The Effect of Fertilisation on the Severity of Sirococcus Shoot Blight in a Mature Norway Spruce (*Picea abies* [L.] Karst.) Stand

Erhard HALMSCHLAGER[a*] – Hans ANGLBERGER[a] –
Klaus KATZENSTEINER[b] – Hubert STERBA[c]

[a] Institute of Forest Entomology, Forest Pathology and Forest Protection (IFFF),
[b] Institute of Forest Ecology, [c] Institute of Forest Growth and Yield Research, Department of Forest and Soil Sciences University of Natural Resources and Applied Life Sciences (BOKU), Vienna, Austria

Abstract – The paper reports on the effect of fertilisation on the severity of Sirococcus shoot blight in a mature Norway spruce stand. Trees with severe symptoms of Sirococcus shoot blight were characterised by insufficient Mg and Ca supply and enhanced N/Mg and N/Ca-ratios in the current-year and 3-year-old needles at the start of the project. Application of appropriate fertilisers in 2001 mitigated disease severity of the fertilised trees and promoted tree recovery. Best results were achieved by fertilisation with a water soluble Ca- and Mg-fertiliser (gypsum + kieserite-variant) which resulted in an 18.9 % decrease of disease severity in the period 2001 – 2006. While dolomitic liming also promoted tree recovery (decrease in disease severity was 11.8 %), in the unfertilised control variant a 3.5 % increase was observed in the same period.

Sirococcus conigenus **/ disease severity / liming / application of gypsum and kieserite**

Kivonat – Tápanyag-utánpótlás hatása a Sirococcus hajtáspusztulásra egy érett lucfenyő (*Picea abies* [L.] Karst.) állományban. A dolgozat témája a tápanyag-utánpótlás hatásának vizsgálata a Sirococcus hajtáspusztulás súlyosságára egy érett lucfenyő állományban. A Sirococcus hajtáspusztulás által súlyosan érintett fákra a kísérlet kezdetén jellemző volt a Mg és Ca elégtelenség és a megnövekedett N/Mg és N/Ca arány a folyó évi és a három éves tűkben. Megfelelő tápanyagok 2001-ben történt kijuttatása enyhítette a betegség súlyosságát és elősegítette a fák gyógyulását. Legjobb eredményt egy vízben oldódó Ca és Mg tápszerrel értünk el (gipsz + kieserite változat), amely a 2001-2006 időszakban a betegség súlyosságát 18,9%-kal csökkentette. A dolomitos mész szintén elősegítette a gyógyulást (a betegség súlyosságának csökkenése 11,8% volt). A kezeletlen kontroll változatnál a betegség mértéke ezalatt 3,5%-kal növekedett.

Sirococcus conigenus **/ betegség súlyossága / meszezés / gipsz és kieserite alkalmazás**

[*] Corresponding author: erhard.halmschlager@boku.ac.at; Hasenauerstraße 38, A-1190 VIENNA

1 INTRODUCTION

Sirococcus conigenus (DC.) P. Cannon & Minter (syn. *S. strobilinus* G. Preuss, *Ascochyta piniperda* Lindau) is an asexually reproducing fungus causing shoot blight and seedling death of many conifer hosts throughout much of the northern hemisphere (Smith 1973, Shahin – Claflin 1978, Sutherland 1987, Sanderson – Worf 1986, Farr et al. 1989, Halmschlager et al. 2000). Although the fungus was described already in 1796 from cone scales of Norway spruce (*P. abies* [L.] Karst.) by Persoon (Cannon – Minter, 1983), the disease was first reported in 1890 from Germany on current-year shoots of Norway spruce by Hartig. Sirococcus shoot blight has subsequently been reported on a wide range of conifer hosts in Europe and North America, where it mainly affects *Picea* and *Pinus* spp. but also attacks *Abies*, *Cedrus*, *Larix*, and *Pseudotsuga* (Peace 1962, Sutherland 1987, Butin 1995, Danti – Capretti 1998, Bronson et al. 2003, Smith et al. 2003, Sinclair – Lyon 2005). There is also one report from *Pinus halepensis* Mill. in North Africa (Morelet 1972) and most recently the disease also has been found on *Picea spinulosa* (Griff.) Henry in Bhutan (Kirisits et al. 2007).

