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BIOMASS AND DISTRIBUTION OF PINE FOREST PHYTOCENOSIS FINE ROOTS IN SANDY SOIL AND SANDY CLAY LOAM SOIL ON RECLAIMED SPOIL HEAP OF THE PIASECZNO SULPHUR MINE[1]

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Summary. The paper presents the results of research on the biomass and distribution of fine roots (of up to 2 mm diameter) in pine forest phytocenosis aged 30 years growing on a reclaimed spoil heap of the Piaseczno Sulphur Mine, in the following two soil and habitat variants: on Quaternary sands (1Pcz) and on Quaternary sands with Krakowiecki clay insertions (2PczNi). The research was conducted using a modified monolith method. The sides of profiles measuring 120 × 120 cm were fitted with a grid of 10 × 10 cm squares, next 250 cm^3 cylinders were used to collect samples from each square. The following factors were determined: the graining of the samples (organoleptically), pH (using Hellig's reagent) and temporary moisture. Next the roots were rinsed and divided into fractions of fine roots with a diameter of up to 2.0 mm, other fractions from 2.0 to 8.0 mm and above 8.0 mm. The roots were then dried at 65ºC and weighed. Soil properties and root biomass were submitted to correlation and spatial variability analysis in the profiles using SIP tools. Total biomass of fine roots in the 0–120 cm horizon was found to be comparable to literature data for „natural" forest habitats, but in 1Pcz variant it was slightly smaller (6.00 $Mg \cdot ha^{-1}$) than in the 2PczNi variant (7.16 $Mg \cdot ha^{-1}$). In both variants a significant correlation was discovered (with p = 0.05) between root biomass distribution and moisture distribution in the soil profiles. In the 2PczNi variant, the root biomass moisture distribution was related to the distribution of clay insertions in sand. The results indicated a positive development of biologically active zone in soils forming on the reclaimed spoil heap.

Key words: spoil heap, reclamation, reforestation, Scots pine, fine roots

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INTRODUCTION

In forest ecosystems, the underground biomass has a significant share in the total phytocenosis biomass and it plays an important role in the matter and energy circulation [Waring and Schlesinger 1985]. Research on tree root systems, including their vitality, range and density as well as biomass distribution with division into fractions of thick and fine roots, is a significant element in the assessment of tree condition [Nielsen and Hansen 2006] and in soil ecology studies [Bednarek *et al*. 2005]. Fine roots, although they only account for 10% of underground tree biomass [Miller *et al*. 2006], are of direct importance in the process of water and nutrients intake by plants from soil solution [Jackson *et al*. 1997]. Moreover, fine roots form around them a macro-habitat for micro-organisms (*rhizosphere*) by secreting special biochemical substances [Richards 1979]. Due to the natural cycle of death and decay, fine roots supply significant amounts of organic matter and carbon to the soil. It has been estimated that these amounts may be even several fold larger than organic matter reaching the soil from the fallout of above-ground biomass [Richards 1979]. The growth of fine root biomass contributes more than 30% of land ecosystem net production [Jackson *et al*. 1997]. It has been estimated that, globally, fine roots contain over 5% carbon of the total amount in the biosphere. Therefore, this part of land vegetation underground biomass plays a significant role in the carbon cycle in ecosystems and in carbon dioxide sequestration in the biosphere, thus decreasing the greenhouse effect [Miller *et al*. 2006].

Research on roots is also important for the assessment of the strategy and adaptation to new habitat conditions of plants introduced to new biotopes (habitats) in reclaimed post-mining sites or of plants which find their way there by way of natural succession [Fabijanowski and Zarzycki 1969, Harabin 1973, Rodrigue *et al*. 2002, Węgorek 2003, Pietrzykowski 2006]. The root depth range, as the so-called biological soil depth, was applied as an ecological assessment criterion for soils forming on post-mining sites [Daniels *et al*. 1992, Węgorek 2003, Pietrzykowski 2006].

