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ELEMENT CONTENT OF SCOTS PINE (*PINUS SYLVESTRIS* L.) STANDS OF DIFFERENT DENSITIES

Modern forestry management should be based on the principle of sustainability. In order to preserve habitat productivity, the amount of nutrients removed from the environment along with forestry products must be taken into consideration. This study shows the exact concentrations of chemical elements in different tree parts of Scots pine, growing on poor soils in north-western Poland. The observed values were compared to the values found in literature. In addition, the relationship between the concentrations of elements and stem diameter or stand density was researched. The highest concentration of chemical elements was observed in the needles (C, N, P, K, Mg, S, Mn, Na, Fe) and the lowest (C, N, P, S, Cu, Na, Ni, Pb, Zn, Fe) in the stem wood. Most of the macronutrients (P, K, Ca, Mg and S) reached optimal values, with the exception of N showing a deficiency, especially in the needles. The relationship between the content of elements and DBH or stand density was rather weak, and in both cases, negative.

Keywords: Scots pine, chemical diversity, nutrients, heavy metals, wood biomass, bark, branches, needles

Introduction

The proper growth and development of plants can be disrupted by inadequate nutrient content or the wrong proportions of elements in the soil. Nutrients are used repeatedly by plants, as they return to the environment with foliage and other

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parts of plants which fall and form litter and then humus. The circulation of elements is to some degree disrupted by the utilization of timber and other parts of plant biomass, which results in a decrease in the pool of elements available for the next generation of living organisms. Pine stands, which usually grow on poor soils, are especially exposed to element shortages. In order to preserve habitat productivity, sustainable forest management should be based on a thorough knowledge of the chemical composition of different tree parts in the Scots pine biomass.

Studies on the content of chemical elements in parts of Scots pine trees have been conducted by many authors. Most studies have focused on the chemical composition of the needles, where most of the elements reached their highest concentrations. The element content in the needles were often studied as part of wider studies concerning various issues, e.g. air and soil pollution [Dmochowski, Bytnerowicz 1995; Giertych et al. 1997; Kurczyńska et al. 1997; Rautio et al. 1998; Lamppu, Huttunen 2003; Rautio, Huttunen 2003; Luyssaert et al. 2005; Merilä, Derome 2008], the influence of various final felling methods on nutrient withdrawal from the forest environment [Jacobson et al. 2000; Olsson et al. 2000; Gornowicz 2002; Palviainen et al. 2004; Luiro et al. 2010; Saarsalmi et al. 2010; Palviainen, Finér 2012], an evaluation of the effects of fertilization [Bramryd 2001; Nilsen, Abrahamsen 2003; Røsberg et al. 2006; Saarsalmi et al. 2006; Prietzel et al. 2008; Moilanen et al. 2013] and other issues [Raitio 1990; Helmisaari 1992; Migaszewski 1997; Reimann et al. 2001, Hytönen, Wall 2006; Baumann et al. 2006; Pensa et al. 2007; Blanco et al. 2008; Mandre et al. 2010; Kuznetsova et al. 2011; Armolaitis et al. 2013; Pietrzykowski et al. 2014].

The chemical composition of other aboveground parts of the tree (stem wood, bark and branches) has been studied significantly less often [Fober 1993; Finer, Kaunisto 2000; Gornowicz 2002; Meerts 2002; Palviainen et al. 2004; Saarela et al. 2005; Kuznetsova et al. 2011; Armolaitis et al. 2013].

The aim of this study was to determine the concentrations of selected elements in different parts of Scots pine trees and to test the relationship between the element content in different tree parts and tree diameter or stand density.

Materials and methods

The research material was collected on experimental plots (0.5 ha) in 82-year old Scots pine (*Pinus sylvestris* L.) stands, located in Drawno Forest District, north-western Poland (longitude from E 15°50' to E 16°00', latitude from N 53°10' to N 53°13'). This area is characterized by poor habitats on sandy soils, where the dominant tree species is Scots pine. It mostly forms single-species and even-aged stands with a small admixture of other tree species, usually birch.

