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Investigations of Ammonia Stressed Scots Pine Trees (*Pinus sylvestris* L.) with Computed Tomography in an Immission Area Around a Cattle Farm

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With 1 Figure

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Summary

KÄTZEL R., RIDDER H.-W. & HABERMEHL A. 1997. Investigations of Ammonia Stressed Scots Pine Trees (*Pinus sylvestris* L.) with Computed Tomography in an Immission Area Around a Cattle Farm. – Phyton (Horn, Austria). 37 (1): 141–149, 1 figure. – English with German summary.

The sapwood-heartwood ratio of middelaged Scots pines, taken from three differently nitrogen polluted sites, was examined by means of computed tomography. The result was, that the examined pines in immediate vicinity of the ammonia emittent possess a lower sapwood-heartwood ratio. The moisture of the sapwood of trees located near a cattle farm was significantly reduced. Possible reasons for the accelerated aging processes are discussed.

Zusammenfassung

KÄTZEL R., RIDDER H.-W. & HABERMEHL A. 1997. Computertomografische Untersuchungen an stickstoffbelasteten Kiefern (*Pinus sylvestris* L.) im Eintragsgebiet einer Rindermastanlage. – Phyton (Horn, Austria). 37 (1): 141–149, 1 Abbildung. – Englisch mit deutscher Zusammenfassung.

Im Frühherbst 1994 durchgeführte computertomografische Untersuchungen im Stammbereich von 28 mittelalten Kiefern aus jeweils drei unterschiedlich stick-

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stoffbelasteten Baumkollektiven zeigen, daß die untersuchten Kiefern in unmittelbarer Nähe des NH_3-Emittenten einen höheren Verkernungsgrad und damit einen verminderten Splintflächenanteil aufweisen. Die Holzfeuchte des Splintes der emittentennahen Bäume war signifikant vermindert. Mögliche Ursachen für die beschleunigten Szeneszenzprozesse werden diskutiert.

Introduction

Over the last two decades, nitrogen inputs in pine forest ecosystems have clearly increased in the North Eastern lowland of Germany by locally very different input intensities. Some pine stands are strongly influenced and partially damaged by vast grounds of livestock farms (MOHR 1990, HEINSDORF 1993, KÄTZEL & al. 1995).

During several years treephysiological investigations were carried out in middle aged pine stands near a big cattle farm. They emphasize changes in the energetic, carbohydrate, aminoacid and phenol metabolisms of the needles up to a distance of 1000 meters from the emittent (KÄTZEL & LÖFFLER 1995b).

In our state of knowledge the detoxification of the ammonia penetrating the needles is connected with an increased synthesis of carbohydrates. Therefore the processes of photosynthesis, including the synthesis of chlorophyll, is activated. Through the longer opened stomata the transpiration rate increases. Subsequently water stress may appear and the penetration of more ammonia is possible (VAN HOVE & al. 1991).

The increasingly formed carbohydrates react with the ammoniaions to aminoacids (f.e. arginine) (WEBER & al. 1995). If the binding capacity of the available C-skeletons isn't sufficient (f. e. because of a shortage of water, a reduced photosynthesis) carbohydrates from other metabolic pathways are redirected. In the consequence the biomass production (KNAPP 1990), the defence capacity (KÄTZEL & LÖFFLER 1995a), the rate of mykorhizza (JANSEN 1987, RITTER 1990, VAN DER EERDEN & al. 1991), and the frost hardness (PIETILÄ & al. 1991) are reduced.

By means of computed tomographic measurements this paper pursues the question if the primary effects in the needles cause long-termed changes in the structure of the trunks with concern especially to the sapwood-heartwood ratio.

Material and Methods

Investigation area

28 trees out of three differently stressed pure pine stands (investigation sites 1, 2 and 3) located inside a 3 km long transect in south – southeast direction of a large cattle farm (24 000 cattles) (forest district Torgelow, county Mecklenburg-Vorpommern, Germany) were tomographed during September 1993 and 1994. Trees with a

