen and deciduous life strategies under severe drought stress was documented elsewhere (E. Taulavuori et al. 2010). We propose that although evergreen strategy is more common in dry habitats, the deciduous strategy may serve better the whole plant in under extreme drought. It was also indicated that juvenile leaves of deciduous species may be more drought-tolerant than mature leaves (E. Taulavuori et al. 2010).

6 Studies on light quality effects

Effects of changed light quality may be discussed in the context of atmospheric changes in broad sense. Global change obviously does not affect the light conditions of a given site (with the exception of UV-radiation). However, as the climate warms the southern vegetation may shift their ranges even 1000 KM northward to the boundary of Arctic Ocean (ACIA 2005). As the sun elevation is lower in the Arctic, the shorter wavelengths are scattered effectively from the solar beam. Thus the vegetation from southern origin that have migrated northward experience different light quality compared to that they have adapted to. Because of the scattering of short wavelengths in the Arctic, the diffuse blue light exists at relatively high proportions during polar summer nights (K. Taulavuori et al. 2010). The ecological significance is that blue light decreases the elongation (i.e. height growth) of some trees (Taulavuori et al. 2005c; Sarala et al. 2007; Sarala et al. 2009).

7 Future prospects

The previous chapter remains open in respect to which species respond and which species do not respond to the changes in light quality? As well, it is highly probable that there are differences in magnitudes of the responses between species and between geographic origins of a single species. Thus the main question concerns the plant communities and populations: Which are the dominating species and ecotypes in the future of the Arctic?

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8 References

ACIA (2005) Arctic Climate Impact Assessment. Cambridge University Press, 1042 p.

Bäck J. and Huttunen S. (1992) Structural responses of needles of conifer seedlings to acid rain treatment. **New Phytologist** 120,77-88.

Kukkola E, Huttunen S, Bäck J and Rautio P (1997) Scots pine needle injuries at subarctic industrial sites. **Trees** 11: 378-387.

Larcher W (1995) Physiological Plant Ecology. 3rd Ed., Springer-Verlag, New York.

Reinikainen J. and Huttunen S. (1989) The level of injury and needle ultrastructure of acid-rain irrigated pine and spruce seedlings after low temperature treatment. **New Phytologist** 112, 29-39.

Sakai A and Larcher W (1987) Frost Survival of Plants. In Ecological Studies, eds. W.D Billings, F. Golley, O.L. Lange, J.S Olson and H. Remmert. Springer Verlag, Berlin.

Sarala M, Taulavuori K, Taulavuori E, Karhu J & Laine K. (2007). Elongation of Scots pine seedlings under blue light depletion is independent of etiolation. **Environmental and Experimental Botany** 60: 340-343.

Sarala M, Taulavuori E, Karhu J, Laine K, Savonen E-M and Taulavuori K (2009). Improved elongation of Scots pine seedlings under blue light depletion is not dependent on resource acquisition **Functional Plant Biology** 36: 742-751.

Skre O., Taulavuori K., Taulavuori E., Nilsen J., Igeland B., Laine K. (2008) The importance of hardening and winter temperature for growth in mountain birch populations Environmental and Experimental Botany 62: 254-266.

Sutimen M-L, Raitio H, Nivala V, Ollikainen R, and Titari A. (1996). Effect of emissions from copper-nickel smelters on the frost hardiness of Pinus sylvestris in the subarctic region. **New Phytologist** 132: 503-512.

Tahkokorpi M, Korteniemi A, Taulavuori, E, Roitto M, Laine K, Huttunen S and Taulavuori K(2010) Trace amounts of nickel in belowground rhizomes of Vaccinium myrtillus L. decrease anthocyanin concentrations in aerial shoots without water stress (submitted).

Taulavuori, E., Taulavuori, K., Laine, K., Saari, E. & Pakonen, T. (1997). Winter hardening and glutathione status in the bilberry (Vaccinium myrtillus L.) in response to trace gases (CO_2, O_3) and nitrogen fertilization. **Physiologia Plantarum** 101: 192 - 198.

Taulavuori E, Tahkokorpi M, Laine K and Taulavuori K (2010) Drought tolerance of juvenile and mature leaves of deciduous dwarf shrub Vaccinium myrtillus L. in boreal environment. **Protoplasma** 241: 19-27.