The chemical analysis was carried out for trees growing in 5 single-species and even-aged stands with different stand densities (table 1). On each 0.5 ha sample plot, 3 model trees, representing the entire range of tree diameters, were chosen (fig. 1). The 15 model trees selected were then cut down, divided into tree parts – the stem, branches, needles and cones – and immediately weighed. In order to establish the dry weight and element content, samples were taken from each part of each tree. Every sample was first weighed fresh, and then again after drying at a temperature of 65°C to constant mass.

Table 1. Main characteristics of sampled Scots pine stands [area 0.5 ha and age 82 years]

Sample plot	Density, [tree ha^{-1}]	Mean DBH, cm]	Mean height, [m]	Basal area, [m^2 ha^{-1}]	Volume, [m^3 ha^{-1}]
1	476	28.2	22.9	30.5	319
2	570	25.7	20.8	31.5	302
3	672	23.6	19.6	30.3	275
4	756	23.9	20.1	35.6	337
5	824	21.8	19.3	31.7	286

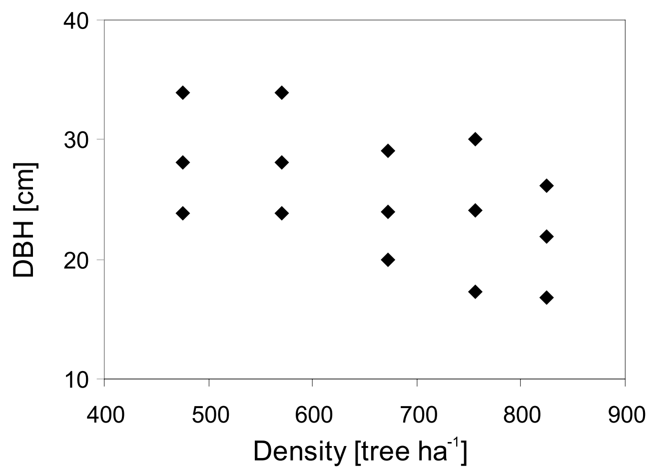

Fig. 1. Stand densities and diameters (DBH) of model trees (N = 15) from which samples were taken for analysis of mineral content

The samples were taken from the tree trunks in the form of two discs. The tree trunks were divided into two parts: one section of more than 14 cm in diameter and the rest of the trunk. The discs were cut out from the middle of each section. The discs had various diameters – corresponding to the trunk diameter – and a length of 10 cm. After drying, the bark and wood were separated. From the cross-sectional area of the discs, shavings were collected using a mechanical planer. Bark and wood shavings were milled and samples for chemical analysis were collected.

The branches were divided into living and dead. The living branches were cut with secateurs into two parts – twigs covered with needles and the rest of the branch. The needles and cones were separated from the twigs. From each of the aforementioned parts samples were milled and taken to determine element content.

Chemical analyses were performed in the Laboratory of Environmental and Soil Remediation Geochemistry, the Department of Forest Ecology and Department of Forest Soil Science, the Faculty of Forestry at the University of Agriculture in Kraków. The samples were mineralized in HNO_3 and by using an ICP-OES device, the content of the following elements was determined: P, K, Ca, Mg, Mn, Cd, Cr, Cu, Na, Ni, Pb, Zn and Fe. Without mineralization, by using a LECO TruMac CNS device, the content of C, N and S was determined.

Statistical analyses were performed using the "Multivariate Platform" tool in JMP 10.0 statistical software (SAS Institute Inc., Cary, NC, USA). From these Pearson correlation coefficients (r) and the corresponding levels of significance were obtained. On this basis, an assessment of the correlations between the element content and tree diameter and density of the stands was performed. The diameter at breast height (DBH) was measured 1.3 m above the ground.

Results and discussion

The average concentrations of 16 elements in individual parts of the aboveground part of the Scots pine trees are shown in table 2. The highest concentrations were usually found in the needles and thin branches. In these parts, the N, P and K content significantly decreased with the increase in trunk diameter (fig. 2, table 3). Such a correlation was not observed regarding the stand density (fig. 3, table 4). In contrast to the other elements – the highest concentration of Ca was found in the bark (fig. 2, fig. 3). For all the other analysed elements, the lowest concentrations were found in the wood and dead branches (table 2).