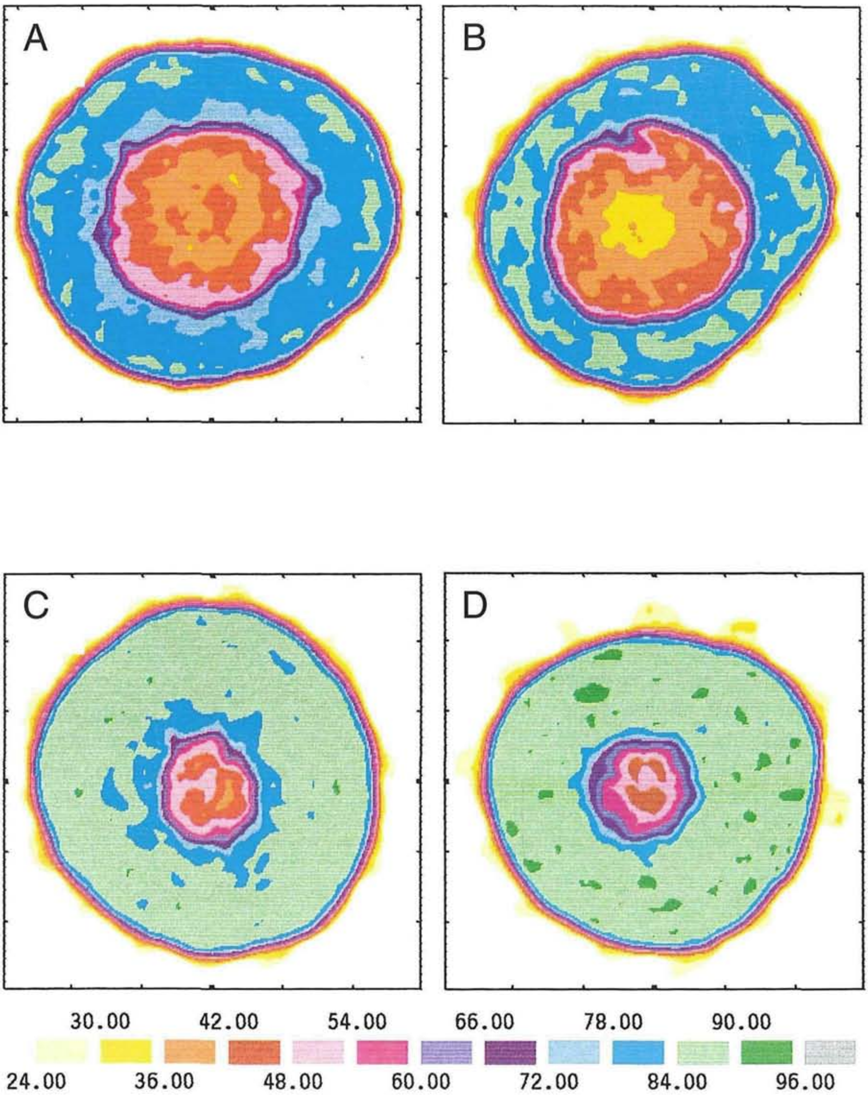

Fig. 1 a–d. Tomograms of the Scots pine 3 (investigation site 1, [a]), of the tree 8 (investigation site 2, [b]) and the trees 2 [c] and 8 [d], both from the investigation site 3 (tomographed on 30.09.94, in a stem hight of 100 cm).
The scale of colours shown below documents the distribution of moisture content corresponding to the CT numbers (30 = dry -> 96 = high moisture).

Table 1

Parameter of the investigation sites in 1994
(*average of the stand)

Number of the investigation plot	Age of the trees (years)	distance to the emittent (m)	DBH 1,3* (cm)	number of tomographed trees
1	73	200	28,0	8
2	73	280	29,5	10
3	75	2900	23,5	10

Table 2

Relations of wood type of Scots pine with the absorption coefficient and the colour scale of tomogramms.

Typ of wood	CT number (10^{-3} cm^{-1})	Colour scale of tomograms
sapwood	72-93	light blue – dark green
outer hardwood	54-72	dark red – violett
inner hardwood	36-54	light yellow ochre – light red
dry decayed regions, bark	24-36	light yellow – dark yellow
hollow spaces	< 24	white

Table 3

Average area of sapwood and heartwood of pines in different distances to the cattle farm (s = standard deviation of mean)

Investigation site	Cross section of the stems (total) cm^2	Sapwood area cm^2	Percentage of sapwood area %	Heartwood area cm^2
1	624	372	53,8	252
	(s =251)	(s = 1321)	(s = 12,7)	(s = 178)
2	745	487	57,8	258
	(s = 263)	(s = 210)	(s = 8,2)	(s = 105)
3	513	393	77,0	124
	(s = 153)	(s = 111)	(s = 8,0)	(s =63)