In Central Europe the pathogen mainly occurs on Norway spruce (Hartig 1893, Rudolph 1898, Klein 1987, Minerbi 1987, Wulf – Maschning 1992, Neumüller 1994, Anglberger 1998, Anglberger – Halmschlager 2003, Stetter et al. 2004). According to recent estimates about 6500 ha of spruce forests are affected by *Sirococcus* shoot blight in the county of Upper Austria (Reisenberger 2007). In two forest districts (Freyung, Passau) in the neighboring Eastern Bavaria 850 ha are affected and on 240 ha stands decline and need to be harvested long before they reach the prescribed rotation age (Stetter al. 2004).

Disease severity was found to be highest in secondary spruce forests on poor and acidified soils and west exposed upper slopes as well as on hilltops, where *Sirococcus* shoot blight has become a major destabilizing factor (Anglberger – Halmschlager 2003, Stetter et al. 2004). Furthermore, the study of Anglberger et al. (2003) revealed insufficient Mg and Ca supply and enhanced N/Mg and N/Ca ratios in the needles of severely affected trees, whereas in healthy trees all needle element contents were above the threshold for deficient supply. Although healthy trees also yielded the fungus, no symptoms developed, which indicates latent infections. Thus, a close relation between supply of base cations, in particular magnesium, and severity of Sirococcus shoot blight of Norway spruce was hypothesized (Anglberger et al. 2003). To test the hypothesis that improved nutrient supply will have an impact upon Sirococcus shoot blight and promote recovery of diseased trees, a single-tree fertilisation experiment was established at a site already investigated by Anglberger et al. (2003).

2 MATERIAL AND METHODS

2.1 Study site and experimental design

The fertilisation experiment was established in autumn 2000 in a 90-year-old Norway spruce stand severely affected by Sirococcus shoot blight *(Table 1)*. The stand is situated in the Kobernausser Wald, Upper Austria (48°04´42´´ N, 13°14´19´´E) and has already been investigated prior to fertilisation by Anglberger et al. (2003). A total of 144 dominant or co-dominant trees, randomly distributed within an 8.2 ha area in the investigated stand, were selected. Half of the trees were severely affected by Sirococcus shoot blight (“Sirococcus +”), whereas the other trees were apparently healthy and vigorous (“Sirococcus -“). A tree was counted as ‘healthy’ when less than 5% of the current year shoots were affected by Sirococcus shoot blight.

A randomised block design with the factors "slope section" (lower slope versus upper slope) and "Sirococcus shoot blight" (severely affected versus healthy trees) was used. Within these blocks sample trees were randomly assigned to one of the three treatments (dolomitic liming, application of gypsum and kieserite, unfertilised control) (*Table 2, Figure 1*). In order to characterise the current nutritional and health status of sample trees and to derive treatments, soil analyses and needle analyses as well as an evaluation of disease severity had been carried out prior to fertilisation. The nutrient status of diseased and healthy trees prior to fertilisation has already been assessed on 72 out of the 144 sample trees in a previous study (Anglberger et al. 2003).

Table 1. Site and stand characteristics of the experimental site

Site characteristics	
Location	48°04´42´´ N, 13°14´19´´E
Elevation (m)	600
Aspect	W
Bedrock	Tertiary gravels
Slope (°)	15
Soil types	Dystric cambisols and podzols
Humus type	Moder
Soil pH ($CaCl_2$)	Organic layer: 3.00, A horizon: 2.99
Base saturation (%)	Mineral horizons: 4.62 – 14.48

Stand characteristics	
Tree age (a)	90
Number of trees per hectare	432
Basal area (m^2ha^{-1})	37.7
Breast height diameter (cm) of the mean basal area stem	33.3
Volume per hectare(m^3ha^{-1})	463
Stocking degree	0.79

Table 2. Experimental design

Treatments	Upper slope (dbh ≥ 33cm)*		Lower slope (dbh ≥ 30cm)*		
	Severely affected trees	Healthy trees	Severely affected trees	Healthy trees	
Dolomitic lime	12 (6)	12 (6)	12 (6)	12 (6)	Σ = 48 (24)
Gypsum & kieserite	12 (6)	12 (6)	12 (6)	12 (6)	Σ = 48 (24)
Unfertilised control	12 (6)	12 (6)	12 (6)	12 (6)	Σ = 48 (24)
Σ	36 (18)	36 (18)	36 (18)	36 (18)	
Σ	72 (36)		72 (36)		
Σ	144 (72)				

