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Concentrations and distributions of Al, Ca, Cl, K, Mg and Mn in a Scots pine forest in Belgium

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ABSTRACT

A *Pinus sylvestris* stand located in Mol, Belgium was studied for its content of six elements: Ca, K, Mg, Al, Cl and Mn. A fractionation of tree components was carried out into 8 classes (heart and sapwood, inner and outer bark, living branches, twigs and young/old needles) and their element contents were measured.

Comparisons were made between the different compartments in terms of absolute and relative element contents. Quantitatively, Ca and K are the main elements: in young needles, Ca + K reach 83% of the elements' whole stock. The wood compartments (heartwood + sapwood) have generally low element content, as does the outer bark except for Ca (which is bound to suberin) and Al, possibly from atmospheric clay deposition. The inner bark, twigs and needles have high element contents possibly linked to high symplasmic content. The Inner bark shows high Ca and K contents as these elements are involved in phloem transport. Positive correlations were found between Ca and Al, Mn and Cl, K and Cl and K and Mn, attributed to similarity in chemical and biological function.

A simple empirical compartment model was developed to derive numerically the transfer rates that reproduce the element distribution within tree compartments. The calculated mass flows appear to be within range of the limited data available from other pine tree studies.

This study highlights the potential for coupling of specific elements (including radionuclides) to Ca, K, Mg, Al, Cl and Mn in context of vegetation modelling, by assuming that these elements follow the same pathways. We found indication that ^{36}Cl, ^{90}Sr and ^{137}Cs (environmentally important from the perspective of nuclear power and waste management) can be coupled to Cl, Ca and K fluxes within the tree, increasing the understanding of the cycling of radionuclides in a forest ecosystem.

1. Introduction

The Scots pine (*Pinus sylvestris*) is one of the main constituents of European forests, exceeding 20% of the productive area of forests in Europe (Mason and Alía, 2000). This conifer is widespread in continental, alpine, coastal and Mediterranean climates (Médial, 2001).

Due to its long life and high biomass turnover, Scots pine forests can absorb and recycle a considerable amount of macronutrients, micronutrients and pollutants when compared to the soil bioavailable reserve (Ranger and Turpault, 1999). The uptake and distribution of elements depend on stand characteristics and vegetation type (e.g. tree species) (Stroble et al., 2001), as well as on their availability in the soil (Misra and Tyler, 1999; Mengel and Kirkby, 2001). Soil input combined with plant selectivity for some elements (micro, macro and contaminants) are likely to be the main factors regulating transfer of elements from the soil to the plant root (Pessarakli, 1999; Mengel and Kirkby, 2001).

Understanding the role of pine forests in element cycling is therefore important, and studies have been performed from the point of view of forest ecosystem functioning (Wright and Will, 1958; Lim and Cousens, 1986a, 1986b; Helmisaari and Mälkönen, 1989; Johansson, 1993; Rautio et al., 1998). These studies illuminate our understanding of the long-term cycling of contaminants at the biosphere-geosphere interface. It is important to capture the essential processes regulating the entry, circulation, storage and exit of substances to the tree – in other words, the biogeochemical cycling (Raven et al., 2001). The key processes involved are root uptake (Li et al., 2001) and sap (xylem and phloem) flow (Hölttä et al., 2006), driven by the biological pumping function of trees, or transpiration (Monteith and Unsworth, 2007), translocation between perennial (trunk, branches) and non-perennial (foliage) parts of

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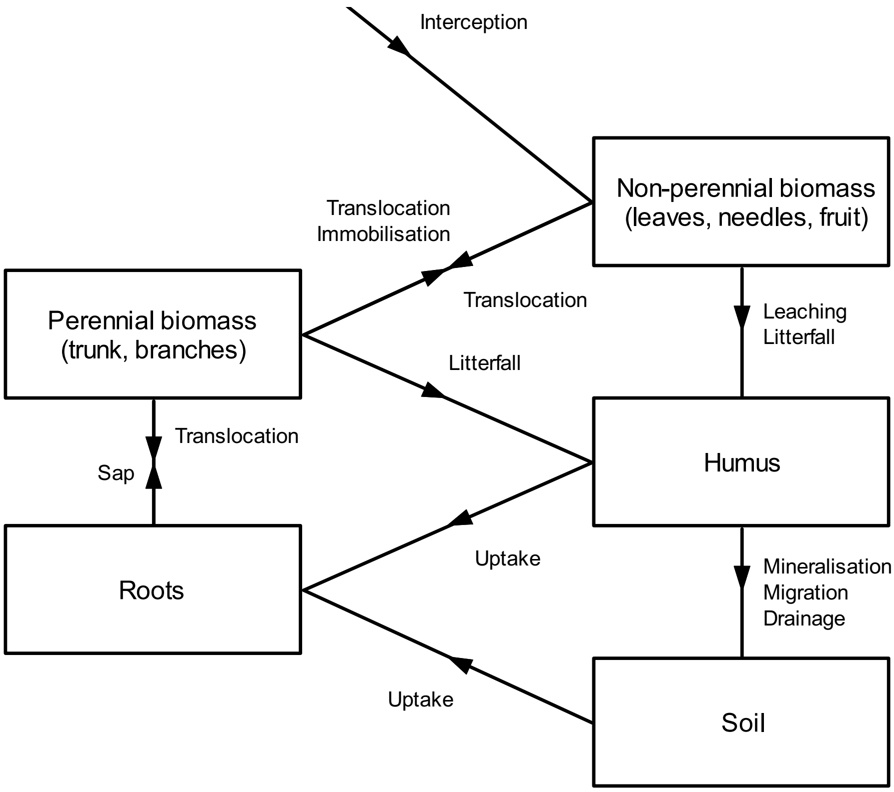

