NUTRIENT DEFICIENCY OF SPRUCE NEEDLES CAUSED BY ROOT AND BUTT ROTS - A FACTOR IN FOREST DECLINE

by Christian Tomiczek

Abstract. Acute needle yellowing of spruce (*Picea abies*) followed by forest decline has been observed in different parts of Austria. Trees with "needle yellowing" usually show specific nutrient deficiency, whereas trees of normal colour appear to be adequately supplied. Twenty-one healthy and 21 diseased spruce trees on 3 different forest sites in Austria were felled and examined for root and butt rots; the nutrient content of needles, root and stem sapwood was compared. Trees with active needle yellowing had significantly higher rates of root and/or butt rot, low levels of potassium, calcium and magnesium in the sapwood of roots and lower stem parts. Acute yellowing as a symptom of mineral deficiency therefore is induced by physiochemical reactions like the reinforcement of cell walls and the compartmentalization of wood after fungal attacks rather than by leaching.

Since the late seventies and early eighties, needle discolouration in Norway spruce (*Picea abies*) followed by forest decline has been observed in several parts of Austria. Symptoms correspond largely to those described by Rehfuess et al. (11), Senser et al. (13), Prinz et al. (10) and Kandler (4), Kandler et al. (5) as " acute needle yellowing" of spruce.

Older needles are affected first by this disorder. Symptoms occur mainly on the upper side of the branches. Within several years needle colour turns from yellow to orange and the youngest needles also become affected. At this stage the trees decline rapidly although they may turn green again. Rehfuess et al. (11) report that the needles of affected spruce trees show nutrient deficiency, especially of N (nitrogen), Mg (magnesium), K (potassium) and Ca (calcium), whereas neighbouring trees without such symptoms seem to be adequately supplied. Hüettl (3) stated that the so-called new types of forest damage are rather frequently associated with nutritional disturbances. Many authors investigating this phenomenon state that leaching and atmospheric deposition (NO_3, NH_4, SO_2) together with nutrient deficiency in soils are the main causal factors. Schwabe (12), Laatsch et al (7), Senser et al. (13) found that needles showing symptoms of chlorosis often had K deficiency and were obviously sensitive to high light intensities.

Löchelt et al. (8) detected genetic differences of "green" and "yellow" subpopulations of affected Norway spruce. The deviations, however, did not show the same trends for all stands.

Investigations undertaken in the southeast of Austria (16) offer a new explanation for the phenomenon of acute needle yellowing. The results have been confirmed by the study of two more forest decline areas in Austria.

Investigation area. The forest area where these investigations were undertaken is situated in a mountainous region southeast of the main alpine ridge at an altitude of 800 m to 2,000 m. Average rainfall ranges form 600 mm to 1,300 mm with maximum rainfall occurring during summer. Geologically, the region belongs to a complex of volcanic amphibolites with high SO_2 content and low levels of Mg (2-3%) and CaO (2-4%). Forest soils in the investigation area are mainly brown semipodsols with low pH (3.3-3.4) ($CaCl_2$), medium to high P, Fe and H, and low K, Ca, and Mg concentrations (9). Until 1970 the forest area was intensively used as pasture. In addition, a high percentage of trees was damaged through debarking by deer (2).

Materials and Methods

Between 1988 and 1993, 21 spruce pairs were selected on different forest sites, felled and systematically tested. Tree selection was made using the following criteria: 1) Each tree pair consisted of

1 healthy spruce (without any symptoms) and 1 diseased spruce (showing symptoms of acute needle yellowing). 2) Both trees of a pair were close together without visible stand differences. 3) Both trees were (more or less) the same age, size and canopy class. 4) None of the trees had a visible bark damage.

After felling needle and wood samples were taken in the following manner: 1) Three wood disks at different tree heights (sample "H1": close to the trunk; sample "H2": at 130 cm; sample "H3": upper crown part). 2) 1 - and 2-year old needles from the fifth to the seventh whorls. Wood disks were surface-sterilized, wrapped in paper and brought to the laboratory where they were examined for presence of butt rot. Wood samples were then taken from the sapwood and the nutrient content analyzed (Fig. 1). In addition, the main root system of each tree was dug or washed out

Figure 1. Taking wood samples from main roots.