Table 2. Mean (±SD) concentrations of elements in different tree parts of sampled Scots pine stands

Element [mg g^{-1}]	Stem wood	Stem bark	Thick branches	Thin branches	Dead branches	Needles	Cones
1	2	3	4	5	6	7	8
C	470±4.9	471±9.5	488±9.6	502±5.7	496±9.9	503±2.9	495±20.7
N	0.83±0.21	4.91±1.06	2.53±0.96	7.08±1.01	1.89±0.54	12.3±1.19	4.78±5.15
P	0.07±0.04	0.62±0.18	0.33±0.08	0.78±0.10	0.09±0.02	1.15±0.14	0.75±0.57
K	0.27±0.15	1.53±0.52	1.15±0.24	2.65±0.44	0.18±0.16	4.45±0.61	3.31±1.51
Ca	0.65±0.13	7.89±1.85	2.05±0.27	2.26±0.28	1.49±0.42	3.16±0.38	0.31±0.17
Mg	0.27±0.10	0.99±0.31	0.42±0.07	0.63±0.09	0.17±0.05	0,65±0.11	0.48±0.20

Table 2. Continued

1	2	3	4	5	6	7	8
S	0.03±0.02	0.43±0.10	0.25±0.16	0.73±0.12	0.21±0.07	1.28±0.10	0.65±0.37
Mn	0.15±0.05	0.65±0.15	0.32±0.06	0.34±0.06	0.22±0.07	1.13±0.21	0.12±0.09
Cd	0.24±0.07	0.97±0.28	0.47±0.11	0.41±0.08	0.36±0.11	0.10±0.03	0.05±0.04
Cr	0.99±0.91	0.00±0.0	1.06±0.73	1.27±0.77	0.74±0.86	1.10±1.78	0.17±0.23
Cu	0.94±0.92	2.39±0.84	1.48±0.76	3.60±1.30	1.44±1.23	2.67±0.93	2.51±1.57
Na	7.33±3.1	10.5±4.2	49.1±9.2	58.9±21.5	26.0±13.8	59.1±20.9	16.8±11.9
Ni	0.25±0.09	0.76±0.42	0.46±0.11	1.21±0.32	0.52±0.26	2.89±2.33	4.30±2.09
Pb	0.79±0.72	1.41±0.87	2.59±0.57	2.80±0.85	1.70±0.65	2.10±1.54	4.01±3.56
Zn	11.7±3.1	66.6±18.7	34.7±6.4	45.0±13.1	25.7±7.5	47.4±6.9	21.5±10.7
Fe	13.4±10.7	22.2±6.8	23.3±19.2	32.7±15.8	21.9±11.1	34.2±15.7	21.9±6.0