Numbers in parentheses refer to the number of trees subjected to needle analyses in the previous study of Anglberger et al. (2003); one-third (= 48) of the sample trees were felled in June 2004. *) Minimum diameter of trees included in the study (dominant or co-dominant trees) – it differed between upper and lower slope due to the lower number of trees per hectare on the upper slope which implied a higher mean tree diameter on this slope section.

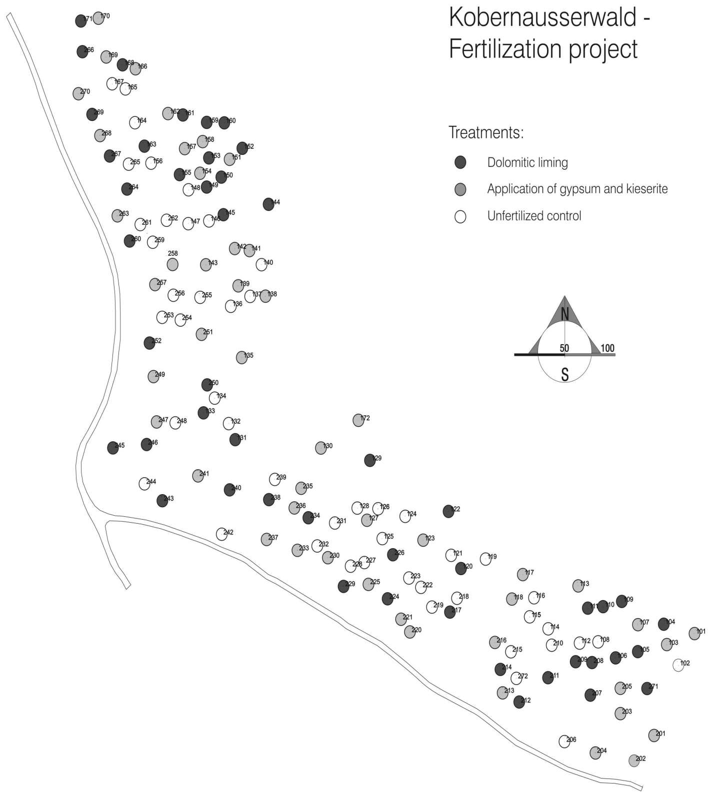

Figure 1. Distribution of sample trees randomly assigned to one of the three treatments (see legend), the dots indicate the area that was fertilised or left untreated; Upper Slope: Tree Nos. starting with 101; Lower slope: Tree Nos. starting with 201; ÖBF district management Traun- & Innviertel, forest district 'Frauschereck', subcompartment 237b$_1$

2.2 Treatments

Because results of needle analyses prior to fertilisation (Anglberger et al. 2003) revealed insufficient Mg and Ca supply especially on severely affected trees, Ca- and Mg-fertilisers were applied in this study to promote recovery of diseased trees. Two different fertiliser treatments (dolomitic liming, combined application of gypsum and kieserite) and an unfertilised control variant were used in this study. Short term amelioration should be achieved by fertilisation with a water soluble Ca- and Mg-fertiliser (gypsum and kieserite variant: 500 kg ha^{-1} gypsum, Co. Moldan, Kuchl and 400 kg ha^{-1} kieserite, Co. Kali & Salz GmbH via Co. Danufert, Krems). As a medium-term amelioration measure slow-release dolomitic liming (3000 kg ha^{-1} dolomitic lime, Co. Bodenkalk, Graz) was applied, aiming at both improving Ca- and Mg-supply, enhancing soil pH and accelerating litter turnover.

The granular fertilisers were spread manually in a circular area around the individual trees (within a horizontal radius of 4 m from the tree base) before bud break in late April 2001. According to the applied amounts of fertilisers the following quantities (kg ha^{-1}) of Ca and Mg were applied in the two fertiliser treatments (*Table 3*).