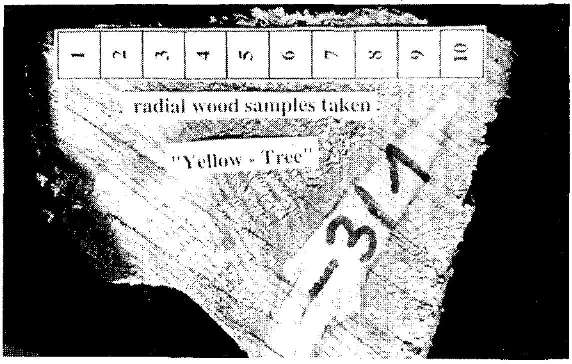

Figure 2. Wood samples were taken at 130 cm height.

and disks were taken from each main root and treated in the same way as the stemwood disks (Fig. 2).

Two healthy and 2 diseased spruce trees were examined in the same way in order to balance the absolute nutrient concentrations of needles and wood. 1) Six wood disks were cut from the stem (near base, at 2 m, 5 m, 7 m, 9 m, 11 m) and one wood disk from each main root. In the laboratory *all* samples were cut out of each centimeter radially and nutrient concentrations analyzed. 2) From the crown of these 4 trees one whole branch per two whorls was taken and the nutrient status of all needles compared.

As part of the total evaluation, three soil samples were taken from near each tree, combined and analyzed in the laboratory for nutrient content.

Results

Root and butt rot. Spruce trees with "needle yellowing" had significantly higher rates of root and butt rot (Fig. 3). Of the investigated declining trees, 92% showed rot, mostly by *Heterobasidion annosum*, whereas less than 12% of the healthy-looking spruce trees were infected.

Nutrient content of the needles. There was a clear difference between the nutrient concentrations of the needles of trees showing symptoms and those not showing any such symptoms (Table 1). The greatest difference was found in the potassium content: Needles of symptomless trees contained twice as much potassium (0.40% K in 1-year-old needles and 0.31% K in 2-year-old needles) as trees showing acute needle yellowing (0.23% K in 1-year-old and 0.16 % K in 2-year-old needles). Symptomless trees showed significantly higher levels of Ca (0.30% in 1-year-old needles, 0.46% in 2-year-old needles) than trees with symptoms (0.19% in 1-year-old needles, 0.33% in 2-year-old needles). All needle samples showed *nitrogen deficiency.*

Nutrient content of the sapwood. Most revealing were the results of the chemical analyses of the wood from stem and main roots. Whereas nutrient concentrations of the wood disks from the upper crown region showed practically no difference (Table 2), K levels of trunk disks of declining Norway spruce were up to nine times higher

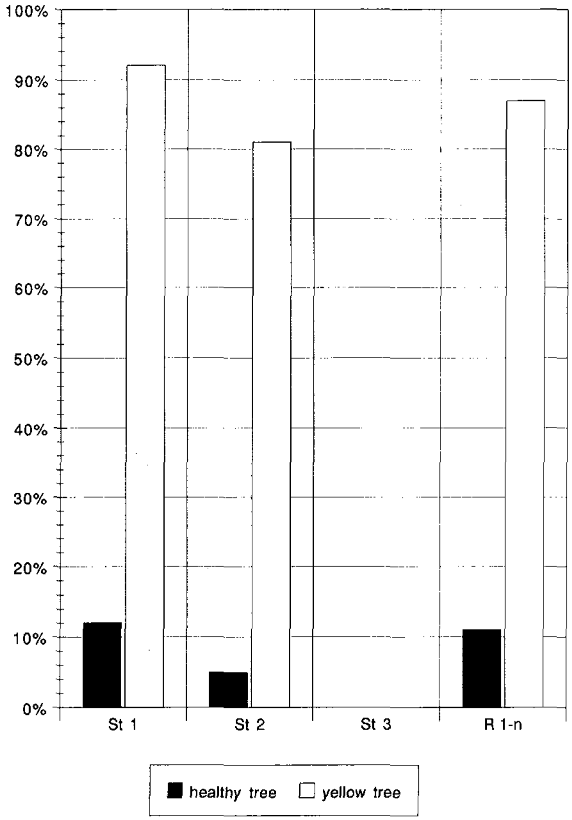

Figure 3. Percentage of root- and butt rot in symptomless and chlorotic Norway spruce.