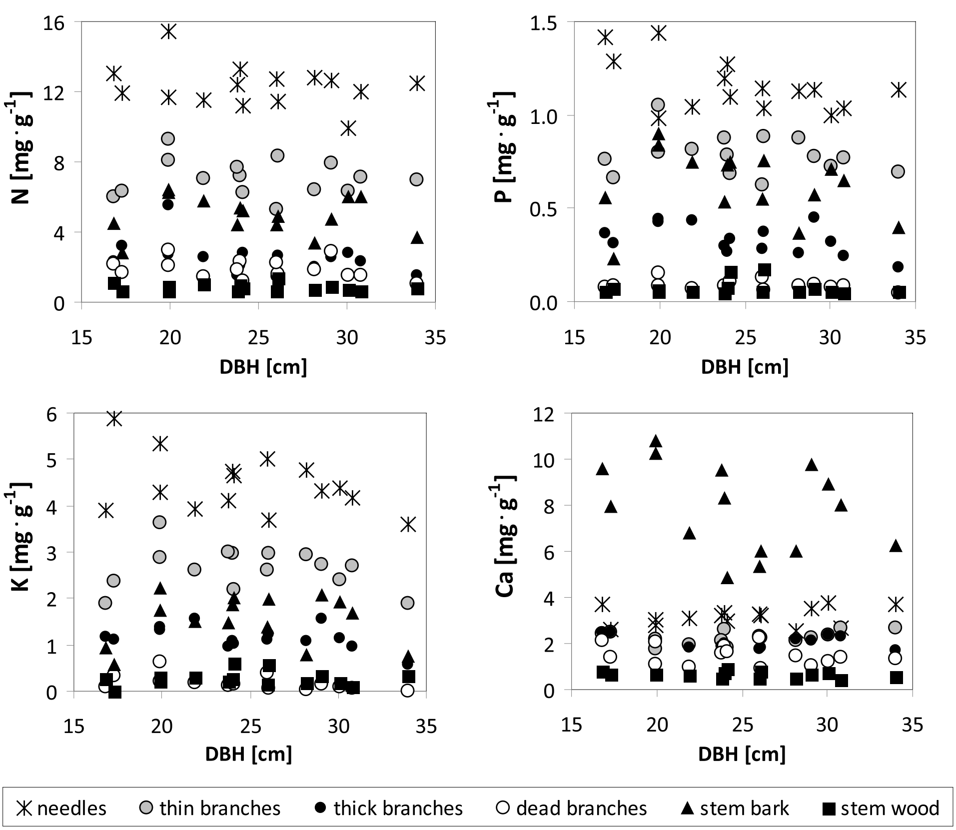

Fig. 2. Concentration of N, P, K and Ca in given parts of Scots pine trees of different stem diameter (DBH)

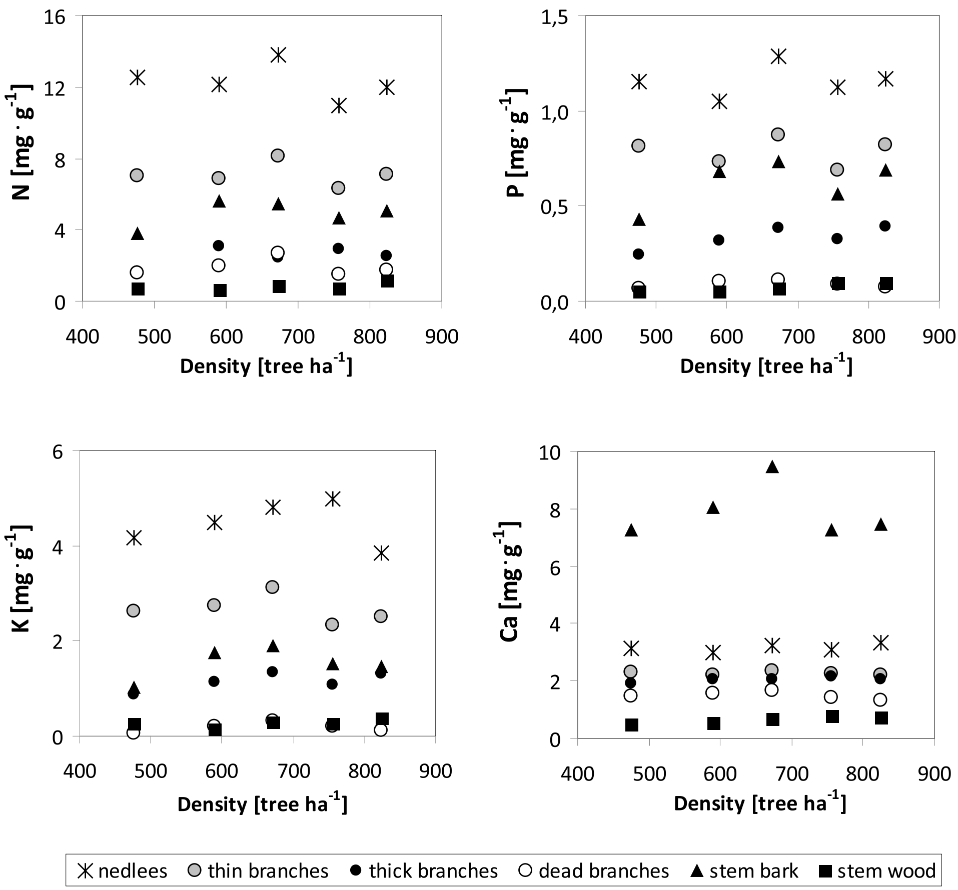

Fig. 3. Concentration of N, P, K and Ca in given parts of Scots pine trees from stands of different densities