Table 3. Quantities (kg ha^{-1}) of Ca and Mg applied in the two fertiliser treatments

	Ca	Mg
Dolomitic liming	974	282
Application of gypsum and kieserite	90	60

2.3 Disease severity of individual trees

Ratings of disease severity of individual trees were carried out yearly from 2001 until the end of the project in summer 2006 by estimating the percentage of diseased previous year shoots in April (before the emergence of new shoots), using a pair of binoculars. If there was an uniform distribution of *Sirococcus* shoot blight in the crown, disease severity (DS) was assessed for the whole crown, whereas in the case of a patchy distribution, DS was estimated separately for each part of the crown (crown halves or crown thirds) and ratings were afterwards weighted with the respective crown mantle area to calculate DS_{total} as follows (*Figure 2*):

Total DS calculated from estimates of crown halves (a):

$$DS_{total} = 0{,}32\ DS_{upper} + 0{,}68\ DS_{lower\ part\ of\ crown}$$

Total DS calculated from estimates of crown thirds (b):

$$DS_{total} = 0{,}14\ DS_{upper} + 0{,}43\ DS_{middle} + 0{,}43\ DS_{lower\ part\ of\ crown}$$

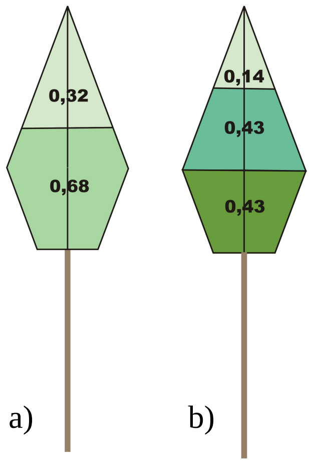

Figure 2. Calculation of disease severity (DS) on trees with patchy distribution of Sirococcus shoot blight

2.4 Statistical analyses

The effects of treatment, tree health status and slope position and the interaction between tree health status and treatment on disease severity (statistical significance of the differences between disease severity of the respective years and disease severity prior to fertilisation) were tested by univariate analyses of variance, using GLM procedure of SPSS.

3 RESULTS

3.1 Effects of treatment, tree health status and slope position

In the period 2001-2002 fertilisation had no effect on disease severity yet, whereas in the 2-year period 2001-2003 a significant effect of treatment occurred for the first time (*Table 4*). This significant effect of fertiliser treatments on disease severity was found in all following periods until the end of the project in 2006.

The affiliation of sample trees to the class of the severely diseased or that of the healthy trees (tree health status) was significant in the periods 2001-2002, 2001-2003 and again in 2001-2006. In the latter period as well as in 2001-2003 and 2001-2005 there was also a significant effect of the interaction between tree health status and treatment. A significant effect of slope position only occurred in the periods 2001-2003 and 2001-2005.

Table 4. Effects of treatment, tree health status and slope position on disease severity (univariate ANOVA)

Factors	Significant probability				
	2001-2002	2001-2003	2001-2004	2001-2005	2001-2006
Treatment	n.s.	*	*	(*)	**
Tree health status (healthy / diseased)	***	**	n.s.	n.s.	***
Interact.: Tree health status x treatment	n.s.	(*)	n.s.	(*)	**
Slope position	n.s.	**	n.s.	**	n.s.

Stars indicate error probability levels obtained by F-tests (n.s. = not significant):
(*) $0.10 \geq P > 0.05$ * $0.05 \geq P > 0.01$ ** $0.01 \geq P > 0.001$ *** $P \leq 0.001$

3.2 Comparison between treatments due to tree health status prior to fertilisation

Although a significant effect of treatment was already detected in the period 2001-2003, a reduction of disease severity could only be achieved by the gypsum + kieserite -treatment in this period. In the unfertilised control variant disease severity increased between 2001-2003 by 6.3%, and in the liming-treatment by 12.5%. In the periods 2001-2004, 2001-2005 and 2001-2006 differences between treatments became more pronounced: From 2004 onwards disease severity was always lower for the fertilised treatments compared to the unfertilised control variant. Until the end of this investigation in 2006, disease severity decreased on the severely affected trees by 18.9% in the "combined gypsum and kieserite"-treatment and by 11.8% in the „liming"-treatment, whereas a 3.5% increase was observed in the control variant. In summary, results indicate that the improvement of the nutritional status of single trees by application of appropriate fertilisers mitigated disease severity of the fertilised trees and promoted tree recovery.

