Changes in the content of indole-3-acetic acid and cytokinins in spruce, fir and oak trees after herbicide treatment

J. MATSCHKE * and I. MACHÁČKOVÁ**

Landwirtschaftskammer Westfalen-Lippe, Bildungs- und Versuchszentrum des Gartenbaus, Münsterstrasse 62-68, 48167 Münster, Germany*
Institute of Experimental Botany, Academy of Sciences of the Czech Republic, Rozvojová 135, CZ-16502 Praha 6, Czech Republic**

Abstract

Treatment of spruce, fir and oak trees with herbicides, which may be one of the forest damage inducing agents, caused pronounced changes in the contents and distribution of indole-3-acetic acid (IAA) and cytokinins (CKs) one year after treatment, i.e. at the time of the first microscopically visible damage in treated trees. In Picea pungens IAA content increased in the terminal buds by about 105 % and in the apical buds of the first order branches by 220 %. The same was true for young sprouts of Abies nordmanniana, while in leaves of oak trees IAA content was decreased by 15 % after glyphosate treatment and by 30 % after 2,4-dichlorophenoxyacetic acid (2,4-D) treatment. Another striking feature was a significantly decreased content of IAA in the lower parts of roots in Picea pungens (50 % of the control), which is accompanied by an increase in IAA content in the middle part of the roots (130 %). On the other hand, the IAA content of both sprouts and roots of A. nordmanniana was significantly increased after herbicide treatment.

In P. pungens, the content of free cytokinins (sum of zeatin, zeatin riboside, isopentenyladenine and isopentenyladenosine) decreased due to herbicide treatment. The strongest decrease was seen in roots, especially in their upper and middle parts (the average reduction of cytokinin content in roots was 63 %). In the above-ground organs the reduction was seen namely for isopentenyladenine and isopentenyladenosine, while the abundance of zeatin riboside was, on the other hand, higher in treated plants. In Quercus robur leaves, the total content of cytokinins also decreased, namely after glyphosate treatment. In consequence of these changes, CK/IAA ratio decreased pronouncedly in all organs of herbicide-treated trees, with the exception of oak leaves treated by 2,4-D.

Additional key words: Abies nordmanniana, anatomical changes, forest decline, Picea abies, Quercus robur.

Introduction

Forest decline is one of the most serious ecological problems, especially in central Europe. The main processes occurring during forest decline are loss of vitality, deformation of the buds, dying of the apical buds and young sprouts, deterioration of the crown, accelerated senescence, loss of photosynthetic capacity and finally, death of the whole trees, both coniferous and deciduous ones. Toxic substances in the atmosphere, like sulphur dioxide, nitrogen oxides and/or ozone together with soil acidification are usually considered to be the main causes of forest decline. However, there are also other causes of the damage in forest trees: lack of water and nutrients (especially of potassium and magnesium), supraoptimal levels of nitrogen-containing compounds (Mohr 1992), lack of oxygen in the soil. The nutritional deficiencies may be in many cases counteracted by special fertilizing, mainly by an increased calcium input into the soil (Rehfuss 1995). Also herbicides may prove to be very
deleterious for the health of the trees. Many herbicides are used in the forest practice and many herbicides are brought to forests by wind or water. The observation that damages occur in Picea and Abies species not only in the old parts of the trees, but also in the young sprouts, is to be considered as the effect of herbicides being used in agriculture or nurseries. Until now, the role of herbicides in forest decline was not sufficiently studied and that is why we paid our attention to this aspect.

The primary physiological consequence of the factors mentioned is usually seen in a degradation of photosynthetic apparatus, i.e. decrease of chlorophyll content, hampered photosynthetic performance (e.g. Hock and Elstner 1988) and premature senescence (Wentzel 1992). We often observe deterioration of membranes and chloroplasts and accumulation of toxic substances. This is usually connected with changes in carbohydrate metabolism, e.g. accumulation of starch in chloroplasts and lack of carbohydrates in roots. This may be one of the causes of the often described root damage (for review see Matschke et al. 1997, Matschke and Amend 1998).