The aim of the work was to determine the root biomass distribution in pine forest phytocenosis in soil profiles on research plots consisting of two soil and habitat variants on the reclaimed top section of the Piaseczno Sulphur Mine external spoil heap.

MATERIALS AND METHODS

Object of study

The research was conducted in autumn 2009 on the reclaimed top section of the former Piaseczno Sulphur Mine external spoil heap. A paper by Krzaklewski [2010] contains a phyto-sociological description of communities on this portion of the spoil heap, while a paper by Pietrzykowski and Socha [2010] contains a description of aboveground tree stands and community biomass. Five species of vascular plants (*Quercus robur, Robinia pseudoaccacia, Sorbus aucuparia, Padus serotina* and *Festuca rubra*) were identified in the 1Pcz variant and 18 species (among shrubs layer mostly *Quercus robur, Padus serotina, Prunus divericata* and *P. spinosa* and among herbaceous plants *Ajuga reptans, Bromus inermis, Calamagrostic epigejos, Moeringia trinervia*) in the 2PczNi variant. The investigated communities were multi-layer [Krzaklewski 2010]. The top layer (A) consisted of pine tree with full canopy closure in 1Pcz variant and no full closure in 2PczNi variant. In that variant the degree of coverage in the shrub layer (B) was significantly higher at 50%, whereas in the 1Pcz it was only 5%. Also in the undergrowth layer the coverage was much higher in the 2PczNi variant (35%) than in 1Pcz (4%). Ground coverage in the bryophyte layer was similar at around 5%. The biomass size in particular phytocenosis layers in the 1Pcz variant was 102.29 $Mg{\cdot}ha^{-1}$, including undergrowth and shrubs which constituted in total only 0.17 $Mg{\cdot}ha^{-1}$. Phytocenosis biomass in the 2PczNi variant was 129.98 $Mg{\cdot}ha^{-1}$, including shrub and vegetation biomass of 0.07 $Mg{\cdot}ha^{-1}$ [Pietrzykowski and Socha 2010].

Field and laboratory studies

Two research plot variants were set up in 30-year-old pine tree stands: on Quaternary sands (1Pcz); and on Quaternary sands with Krakowiecki Neogene clays (2PczNi).

To study the fine root biomass and its distribution in the phytocenosis, on each research plot (1Pcz and 2PczNi) a single soil profile was made between the rows of pine trees. The profiles were fitted with grids of 120 × 120 cm and a net of squares to form cells measuring 10 × 10 cm (144 cells in each profile). In order to determine the fine root biomass, a modified monolith method was applied [Böhm 1985]; it consisted of collecting volumetric samples from each cell using 250 cm^3 cylinders. The samples were then placed in tightly sealed plastic bags and immediately taken to a lab. They were stored at 4°C (for a maximum of two weeks), and successive assays were conducted in the lab. In the soil samples graining was organoleptically determined using an agreed 3-degree scale: 1 – sands , 2 – sandy clay loam, 3 – clays (a numerical conversion served to compile them in a database and for further calculations); pH was determined using Hellig's method, whereas temporary moisture using the dryer-weight method (5 g × 2 repetitions per sample from each cell). Temporary moisture was expressed in percentage of weight to dry soil (in weight %), and the obtained results also allowed to calculate water stock for particular horizons of the soil profiles ($Mg{\cdot}ha^{-1}{\cdot}cm^{-1}$ of soil layer). Roots were rinsed of soil samples, and measured with a calliper with accuracy of 0.1 mm, then divided into the fine root fraction with root diameter of up to 2.0 mm [Böhn 1985] and other fractions divided into fractions from 2.0 to 8.0 mm, and above 8.0 mm. The root samples were then dried at 65°C and weighed with an accuracy of up to 0.00 g on a technical balance. The weight was than calculated per root biomass in a volume unit ($g{\cdot}dm^{-3}$). The fine root biomass and graining, pH and temporary moisture for each cell (a total of 144 per profile) then underwent a correlation analysis using Statistica software [StatSoft 8.0]. Next, using the SIP (Spatial Information System tools; ArcGIS ArcView 9) with Spatial Analyst, the spatial distribution of fine roots and variability in profiles of assayed soil properties were displayed. The IDW (Inverse Distance Weighted) method was applied during interpolation, with borders taken into account and an assumption of searching for the 10 closest neighbours.