Table 5. Mean decrease (-) or increase (+) of disease severity [in %] for the healthy and the severely affected trees due to treatments and tree health status (in relation to disease severity prior to fertilisation)

Periods	Tree health status	Treatments		
		Dolomitic liming	Gypsum and kieserite	Unfertilised control
2001-2003	Healthy	-0.1	-0.8	0.0
	Severely affected	+12.5	-0.6	+6.3
2001-2004	Healthy	-0.3	-0.8	+0.9
	Severely affected	-1.9	-8.8	+3.5
2001-2005	Healthy	-1.3	0.0	0.0
	Severely affected	+0.4	-9.2	+4.0
2001-2006	Healthy	-1.0	0.0	-0.4
	Severely affected	-11.8	-18.9	+3.5

3 DISCUSSION

Stands suffering from Sirococcus shoot blight are mostly growing on poor sites with soils characterized by low base saturation (Klein 1987, Neumüller 1992, Anglberger – Halmschlager 2000, Halmschlager et al. 2000, Jandl et al. 2000, Stetter et al. 2004). Furthermore, the majority of Central European forest ecosystems were additionally impoverished by litter raking in the past (Glatzel 1991, Katzensteiner – Glatzel 1997), which was also a common form of historic land use in the investigation area (Reinisch 1873, Jenner 1979).

Consequently, affected stands are characterized by poor supply of soil Mg and Ca which causes poor status of these nutrients in foliage. Berger – Katzensteiner (1994) found high input rates of air pollutants, in particular nitrogen, in the research area, further deteriorating base cation supply. The input of nitrogen compounds by atmospheric deposition is most likely to induce nutritional imbalances (Glatzel et al. 1987, Schulze 1989, Katzensteiner et al. 1992) and is probably the cause for enhanced N/Ca and N/Mg ratios in the foliage. Poor supply of base cations and nutritional imbalances are suggested to increase susceptibility of Norway spruce to *Sirococcus* shoot blight (Anglberger et al. 2003). The nutritional status of the stands may worsen in the following decades as long as measures of amelioration are lacking. However, fertilisation of forest stands remains a controversially discussed topic until today, because amelioration fertilization often caused a change in resistance of trees to fungal diseases and insect pests (e.g. Dimitri 1977, Marschner 1995, Kytö et al. 1996, Piri 1998).

In the present study, however, site-specific compensatory fertilisation with Ca- and Mg-fertilisers (dolomitic liming, application of gypsum and kieserite) resulted in a significant decrease of disease severity of the severely affected trees and promoted tree recovery. The lower level of significance observed in 2005 ($P \leq 0.10$) may be due to the reduced sample size, because one-third of sample trees were felled in June 2004 for a growth study. Results correspond well with the findings of Anglberger - Halmschlager (2000) and Jandl et al. (2000) in earlier studies, comparing the severity of Sirococcus shoot blight on fertilised and unfertilised plots in degraded Norway spruce stands on poor podzolic soils over old silicate bedrock or tertiary gravels. In both studies the application of magnesium rich carbonate fertilisers harmonised tree nutrition and mitigated severity of Sirococcus shoot blight at the investigated sites, whereas the application of fertilisers with relatively high N-contents and only small portions of Mg did not achieve similar results. However, in contrast to the present study the health status of trees prior to fertilisation could not be assessed in these earlier studies. Furthermore, comparison was carried out for trees on adjacent plots whereas in the present study sample trees were randomly assigned to one of the three treatments within the given blocks on the study site.

The applied quantities of Ca and Mg in the two fertiliser treatments correspond to the amounts that were used in other vitality fertilisation studies (Kilian et al. 1995, Kytö et al. 1996). Due to the slow release of Ca and Mg from dolomitic lime, amounts of applied Ca and Mg were five (Mg) to ten times higher (Ca) in the liming variant compared to the gypsum and kieserite variant.