Taulavuori K. (1996a). Determination of frost resistance of woody plant species: practical approach (a minireview). **Aquilo Series Botanica** 36: 43 - 48.

Taulavuori K., Rankka, N., Laine, K., Pakonen, T. & Karhu, M. (1996b). A controlled rate freezer for frost manipulations of plant organs: a system description. **Aquilo Series Botanica** 36: 49 - 52.

Taulavuori, K., Laine, K., Taulavuori, E., Pakonen, T. & Saari, E. (1997). Accelerated dehardening in the bilberry (Vaccinium myrtillus L.) induced by a small elevation in air temperature. **Environmental Pollution** 98: 91-95.

Taulavuori K., Taulavuori, E., Niinimaa, A. & Laine, K. (2001). Acceleration of frost hardening in Vaccinium vitis-idaea (L.) by nitrogen fertilization. **Oecologia** 127: 321-323.

Taulavuori, K., Taulavuori, E. & Laine K. (2003). A review: Frost survival of woody plants at high latitudes with special reference to global change. **Recent Research Developments in Biochemistry** 4: 1017-1028.

Taulavuori K., Taulavuori E., Skre O., Nilsen J., Igeland B. & Laine K. (2004) Dehardening of mountain birch (Betula pubescens ssp. czerepanovii) ecotypes at elevated winter temperatures. **New Phytologist** 162: 427-436.

Taulavuori K., Prasad M.N.V., Taulavuori E. & Laine K. (2005a) Metal stress consequences on frost hardiness of plants at northern high latitudes: Review and hypothesis. **Environmental Pollution** 135: 209-220.

Taulavuori, K., Taulavuori, E., & Laine, K. (2005b). UV-B and plant frost hardiness in the sub-arctic. **Arctic, Antarctic and Alpine Research** 37 (1): 102-106.

Taulavuori, K., Sarala, M., Karhu, J., Taulavuori, E., Kubin, E., Laine, K., Poikolainen, J. & Pesonen, E. (2005). Elongation of Scots pine seedlings under blue light depletion. **Silva Fennica** 39: 131-136.

Taulavuori K, Sarala M and Taulavuori E (2010). Growth responses of trees to arctic light environment. **Progress in Botany** 71: 157-168.

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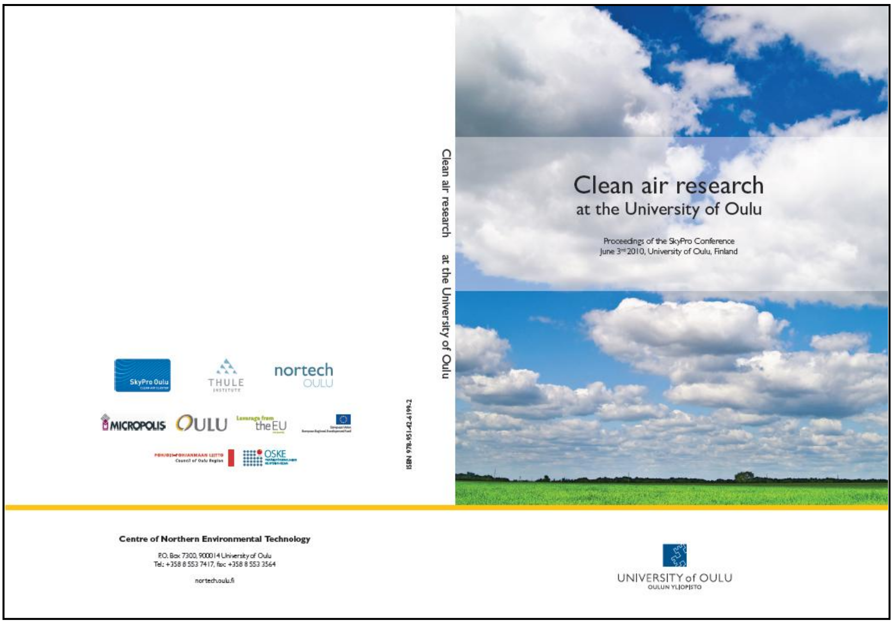

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