For 9 of the studied elements (C, N, P, K, Mg, S, Mn, Na and Fe), the highest concentration was found in the needles, for 3 (Ca, Cd, Zn) in the bark, for 2 (Cu, Cr) in the twigs and for 2 in the cones (Ni, Pb). The lowest concentrations for 9 of the studied elements were found in the stem wood (C, N, P, S, Cu, Na, Ni, Pb, Zn and Fe), for 3 in the cones (Ca, Mn, Cd), for 2 in the dead branches (K, Mg) and for 1 (Cr) in the bark.

In most of the analysed cases, an inverse relationship between the concentration of elements in the individual parts of the tree and the diameter at breast height (DBH) of the particular tree was found (table 3). A statistically significant relationship was observed in six cases for Cd and in five cases for Zn. The relationship between the concentration of elements and the stand density was much weaker (table 4). Nevertheless, in those cases where it was statistically significant, the correlation coefficient was of a negative value, as it was for DBH.

Table 3. Correlation between tree diameter (DBH) and concentrations of elements in different tree parts of Scots pine trees

Element	Stem wood	Stem bark	Thick branches	Thin branches	Dead branches	Needles
C	-0.449*	0.254	0.150	0.013	-0.123	-0.232*
N	-0.128	-0.032	-0.437*	-0.070	-0.315	-0.270*
P	0.002	-0.141	-0.523*	-0.190	-0.331	-0.543*
K	0.083	0.085	-0.428*	-0.133	-0.498*	-0.405*
Ca	-0.347*	-0.365*	-0.292	0.365	-0.316	0.266
Mg	-0.211	-0.196	-0.257	-0.023	-0.227	-0.145
S	0.010	-0.210	-0.389*	-0.188	-0.284	-0.316*
Mn	-0.287*	-0.419*	-0.356*	-0.063	-0.261	-0.331*
Cd	-0.500*	-0.689*	-0.631*	-0.555*	-0.550*	-0.236*
Cr	-0.656*	0.000	-0.200	-0.135	-0.630*	0.241
Cu	0.221	0.313	-0.314	-0.224	-0.116	-0.255*
Na	0.092	0.014	0.008	-0.060	-0.404*	-0.043
Ni	-0.173	-0.181	-0.575*	-0.306*	-0.432*	0.311
Pb	-0.395*	-0.018	-0.255	-0.333*	-0.282	-0.003
Zn	-0.086	-0.333*	-0.619*	-0.350*	-0.549*	-0.377*
Fe	0.574	0.254	-0.385	-0.168	-0.081	-0.066

* Significant at $p < 0.05$

Table 4. Correlation between stand density and concentrations of elements in different tree parts of sampled Scots pine stands

Element	Stem wood	Stem bark	Thick branches	Thin branches	Dead branches	Needles
C	-0.064	-0.170	0.146	0.096	0.107	0.528
N	0.670	0.463	0.409	-0.010	-0.038	0.043
P	0.812	0.683	0.849	0.048	-0.132	0.591
K	0.659	0.439	0.789	0.263	-0.264*	0.235
Ca	0.804	-0.191	0.301	-0.460*	-0.052	0.769
Mg	0.655	0.620	0.781	0.055	-0.283*	-0.246
S	0.553	0.374	-0.020	-0.044	-0.432*	0.186
Mn	0.486	0.042	0.468	0.130	-0.019	0.656
Cd	0.991	0.745	0.565	0.522	0.472	-0.484*
Cr	0.830	0.000	0.822	0.591	-0.026	0.508
Cu	-0.090	-0.153	0.288	-0.697*	-0.321*	0.972
Na	-0.966*	-0.630*	0.092	0.581	0.221	0.389
Ni	-0.471*	-0.355*	0.639	0.616	0.486	-0.409*
Pb	0.905	0.209	0.098	0.848	0.809	0.455
Zn	0.043	-0.300*	0.932	0.641	0.588	0.268
Fe	-0.888*	-0.511*	0.158	-0.092	0.261	0.580