In the gypsum and kieserite variant a significant effect of treatment was already detected 2 years after fertilisation, indicating that short term recovery of trees can be achieved with this water soluble fertiliser. This effect proceeded till the end of the project in 2006, when disease severity decreased on the severely affected trees by 18.9%. The rapid response of fertilised trees can be explained by the quick plant availability of Ca and Mg in this treatment. In the dolomitic liming slight differences compared to the control occurred already after 3 years, but a considerable decrease in disease severity was not found until 5 years after fertilisation (-11.8%). Thus, liming has a medium term effect due to the slow release of Ca and Mg, by increasing soil pH and by acceleration of litter-turnover. In the unfertilised control variant disease severity of the severely affected trees increased by 6.3% in the period 2001-2003 and then was constant about 3.5 – 4% above the value obtained in 2001. Thus, no recovery of trees was observed in the control variant. On the other hand, disease severity did not further increase over years.

As it was clearly shown, application of appropriate fertilisers diminished disease severity in both fertiliser treatments and promoted tree recovery. It is therefore suggested that microsite differences and/or genetic variation may contribute to differences in disease incidence and severity of individual trees.

Increased host susceptibility due to nutritional imbalances has already been reported from other fungi, causing shoot blight and canker on conifers. Ylimartimo (1991) demonstrated that high N/K and N/Mg ratios reduced resistance of Scots pine seedlings to *G. abietina* infections and Roelofs et al. (1985) reported that foliar K and Mg levels were lower in *Pinus nigra* var. *maritima* trees infected by *Gremmeniella abietina* (Lagerb.) Morelet and/or *Sphaeropsis sapinea* (Fr.) Dyko & Sutton, compared with uninfected trees, whereas availability of N was increased in the damaged trees. However, there were no studies up to now to our knowledge that aimed to reduce disease severity and to promote tree recovery by application of site-specific compensatory fertilisers.

Acknowledgements: We gratefully acknowledge the support of the Austrian Federal Forests (Österreichische Bundesforste AG), district management Traun- & Innviertel in supplying the plot and local resources for this investigation. Thanks are also due to the local forest service officer, H. Haberzettl, and all stuff of the collaborating institutes involved in this project for field and laboratory assistance. This research was funded by the Ministry of Agriculture, Forestry, Environment and Water Management (Grant 56.810/17-VA2b/2001). This paper is part of a broader study on *Sirococcus* shoot blight in Austria.

REFERENCES

ANGLBERGER, J. (1998): Zusammenhänge zwischen Düngung und der Intensität des Triebsterbens an Fichte (*Picea abies* [L.] Karst.) in den Untersuchungsgebieten Kobernaußerwald und Sauwald. Diploma thesis, BOKU - University of Natural Resources and Applied Life Sciences, Vienna, Austria.

ANGLBERGER, H. – HALMSCHLAGER, E. (2000): Fertilisation as a control measure to *Sirococcus* shoot blight in secondary Norway spruce stands. In: Hasenauer, H. (ed.): Forest Ecosystem Restoration: Ecological and Economical Impacts of Restoration Processes in Secondary Coniferous Forests. Proc. Int. Conf. on Forest Ecosystem Restoration, Vienna, Austria. 29-34.

ANGLBERGER, H. – HALMSCHLAGER, E. (2003): The severity of *Sirococcus* shoot blight in mature Norway spruce stands with regard to tree nutrition, topography and stand age. For. Ecol. Managem. 177: 221-230.

ANGLBERGER, H. – SIEGHARDT, M. – KATZENSTEINER, K. – HALMSCHLAGER, E. (2003): Needle nutrient status of *Sirococcus* shoot blight-diseased and healthy Norway spruces. For. Path. 33: 21-29.

BERGER, R. – KATZENSTEINER, K. (1994): Massenauftreten der kleinen Fichtenblattwespe *Pristiphora abietina* (Christ) im Hausruck. Teil II Immissionsökologische Einflüsse. J. Appl. Entomol. 118: 253-266.

BUTIN, H. (1995): Tree Diseases and Disorders: Causes, Biology, and Control in Forest and Amenity Trees. Ed. by Lonsdale, D. from a translation by Strouts, R., Oxford University Press, Oxford, UK. 252 p.

BRONSON, J.J. – STANOSZ, G.R. – PUTNAM, M.L. (2003): First report of *Sirococcus conigenus* on deodar cedar in Oregon. Plant Disease 87: 1006.