STUDY RESULTS AND DISCUSSION

Soils in the 1Pcz variant were more uniformly grained in the whole soil profile. The applied organoleptic methods allowed determining a small amount of clay in only 9 out of 144 samples. In the soil profile of the 2PczNi variant, there was significant diversification of graining due to uneven distribution of clay insertions mixed with sands. In this case, among the collected samples three groups of substrates were distinguished (sands, sandy clay loams, clays). pH in the 1Pcz profile varied from 4.5 to 6.0, and in the 2PczNi profile it was much higher at 6.5 to 8.0. Water stock in 1Pcz soils was 478 $Mg \cdot ha^{-1} \cdot 120\ cm^{-1}$, and in 2PczNi soils it was much bigger at 775 $Mg \cdot ha^{-1} \cdot 120\ cm^{-1}$. In the 2PczNi variant an addition of clay significantly increased water retention. The 0–10 cm soil horizon displayed the biggest water stock in the 1Pcz variant (51 $Mg \cdot ha^{-1}$). Other horizons with a big water stock included the 10–20 cm (48 $Mg \cdot ha^{-1}$) and the 40–50 cm (49 $Mg \cdot ha^{-1}$) horizons. Similarly in the 2PczNi variant, the 0–10 cm (93 $Mg \cdot ha^{-1}$) and 10–20 cm (88 $Mg \cdot ha^{-1}$) horizons displayed the largest water stock. However, what should be noted here is the fact of big water stock in the 2PczNi profile at a depth of 60–70 cm and 80–90 cm, which was associated with the occurrence of clay insertions.

The fine root biomass (up to 2.0 mm) in the 1Pcz variant was 6.00 Mg $ha^{-1} \cdot 120\ cm^{-1}$, of which 56.7% (3.40 $Mg \cdot ha^{-1}$) was to be found in the 0–40cm horizon, 24.9% (1.50 $Mg \cdot ha^{-1}$) in the 40–80 cm horizon and the remaining 18.4% (1.10 $Mg \cdot ha^{-1}$) in the 80–120 cm horizon. These dependencies are well-illustrated by a diagram showing the spatial distribution of biomass (Fig.1). In the 0–40 cm horizon, the maximum values for root biomass of thickness up to 2.0 mm in single clusters of soil profile ranged from 2.5−3.0 $g \cdot dm^{-3}$ (Fig. 1). The total biomass of 2.0–8.0 mm roots in this variant (1Pcz) was 2.6 $Mg \cdot ha^{-1} \cdot 120\ cm^{-1}$, of which 2.00 $Mg \cdot ha^{-1}$, that is 77.0%, was found in the 0–40 cm horizon. The total biomass of thicker roots from 8.0 mm in the 1Pcz variant was 3.27 $Mg \cdot ha^{-1} \cdot 120\ cm^{-1}$. The largest percentage of root biomass of this thickness (74.5%) was found in the 0–40 cm horizon. In the conditions of „natural" forest habitats, most fine root biomass is to be found in the upper soil horizons. In the case of coniferous species, up to 95% of fine root biomass may be found in the 0–30 cm horizon [Olsen 1968, cited by Węgorek 2003].