Table 4

Average CT-numbers (10^{-3} cm^{-1}) as a measure of wood moisture contents of wood in pine stands, which are differently far off the cattle farm

Investigation site	Moisture of wood (total) CT-number	Moisture of sapwood CT-number	Moisture of heartwood CT-number
1	67	81	50
	(s = 4)	(s = 2)	(s = 3)
2	69	81	51
	(s = 3)	(s = 1)	(s = 4)
3	74	86	53
	(s =5)	(s = 2)	(s = 2)

Table 5

Ratio of sapwood and heartwood area and the "qualified proportion of sapwood" in the stem of three different pine stands in different distances to the cattle farm

Investigation site	Ratio of sapwood and heartwood area	"Qualified proportion of sapwood" (absolut)*	"Qualified proportion of sapwood" (relative)**
1	1,5	300,6	43,6
	(s = 1)	(s = 103,4)	(s = 9,8)
2	1,9	395,5	46,9
	(s =1)	(s = 172,9)	(s = 6,1)
3	3,2	333,1	57,8
	(s = 2)	(s = 91,0)	(s = 7,7)

*absolut sapwood area x CT-number / 100

**percentage of sapwood area x CT-number / 100

comparable social status to be tomographed were selected from three stands having the same average diameters. The stands grow on uniform moderate moist soil with average nutrient supplied site quality (class Z2M).

Computed Tomography

The computed tomography (CT) is used for 15 years for non destructive examination of living trees. A mobile equipment measures the absorption of gamma rays within a thin layer of the trunk and computes the local distribution of absorption coefficients. The computed two dimensional matrix of absorption values (CT numbers), the tomogram, can be visualized by colour coding. The tomogram shows the extension of the water conducting sapwood area and the dry heartwood. It allows an indirect determination of the moisture content within different regions of the examined layer by means of the CT values (Habermehl & al.1986). Sections with CT values between 72 and 93 are here considered as sapwood (Table 2).

For the investigations described here the mobile tomograph MCT-3, constructed by the university of Marburg/Germany, was used. It contains 12.95 Gbq of the radionuclide Cs-137 (quantum energy 662 keV) as the source of the gamma radiation. The absorption of the rays penetrating the tree is measured by three detectors consisting of NaJ scintillation crystals and photomultipliers. With this equipment trees with diameters up to 72 cm can be examined (Habermehl & Ridder 1992).

Investigated were: the total cross section of the stems , the area of sapwood and heartwood, percentage of the sapwood, the CT-numbers of sapwood and heartwood as relative measure of the moisture content and the relative and absolut "qualified proportion of sapwood" (NAUMANN & al. 1995).

Results

Sizes of sapwood and heartwood regions

Although the three examined stands are nearly of the same age, the trees far away from the emittent show the smallest cross section of the stem. This was expected by the measured diameters of the stems. The pines of the investigation plot 2 possess the largest cross sections of the stems and the largest sapwood areas. Also the heartwood areas of trees whithin the sites 1 and 2 are about 130-140 cm^2 larger then those located on the more distant investigation area 3.

The percentage of the sapwood is largest (67,5%) for less nitrogen polluted trees. The differences of the ratio of sapwood to heartwood area are remarkable. Whereas the pines far away from the emittent (investigation site 3) possess a sapwood area four times larger than heartwood area, those on sites near the cattle farm (investigation site 1) have their sapwood area only twice as large as the heartwood area (Table 5). The differences are significant (multipe t-test; a = 0,05).

Absorption coefficients

The absorption coefficients (CT-numbers) as measured by CT are proportional to the physical density of the object. Applied to trees with comparable density of wood the CT-numbers are a relative measure of the moisture content (GRUBER 1995). The total moisture content of wood (amount of moisture of sap- and heartwood) of the examined trees near the cattle farm is significantly reduced compared to the less stressed trees, which is caused both by reduced sapwood and heartwood moisture contents (TUKEY-test, Table 4).

The multiplication of the percentage of sapwood area and its CT-number is a relative measure of moisture contents ("qualified proportion of sapwood", modified by KUCERA & BOSHARD 1993), which allows a valuation of the water transport capacity. This parameter increases with the increasing distance from the cattle farm (Table 3). On site 1 located near the emittent this "qualified proportion of sapwood" comes up to only 75,5 % of the value of site 3.