In fact, the first changes may be observed at the cell level, usually in meristems. Polarity of the cells and of the cell division is often disturbed and bud sprouting is delayed. These changes are seen in the microscope, but at that time the plants still seem to be healthy. It is only in the following growth season, when new tissues and organs develop from these damaged meristems, that the damage can be seen with the naked eye. The changes of the morphology are usually accompanied by highly increased sensitivity to phytopathogens, by reduced vitality and cold resistance and decreased ability to withstand unfavourable conditions (Hartman 1996).

Many of the described processes, both at the cell and the whole plant level, suggest that phytohormones may be involved in their induction and regulation. In spite of this, not much attention was paid to the phytohormones in forest decline. The content of free IAA was measured in needles of healthy and damaged trees of Picea abies and found to be distinctly lower in damaged trees (Völkers and Wild 1988). In addition, both annual and daily rhythms in the free IAA content were damped in damaged trees (Wessler and Wild 1993). The authors hypothesize that the lower IAA content may be responsible for the premature needle abscission. On the other hand, a higher content of ABA and ethylene were found in damaged trees (Johnson 1987). A detailed study of ABA contents in needles of healthy and damaged fir (Abies alba) and Norway spruce (Picea abies) trees from Nothern Black Forest showed no significant seasonal variations (Christmann et al. 1995). Also, no significant differences were seen between healthy and declining fir trees. When exposed to water stress, declining trees accumulated more ABA, showing higher sensitivity to stress conditions. The content of cytokinins was also studied in Picea abies and in 2-year-old needles higher cytokinin content was found in damaged trees. The increase was mainly due to an increased content of zeatin riboside and isopentenyladenosine (von Schwartzzenberg et al. 1988).

Here we describe changes in the contents of the two main hormone classes - cytokinins and auxin in healthy, declining and herbicide-treated spruce (Picea pungens var. glauca), nordmann fir (Abies nordmanniana) and oak (Quercus robur) trees.

Materials and methods

Plants and herbicide treatment: Three- and four-year-old trees of Picea pungens var. glauca (origin Kaibab and Apache) and of Abies nordmanniana (origin Ambrolauri-Tagi) were treated with a mixture of the herbicides glyphosate (Roundup) and hexazinone (Velpar) in a way commonly used in plantation of Christmas trees, i.e. spraying from above ("over the head") in a concentration of 2.5 g m⁻³ for spruce and 1.5 g m⁻³ for fir and a dose of 5 × 10⁻⁵ m⁻³ m⁻² in January and March, respectively. Control plants were treated with the same amount of water. As glyphosate inhibits 5-enolpyruvylshikimic acid-3-phosphate synthase and thus synthesis of aromatic amino acids (Steinrücken and Amrhein 1980) and hexazinone inhibits photosynthesis (Börner 1995), we used also a third treatment comprising the mentioned herbicides combined with a mixture of aromatic amino acids (tryptophane, tyrosine and phenylalanine at the concentration 15 × 10³ g m⁻³) and a specific cytokinin m-topolin (m-hydroxybenzyladenine) (Strnad et al. 1992) at concentration 10 mmol m⁻³. These substances could serve as a replace of endogenous aromatic amino acids and the cytokinin application could be expected to stimulate protein synthesis and increase the photosynthetic capacity (Mothes 1964, 1966, Mothes and Partthier 1984, El-Hattab et al. 1987). Samples were taken during the vegetation period one year after the treatments, but before the outgrowth of the buds. Terminal and axillary buds were sampled together with young and older needles and roots. The samples were separated into upper, middle and lower parts and were immediately frozen and freeze-dried. Each sampling was performed in four repetitions, each containing materials from 35 trees. In oak (Quercus robur), 10 - 120-year-old trees in a forest, were taken as experimental material. Some of the 10-year-old trees were treated with glyphosate and 2,4-dichlorophenoxyacetic acid (2,4-D) (1.5 g m⁻³) in the way described above.