The fine root biomass (up to 2.0 mm) in the 2PczNi soil profile variant was 7.16 Mg·ha^{-1}·120 cm^{-1}, of which 42.8% (3.06 Mg·ha^{-1}) was to be found in the 0–40 cm horizon, 27.1% (1.94 Mg·ha^{-1}) in the 40–80 cm horizon, and 30.1% (2.15 Mg·ha^{-1}) at 80–120 cm (Fig. 2). The 2–8 mm root biomass in the 2PczNi variant was 2.98 Mg·ha^{-1}·120 cm^{-1}, and the largest percentage (37.2%) was to be

1.a)

1.b)

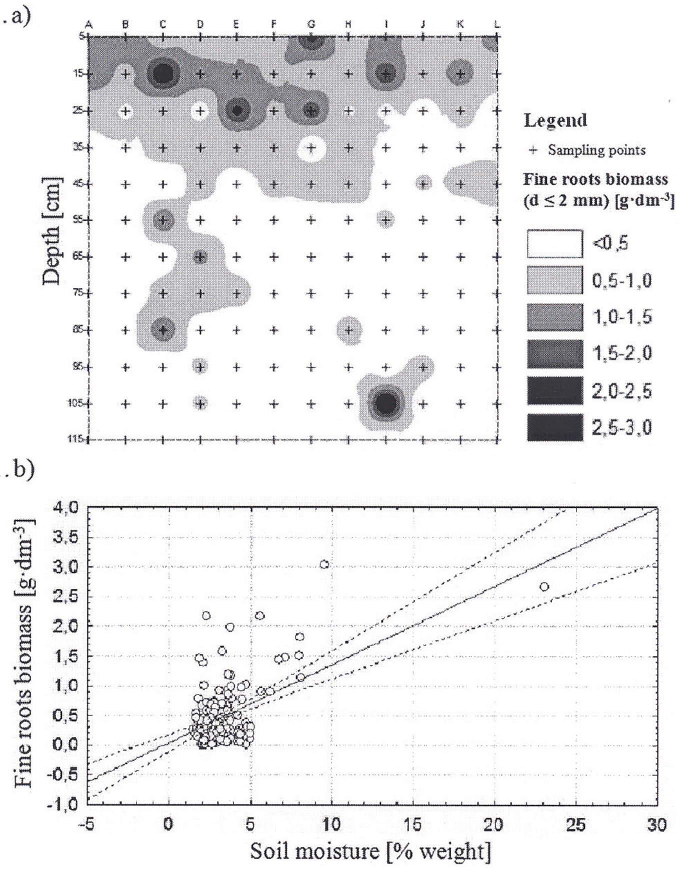

Fig. 1. a) Spatial variability of fine root biomass distribution (d ≤ 2.0 mm) in the soil profile of the 1Pcz variant (on sandy soil), b) dependence between spatial variability of temporary moisture [weight %] in the soil profile of the 1Pcz variant (on sandy soil) and the fine root biomass distribution (d ≤ 2,0 mm) (g·dm^{-3})

found in the 0–40 cm horizon, 31.9% roots were found at 40–80 cm, and 30.9% at 80–120 cm. The thicker root biomass from 8.0 mm in this variant was 2.56 Mg·ha^{-1}·120 cm^{-1}, of which 31.2% at 0–40 cm, 41.8% at 40–80 cm, and the remaining 27.0% at 80–120 cm.

The 2PczNi variant profile displayed a more uniform distribution of fine root biomass than the 1Pcz profile (Fig. 1 and 2). This was related with the distribution of clay insertions in the 2PczNi profile, particularly in deeper horizons.

These results prove that Krakowieckie (Neogene) clays are a good soil-forming material, but only if they are evenly distributed in sandy deposits. This issue was raised 30 years ago in a paper by Adamczyk and Maciaszek [1968]. It was then noted that Krakowieckie clays mixed with sands may be considered valuable soil-forming material. However, these findings were not fully applied, as the for-