(0.36%K) than those of healthy spruce (0.04% K). At 130 cm height the K content was six times higher in trees suffering from acute needle yellowing. Mg and Ca levels showed similar correlations. Wood samples of lower stem parts of affected

Table 1. Mean percentage of nutrient content of needles of symptomless and chlorotic trees.

	symptomless trees		chlorotic trees	
	N1	N2	N1	N2
N	1.22	1.13	1.25	1.10
P	0.17	0.14	0.18	0.14
K	0.40	0.31	0.23	0.16
Ca	0.30	0.46	0.19	0.33
Mg	0.10.	0.11	0.09	0.10
Mn	0.05	0.06	0.04	0.06

N1 =1-year-old needles
N2 = 1-year-old needles

Table 2. Mean percentage of nutrient content of wood of symptomless and chlorotic trees.

	symptomless trees				chlorotic trees			
	H1	H2	H3	R	H1	H2	H3	R
N	0.08	0.07	0.08	0.09	0.12	0.09	0.08	0.09
P	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
K	0.04	0.04	0.03	0.05	0.36	0.23	0.03	0.28
Ca	0.07	0.07	0.08	0.07	0.17	0.10	0.07	0.14
Mg	0.01	0.01	0.01	0.01	0.04	0.03	0.01	0.04
Mn	0.01	0.01	0.01	0.01	0.02	0.01	0.01	0.01

H1. Wood sample near tree base taken at 20 cm height.
H2. Wood sample taken at 130 cm height.
H3. Wood sample from upper crown.
R. Wood sample from main roots.

trees contained much more Mg (0.03-9.04% Mg) and Ca (0.17% Ca) than healthy spruce (Mg 0.01 % Mg and Ca 0.07%). K, Mg and Ca levels of main root sapwood of declining trees were two to five times higher than those of healthy spruce.

Nutrient balance. The potassium concentrations of stem wood and the whole needle crown of two symptomless and two chlorotic Norway spruce are presented in Fig. 3. These data demonstrate that elevated levels of K are concentrated in lower stem parts of diseased trees affected by root and butt rots. Diseased trees have four to eight times more K in stem wood and seven times less K in the needles than healthy trees. The balance of K concentrations of wood and needles shows that up to 79 times more K is concentrated in the stem wood than is missing from needle crown of diseased (chlorotic) trees. The K concentrations of symptomless trees are balanced more or less evenly (1.5 times more K in the stem wood). The balance of Mg and Ca seems quite similar to that of K (Figs. 4 and 5).

Nutrient content of the soil. Generally it can be stated that the K, Ca and Mg supply of the soil is insufficient, but that trees with symptoms of acute needle yellowing are better supplied with nutrients from the soil than healthy ones (Table 3).

Discussion and Conclusion

The results indicate a significant correlation between symptoms of acute needle yellowing and the occurrence of root and butt rot. In addition, chemical analyses showed mineral deficiency of

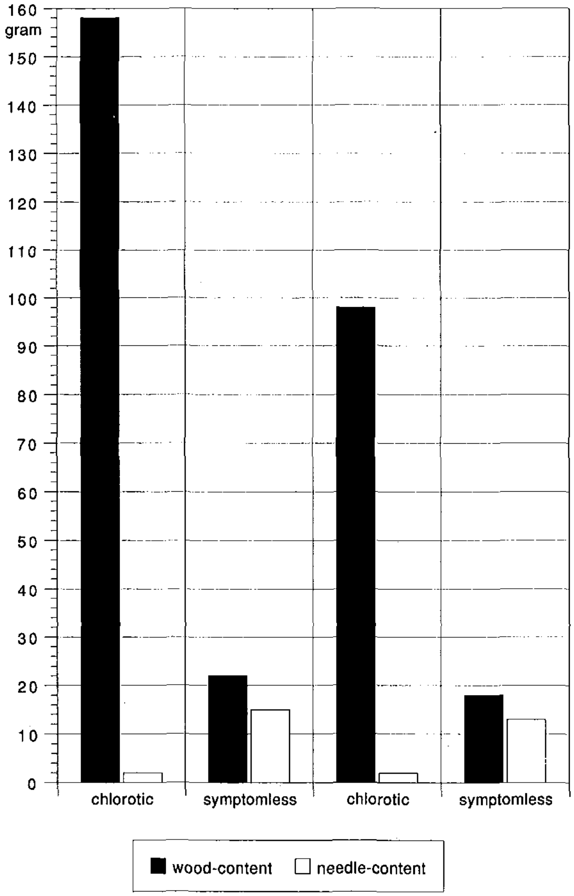

Figure 4. Balance of K - content of stem wood and needles of symptomless and 2 chlorotic trees.