CANNON, P.F. – MINTER, D.W. (1983): The nomenclatural history and typification of *Hypoderma* and *Lophodermium*. Taxon 32: 572-583.

DANTI, R. – CAPRETTI, P. (1998): Shoot blight of *Pinus halepensis* Mill. in the Italian peninsula. In: LaFlamme, G. – Bérubé, J.A. – Hamelin, R.C. (eds.): Foliage, Shoot and Stem Diseases of Trees. Proceedings of the IUFRO WP 7.07.02, Quebec City, Canada, Laurentian Forestry Centre, Information Report LAU-X-122. Canadian Forest Service, Quebec City, Canada. May 1997. 103-107.

DIMITRI, L. (1977): Influence of nutrition and application of fertilisers on the resistance of forest plants to fungal diseases. Eur. J. For. Path. 7: 177-186.

FARR, D.F. – BILLS, G.F. – CHAMURIS, G.P. – ROSSMAN, A.Y. (1989): Fungi on plants and plant products in the United States. APS Press, St. Paul. 961 p.

GLATZEL, G. (1991): The impact of historic land use and modern forestry on nutrient relations of Central European forest ecosystems. Fertiliser Research 27: 1-8.

HALMSCHLAGER, E. – ANGLBERGER, H. – NEUMÜLLER, A. (2000): Die Bedeutung des *Sirococcus*–Triebsterbens in sekundären Fichtenwäldern. In: Müller, F. (ed.): Umbau sekundärer Nadelwälder. FBVA Berichte 111/2000: 95-100 (Schriftenreihe der Forstlichen Bundesversuchsanstalt Wien), Federal Forest Research Centre Vienna, Austria.

HARTIG, R. (1890): Eine Krankheit der Fichtentriebe. Z. Forst- u. Jagdw. 22: 667-670.

HARTIG, R. (1893): *Septoria parasitica* in älteren Fichtenbeständen. Forstl.-Naturw. Zeitschr. 2: 357–359.

JANDL, R. – ANGLBERGER, H. – REH, M. – HALMSCHLAGER, E. (2000): Auswirkung von Düngemaßnahmen auf einen sekundären Fichtenbestand im Kobernaußerwald mit Symptomen des Fichten-Triebsterbens. Die Bodenkultur 51: 247-258.

JENNER, R. (1979): Forstgeographie des Kobernaußerwaldes. Dissertationen der Universität Salzburg 10, Verband der wissenschaftlichen Gesellschaften Österreichs, Vienna, 304 p.

KATZENSTEINER, K. – GLATZEL, G. (1997): Causes of magnesium deficiencies in forest ecosystems. In: Hüttl, R.F. – Schaaf, W. (eds.): Magnesium deficiency in forest ecosystems. Kluwer Academic Publishers, Dortrecht.

KATZENSTEINER, K. – GLATZEL, G. – KAZDA, M. (1992): Nitrogen induced nutritional imbalances – a contributing factor to Norway spruce decline in the Bohemian Forest (Austria). For. Ecol. Manage. 51: 29-42.

KILIAN, W. ET AL. (1995): Düngung im Wald II. Teil Fachbeirat für Bodenfruchtbarkeit und Bodenschutz im Bundesministerium für Land- und Forstwirtschaft, Wien, 1995, 41 p.

KIRISITS, T. – KONRAD, H. – HALMSCHLAGER, E. – STAUFFER, C. – WINGFIELD, M.J. – CHHETRI, D. (2007): Sirococcus shoot blight on *Picea spinulosa* in Bhutan. For. Path. 37: 40-50.

KLEIN, E. (1987): Breiten sich Rindenpilzschäden bei Hochlagenfichten aus? Allg. Forstz. 42: 356-358.

KYTÖ, M. – NIEMELÄ, P. – LARSSON, S. (1996): Insects on trees: Population and individual response to fertilisation. Oikos 75: 148-159.

MARSCHNER, H. (1995): Mineral nutrition of higher plants. Academic Press, London-New York. 889 p.

MINERBI, S. (1987): Zweigsterben an Waldbäumen in mittleren Berglagen Südtirols. Allg. Forstz. 42: 762-763.