Discussion

As previous examinations demonstrate the ammonia emissions from the cattle farm during more than twenty years affect the growth and the vitality of the adjoining trees. CIR-aerial photographs show that accelerated ageing takes place years earlier than decline processes start.

The trees in investigation site 3 differ significantly from those in plots 1 and 2 concerning the area of heartwood, the sapwood moisture, and the total moisture content (multiple t-test). The last two differences are significant even with the TUKEY-test.

Whereas the increased stem diameters and cross-sections of the trees near the emittent can be explained by the earlier supporting effect of the nitrogen emmissions, the diminished ratios of sapwood to heartwood area refer to the early beginning of aging processes. The ratio between sapwood and heartwood areas of nitrogen stressed trees is only half as large as that of the pines in the investigation point 3 (Table 5). A reduction of sapwood area causing an accelerated aging of wood of spruces and pines in connection with air pollutants (e.g. SO_2) is described by various authors (HAPLA 1986a; HAPLA & al. 1987, SCHNELL & al. 1987).

As trees near the emittent (investigation sites 1 and 2) have not only a reduced sapwood area for water conduction but also a reduced moisture content, a significant smaller absolute water content inside the sapwood as well as inside the the heartwood can be assumed comparated with the pines of the investigation area 3. HAPLA 1986b found in the heartwood of differently damaged pines no significant differences of moisture contents, which is in contrast to our results presented here. A decrease of moisture contents of the sapwood and the percentage of sapwood with increasing forest decline class of damaged spruces (Decline class 2 and 3) was observed frequently (SAUR & al. 1986, FRÜHWALD & al. 1984, ASZMUTAT & KNIGGE 1987).

GRUBER 1995 found strong correlations between the sapwood areas and the needle mass of the crown. Equally the moisture contents of wood in connection with the flow velocity is an indirect measure of the water supply of the needles (LÜTTSCHWAGER 1991). If the water supply were more and more reduced, the total transpiration surface of the crown might be be diminished by an increasing loss of needles or a yearly decrease of needle surface. Symptoms like that were observed only occasionally in the investigation area. As the detoxification reactions cause a higher water demand (increasing photosynthesis- and transpiration rate), future investigations have to prove, if flow velocity in xylem and the water potential increases with higher ammonia concentration.

Results presented here arise the question, which sequences of reactions inside the trees accelerate the development of heartwood caused by nitrogen emissions. Two interconnected processes may be involved in this:

The process developing heartwood begins with dying of the interior parenchymatic cells which is linked with the loss of a water transport function and the storage of assimilates. Trigger for the development of heartwood is on one side insufficient supply of the xylem cells with water. The conductivity loss of xylem cells is the consequence (HUBER 1956). Though only insufficiently examinated till now, ammonia immissions can cause or amplify water demand under certain circumstances (for instance through longer opened stomata) (VAN HOVE & al. 1991). At the same time high nitrogen influx causes secondary effects e.g. dense *Calamagrostis* grass or reductions of fine roots which affect the water uptake. In particular, during periods of water deficit in xylem the vulnerability to embolism is increased and can accelerate the development of heartwood.

On the other side the efficiency of the sapwood is strongly connected with the ability to assimilate carbon by needles. The parenchymatic cells of the stem are supplied with carbohydrates for the processes of respiration and storage. Because a large part of the sugar compounds enters into synthesis of amino acids, the parencymatic cells located at the utmost part within the sapwood are only insufficiently supplied with high energetic assimilates, which causes them to die.

As the first available examinations confirm those unfavourable factors for growth of trees (air pollution, nutrient poor soils, suppressed social position, dry wheather periods etc.) promote the development of heartwood in the stem, which decreases the sapwood area (RADEMACHER & al. 1986, SCHNELL & al. 1987). Therefore the survival prognosis may be deteriorated.

As the aging of wood (and so of the tree itself) can be noticed especially by the change of sapwood-heartwood ratio the computed tomography offers the possibility to destine these processes inside the living tree without destruction. In connection with organic, anorganic, and biophysical analysis of needles and crown appearance a more secure diagnosis is possible. Whether it is possible to conclude from sapwood percentage on to the biological (not annual) age of pines is up to future investigations.

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