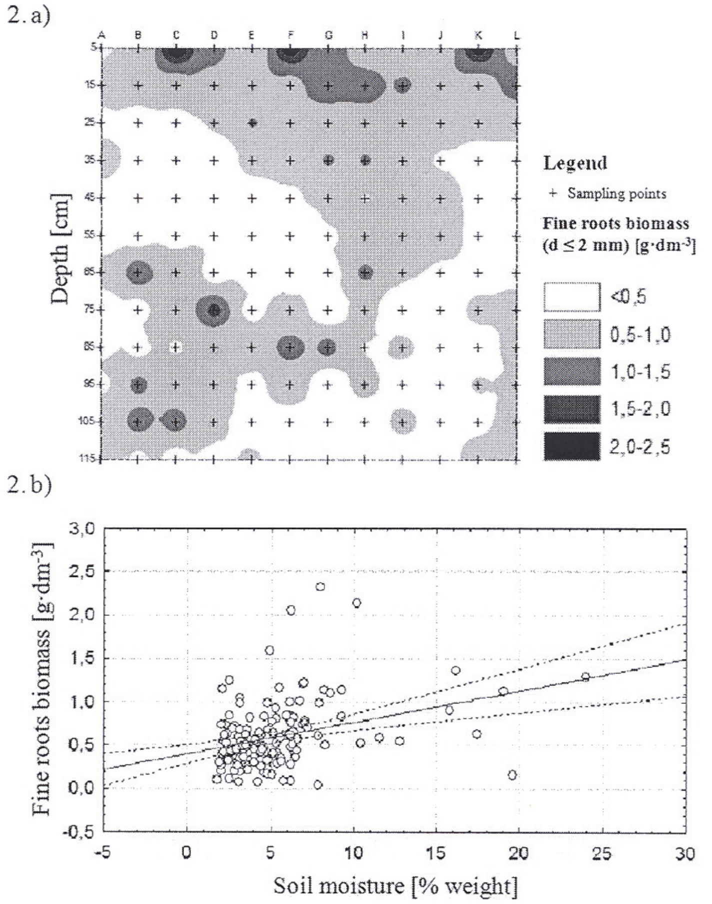

Fig. 2. a) Spatial variability of fine root biomass distribution (d ≤ 2.0 mm) in the soil profile of the 2PczNi variant (sands with addition of clay), b) dependence between spatial variability of temporary moisture [weight %] in the soil profile of the 2PczNi variant (sands with addition of clay) and the fine root biomass distribution (d ≤ 2,0 mm) (g·dm^{-3})

med top layer of the spoil heap contained clusters of clay which were not sufficiently fragmented and unevenly distributed. Soils consisting of Krakowiecki clays alone, although rich, are also characterised by unfavourable aeration and water properties [Adamczyk and Maciaszek 1968].

The fine root biomass (a total of dead and living roots) has been estimated by different authors as ranging from 1.0 to 20.0 Mg·ha^{-1} [Magill *et al.* 2004]. Research in Eastern Finland indicated living fine root biomass (up to 2 mm) in pine tree stands ranging from 3.69 to 7.42 $Mg \cdot ha^{-1}$, and dead fine root biomass from 1.06 to 30,82 $Mg \cdot ha^{-1}$ [Makkonen and Helmisaari 1998]. Living fine root biomass of Scots pine from a 40-year-old plantation from Great Britain was found to range from 0.74 to 1.48 $Mg \cdot ha^{-1}$, and dead root biomass from 0.34 to 0.94 $Mg \cdot ha^{-1}$ [Vanguelova *et al*. 2005]. According to research conducted by the Polish Academy of Sciences, Institute of Dendrology in Kórnik on 12-year-old pine tree stands of various origin, fine root biomass ranged from 1.30 $Mg \cdot ha^{-1}$ (originating from Poland) to 3.30 $Mg \cdot ha^{-1}$ (originating from Russia) [Oleksyn *et al*. 1999].