MORELET, M. (1972): *Ascochyta piniperda* on *Pinus halepensis* in Provenece and Morocco. Bulletin de la Societe des Sciences Naturelles et d' Archeologie de Toulon et du Var. 198: 8-9.

NEUMÜLLER, A. (1992): Untersuchungen zum Zweig- und Aststerben an Fichte (*Picea abies* (L.) Karst.) in Schöneben. Diploma thesis, BOKU - University of Natural Resources and Applied Life Sciences, Vienna, Austria. 70 p.

NEUMÜLLER, A. (1994): Beteiligung von Pilzen am Zweig- und Aststerben der Fichte im Revier Sonnenwald (Böhmerwald). In: Führer, E. – Neuhuber F. (eds.): Zustandsdiagnose und Sanierungskonzepte für belastete Waldstandorte in der Böhmischen Masse. Forstl. Schriftenreihe Univ. Bodenkultur Wien 7: 171-190.

PEACE, T. R. (1962): Pathology of Trees and Shrubs. Oxford University Press, Oxford, U.K. 753 p.

PIRI, T. (1998): Effects of vitality fertilisation on the growth of *Heterobasidion annosum* in Norway spruce roots. Eur. J. For. Pathol. 28: 391-397.

REINISCH, K. (1873): Betriebs-Einrichtung für den Kobernauserwald des K. K: Familiengutes Mattighofen. Selbstverlag der K. K. Familien-Fonds-Direction Wien, 128 p.

REISENBERGER, J. (2007): Waldschadenssituation 2006 in Oberösterreich. Bericht für BOKU-Forstschutzexkursion 14. Juni 2007 in Lambach, OÖ Landesforstdienst, Linz.

ROELOFS, J.G.M. – KEMPERS, A.J. – HOUDIJK, A.L.F.M. – JANSEN, J. (1985): The effect of air-borne ammonium sulphate on *Pinus nigra* var. *maritima* in the Netherlands. Plant Soil 84: 45-56.

RUDOLPH, (1898): Vortrag über die Pilzkrankheit *Septoria parasitica*. Forstl.-Naturwiss. Zeitschr. 7: 265-273.

SANDERSON, P. G. – WORF, G. L. (1986): *Phomopsis* and *Sirococcus* shoot blights of Colorado blue spruce in Wisconsin. Plant Dis. 70: 1159.

SCHULZE, E.-D. (1989): Air pollution and forest decline in a spruce (*Picea abies*) forest. Science 244: 776-783.

SHAHIN, E.A. – CLAFLIN, L.E. (1978): The occurrence and distribution of *Sirococcus* shoot blight of spruce in Kansas. Plant Dis. Rep. 62: 648-650.

SINCLAIR, W.A. – LYON H.H. (2005): Diseases of Trees and Shrubs, second edition. Cornell University Press, Ithaca. 660 p.

SMITH, D.R. – BRONSON, J.J. – STANOSZ, G.R. (2003): Host-related variation among isolates of the *Sirococcus* shoot blight pathogen from conifers. For. Path. 33: 141-156.

SMITH, R.S., Jr. (1973): *Sirococcus* tip dieback of *Pinus* spp. in California forest nurseries. Plant Dis. Rep. 57: 69-73.

STETTER, U. – BLASCHKE, M. – HELFER, W. (2004): Krumme Triebe, dürre Wipfel. Sirococcus-Triebstreben der Fichte im Bayerischen Wald. LWF aktuell 47: 24-25.

SUTHERLAND, J. R. (1987): Sirococcus blight. In: Sutherland, J.R. – Miller, T. – Quinard, R.S. (eds.): Cone and Seed Diseases of North American Conifers. Victoria, NAFC Publ. 1: 34-41.

WULF, A. – MASCHNING, E. (1992): *Sirococcus* – Triebsterben der Fichte. In: 48. Deutsche Pflanzenschutz-Tagung. Mitt. Biol. Bundesanst. Land- Forstwirtsch. Berlin-Dahlem 283: 412.

YLIMARTIMO, A. (1991): Effects of foliar nitrogen, potassium and magnesium concentrations on the resistance of Scots pine seedlings to Scleroderris canker infection. Eur. J. For. Path. 21: 414-423.