Fig. 1. Generally accepted forest biogeochemical cycle in terms of the major compartments (boxes) and fluxes (indicated by arrows) based on the BIOMASS approach (IAEA, 2002).

the tree, immobilisation and storage (from foliage to trunk and branches), washout (throughfall and weathering), litterfall (Berg, 2000; Copplestone et al., 2000) and element redistribution in the soil, as illustrated in Fig. 1.

Trees are often deep-rooted and may therefore access deeper soil profiles than annual grasses (Boutton et al., 1999). Together with their longevity, forest stands can over time store large amounts of elements in the tree biomass, and thereby act as an effective biological sink (Thiry et al., 2005). Once the elements have been taken-up, they will be expected to distribute to the different parts of the plant through conducting systems, namely xylem and phloem (Raven et al., 2001). Unwanted elements (such as aluminium or excess chlorine) are expected to be displaced towards the non-living parts of the plant. Other elements (e.g. Mg, Mn) may be transported to metabolically active parts and partake in several processes (e.g. photosynthesis) or functions (e.g. regulating turgor pressure) (Raven et al., 2001). Elements return to the soil either through leaching and/or through litterfall, thus completing the biogeochemical cycle.

The objective of this study was to investigate Al, Cl, Ca, K, Mg and Mn concentrations and pools in a Scots pine forest in the Campine region in Belgium, focussing on element distributions in different tree compartments, similarities and differences between these elements and associated interrelations. As a secondary objective, element fluxes between the different compartments of the ecosystem were investigated (soil, forest floor, roots, wood and foliage) using a simple linear pool and flux empirical model, taking advantage of a forest stand well characterised and well monitored for water flows in vegetation in previous studies (Vincke, 2006; Vincke and Thiry, 2008a; Van den Hoof and Thiry, 2012). The observed distributions of these elements are related to wider issues of chemical and physiological functional properties, and to the water and nutrient circulation in the forest vegetation.

2. Materials and methods

2.1. Forest stand, biomass and soil sampling

The pine forest in Mol is a monocultural Scots pine forest approximately 60 years old. The stand is a pine stand with an unclosed canopy having a surface area of 4489 m^2 (Vincke, 2006). The location and dimensions of the forest stand are shown in Fig. 2. In 2006, when samples used in this study were collected, the stand presented a typical even-aged distribution (55 years old) with a mean height of 22.4 ± 3.7 m (dominant height is 26 m) and a mean circumference of 91.1 ± 15.4 cm for 161 trees (i.e. 358.7 trees ha^{-1}). The understorey vegetation is mainly constituted by *Sorbus aucuparia*, *Prunus serotina*, *Rubus* sp. and *Athyrium filix-femina*. A shallow water table appears at 0.50–1.20 m depth at the end of the winter (Vincke, 2006).

The soil is a podzol, classified as a dystric Cambisol (FAO, 1998). Six distinct horizons are observed down to 110 cm deep; the main constituent was invariably sand (>91%) with a small fraction of silt. The soil was found to have a pH H_2O of about 4.5 (varying between 4 and 5 depending on the horizon) (Vincke and Thiry, 2008a).

Previous research (Vincke and Thiry, 2008a) quantified the water table cycle in Scots pines in the plot studied here. Continuous monitoring in 2005 revealed a shallow water table. Pine transpiration was estimated to be <1.85 mm d^{-1}, 25% of the potential evapotranspiration (PET). Understorey transpiration was estimated as 18–20% of the stand water use. The maximum soil water reserve measured over the soil rooted zone was 250 mm, in which 145 mm was extractable water. The contribution of the water table to forest transpiration reached 61% (98.5% in dry periods).

Six pine trees were felled in March 2006 for use in this study. These trees were randomly chosen as part of a forest management plan from a sample consistent with the average diameter of trees in the plot, reflecting its typical even-aged distribution (the trees