Water conditions of soils are one of the ecological factors that are of key significance for vegetation, particularly on reclaimed spoil heaps with ombrophilous type of water management. A key dependency was shown (with $p = 0.05$) between temporary moisture in the soil profiles of investigated habitat variants and biomass distribution of all root thicknesses, however, the correlation factor ($r = 0,59$) was higher in the 1Pcz variant. Similar dependencies were found in numerous other studies [Böhm 1985]. No significant correlation was found between root biomass and other assayed soil features (graining and pH). This may have been due to low sensitivity of the methods applied to determine graining (organoleptic method) and pH (using Hellig's reagent).

CONCLUSIONS

1. The fine root biomass in both soil substrate variants was comparable to literature data for „natural" forest habitats. It indicates a positive course of underground phytocenosis development forming in the process of forest reclamation of an external spoil heap of Piaseczno Sulphur Mine.
2. Temporary moisture distribution in profiles clearly affected the fine root biomass distribution in the soils of both variants.
3. Like in the case of forest soils, the majority of fine root biomass was accumulated in the upper horizons of the soil (up to 40 cm). This was particularly apparent in the Quaternary sand with no clay (1Pcz). In the sandy-clay loams (2PczNi), most fine root biomass was also found at 40 cm, but the root biomass distribution in the whole profile was more even, which was related to the distribution of clay insertions.
4. The conducted researched proved the correctness of postulates made over 30 years ago (at the design stage of Piaseczno spoil heap reclamation process) concerning the necessity of mixing sand and clay evenly [Adamczyk and Maciaszek 1968] in order to create favourable soil and habitat conditions.

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MASA I ROZMIESZCZENIE KORZENI DROBNYCH FITOCENOZY LASU SOSNOWEGO W PROFILACH GLEBY PIASZCZYSTEJ ORAZ PIASZCZYSTO-ILASTEJ NA REKULTYWOWANYM ZWAŁOWISKU KOPALNI SIARKI PIASECZNO

Streszczenie. W pracy przedstawiono wyniki badań biomasy i dystrybucji korzeni drobnych (o grubości do 2 mm) w fitocenozach lasu sosnowego w wieku 30 lat na rekultywowanym zwałowisku po Kopalni Siarki Piaseczno w 2 wariantach glebowo-siedliskowych: na piaskach czwartorzędowych (1Pcz) i piaskach czwartorzędowych z wstawkami iłów krakowieckich (2PczNi). Badania prowadzono zmodyfikowaną metodą monolitową. Na ścianach profili o wymiarach 120 × 120 cm zainstalowano siatkę kwadratów o bokach 10 × 10 cm, a następnie z każdego kwadratu pobrano próbki cylindrami o pojemności 250 cm^3. Na próbkach oznaczono uziarnienie (organoleptycznie), pH (odczynnikiem Helliga) i wilgotność chwilową. Następnie dokonano płukania korzeni i rozdziału na frakcje korzeni drobnych o średnicy do 2,0 mm i pozostałych frakcji od 2,0 do 8,0 mm i powyżej 8,0 mm. Korzenie wysuszono w 65ºC i zważono. Właściwości gleb i masę korzeni poddano analizie korelacji oraz zmienności przestrzennej w profilach z wykorzystaniem narzędzi SIP. Całkowita masa korzeni drobnych w warstwie 0–120 cm była porównywalna z danymi literaturowymi dla „naturalnych" siedlisk leśnych, przy czym w wariancie 1Pcz była nieznacznie mniejsza (6,00 $Mg \cdot ha^{-1}$) niż w wariancie 2PczNi (7,16 $Mg \cdot ha^{-1}$). W obydwu wariantach stwierdzono istotną korelację (z p = 0,05) rozkładu masy korzeni z rozkładem wilgotność w profilach glebowych. W wariancie 2PczNi rozkład wilgotności masy korzeni związany był z rozmieszczeniem wkładek iłów w piaskach. Wyniki wskazują na pozytywny rozwój biologicznie czynnej strefy gleb kształtujących się na rekultywowanym zwałowisku.

Słowa kluczowe: zwałowisko, rekultywacja leśna, sosna zwyczajna, korzenie drobne