* Significant at $p < 0.05$

From all the analysed macronutrients, only N showed a deficiency. In the needles, an N content lower than 12 $g \cdot kg^{-1}$ is considered insufficient [Fober 1993; Kurczyńska et al. 1997; Moilanen et al. 2013]. From the five analysed sample plots, only one had an optimal N concentration, on three it was at the limit of the range, and on one it was below the optimal range. Similarly low N concentrations were found in the other tree parts.

The other analysed macronutrients (P, K, Ca, Mg and S) reached concentrations within the acceptable range and close to the values quoted by other authors [Raitio 1990; Johansson 1995; Kurczyńska et al. 1997; Giertych et al. 1997; Migaszewski 1997; Rautio et al. 1998; Olsson et al. 2000; Reimann et al. 2001; Gornowicz 2002; Luyssaert et al. 2005; Saarela et al. 2005; Hytönen, Wall 2006; Saarsalmi et al. 2006; Merilä, Derome 2008; Prietzel et al. 2008; Saarsalmi et al. 2010; Luiro et al. 2010; Kuznetsova et al. 2011; Armolaitis et al. 2013; Moilanen et al. 2013].

With regard to the micronutrients and heavy metals, the one deviating most from the accepted ranges was Mn. According to Fober [1993], the correct content of Mn in Scots pine needles should not exceed 1000 $mg \cdot kg^{-1}$. Among the 5 sample plots studied, the concentration of Mn in the needles exceeded on 4 sample plots and was close to the upper limit on one. The concentration of Mn in the wood and bark, however, did not differ from the values given by Fober [1993] and Saarela et al. [2005]. The Fe content in the needles was lower than the range quoted by Fober [1993], but did not differ from the results obtained by other authors. However, the concentration of Fe in the branches and bark was lower than quoted by other authors [Fober 1993; Palviainen et al. 2004; Saarela et al. 2005]. The concentration of Cr had a wider range, compared to literature [Rautio et al. 1998; Bramryd 2001; Reimann et al. 2001; Saarsalmi et al. 2006]. The concentration of Cu, Zn, Ni and Pb was within the range given by other authors [Raitio 1990; Helmisaari 1992; Dmochowski, Bytnerowicz 1995; Giertych et al. 1997; Rautio et al. 1998; Bramryd 2001; Reimann et al. 2001; Saarsalmi et al. 2010; Moilanen et al. 2013].

Conclusions

The highest concentration of chemical elements was observed in the needles and the lowest in the stem wood. For C, N, P, K, Mg, S, Mn, Na and Fe, the highest concentration was found in the needles, for Ca, Cd and Zn in the bark, for Cu and Cr in the twigs and for Ni and Pb in the cones. The lowest concentrations were observed for C, N, P, S, Cu, Na, Ni, Pb, Zn and Fe in the stem wood, for Ca, Mn and Cd in the cones, for K and Mg in the dead branches and for Cr in the bark.

Among all the studied macronutrients, only N showed a deficiency, especially in the needles. Similarly, low concentrations of N were found in the other tree parts. The rest of the macronutrients (P, K, Ca, Mg and S) reached optimal values.

From the microelements and heavy metals, the one deviating the most from the accepted ranges was Mn, with the exception of its concentration in the stem wood and bark, where it was within the optimal range.

In most of the analysed cases, the inverse relationship between the element content of the various tree parts and the DBH of these trees was found. A statistically significant relationship was observed in all six cases for Cd and in five cases for Zn.

The relationship between the mineral content and stand density was much weaker. Nevertheless, whenever it was statistically significant, the correlation coefficient was always negative.

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