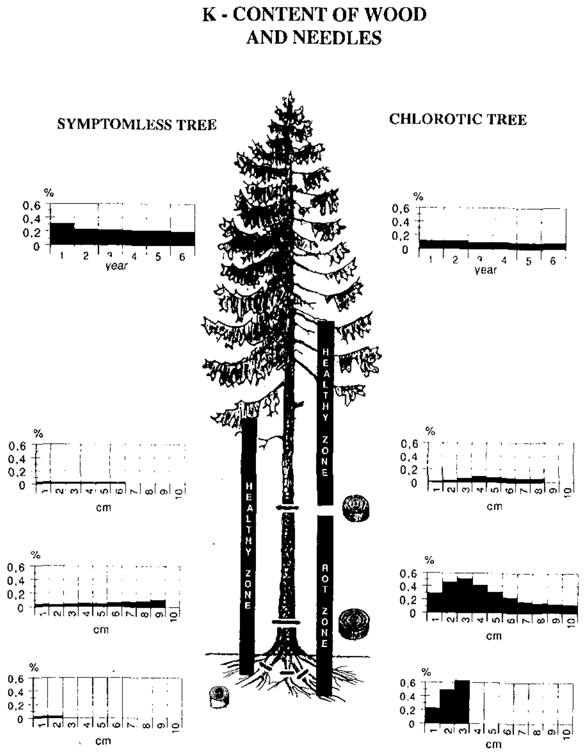

Figure 5. Comparision of the K - content of wood and needles of 1 symptomless and 1 chlorotic Norway spruce.

K, Mg, Ca in the needles and, at the same time, an increase of these nutrients in the sapwood of chlorotic Norway spruce.

Trees affected by butt and/or root rot need special nutrients for physiochemical defense reactions. Compartmentalization, described by Shigo (14), is such a physiochemical reaction where enzymes are necessary and among other things, phenolic compounds are built (15). Kramer et al. (6) reported on the great importance of K for many enzymatic reactions in plants. K and Ca exist in numerous co-enzymes and buffer systems of plants and are needed for the energy transfer within plants. Bonner et al. (1) considered K the most important element for the regulation of the osmotic pressure of plant cells and, therefore, for the defense system of plants.

The importance of the cations K, (Mg), Ca for enzymatic reactions within plants on the one hand and the investigated imbalance caused by root and/or butt rot affected Norway spruce on the other, let us assume that mineral deficiency in spruce needles and acute chlorosis as its symptom are caused by physiochemical reactions like the reinforcement of cell walls and the compartmentalization of wood after fungal attacks.

Table 3. Mean percentage of nutrient content of soil near sample trees.

	symptomless trees	chlorotic trees
N	0.51	0.57
P_2O_5	0.143	0.136
K	0.20	0.23
Ca	1.68	3.44
Mg	0.31	0.70
Mn	0.07	0.103

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Résumé. Vingt et unes épinettes de Norvège (*Picea abies*) en bonne santé et 21 malades, présentes sur trois sites forestiers différents en Australie, ont été abattues et étudiées en regard de la présence de pourriture dans les racines et la souche. Le contenu en éléments nutritifs des aiguilles et du bois d'aubier des racines et des branches a été comparé. Les arbres présentant des aiguilles très jaunies avaient des taux significativement plus élevés de pourriture des racines et/ou de la souche ainsi que des taux plus bas de potassium, de calcium et de magnésium dans le bois d'aubier des racines et des branches basses de l'arbre.

Zusammenfassung. Seit den späten 70er und frühen 80er Jahren wird in einigen Teilen Österreichs, sowie Mittel- und Nordeuropas das Phänomen der "akuten Nadelvergilbung" an Fichte (*Picea abies*) beobachtet. An ausgewählten Baumpaaren bestehend aus je einem "symptomfreien" und einem "vergilbten" Baum wurden Nadelproben, Holzproben aus dem Stamm- und Wurzelbereich sowie Bodenproben geworben. Vergilbte Fichten hatten signifikant höhere Fäuleanteile in Wurzel- und Stammholz, geringe Kali-, Calcium- und Magnesiumgehalte in den Holzproben der Wurzeln und der unteren Stammscheiben. Eine Bilanzierung der absoluten Nährelementgehalte im Stammholz im Verhältnis zu den Gehalten aller Nadeln in der Baumkrone ergab, daß im Holz der vergilbten Fichten bis zum 79-fachen an Kalium gespeichert wird, während das Holz "symtpomfreier" Fichten "nur" etwa das 1,5-fache an Kalium der Nadelmasse enthält. Die Bilanzierung von Calcium und Mangesium ergab ähnliche Resultate. Die Bodenanalysen zeigten keine signifikanten Unterschiede in den Nährelementgehalten im Bereich der vergilbten bzw. der symtomfreien Fichten. Es wird daher angenommen, daß physiochemische Abwehrreaktionen, wie z.B. Kompartmentierung und Zellwandverstärkung in Zusammenhang mit Fäulepilzbefall, die akute Nadelvergilbung