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Above- and belowground nutrients storage and biomass accumulation in marginal *Nothofagus antarctica* forests in Southern Patagonia

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Abstract

The above- and belowground biomass and nutrient content (N, P, K, Ca, S and Mg) of pure deciduous *Nothofagus antarctica* (Forster f.) Oersted stands grown in a marginal site and aged from 8 to 180 years were measured in Southern Patagonia. The total biomass accumulated ranged from 60.8 to 70.8 Mg ha^{-1} for regeneration and final growth stand, respectively. The proportions of belowground components were 51.6, 47.2, 43.9 and 46.7% for regeneration, initial growth, final growth and mature stand, respectively. Also, crown classes affected the biomass accumulation where dominant trees had 38.4 Mg ha^{-1} and suppressed trees 2.6 Mg ha^{-1} to the stand biomass in mature stand. Nutrient concentrations varied according to tree component, crown class and stand age. Total nutrient concentration graded in the fallowing order: leaves > bark > middle roots > small branches > fine roots > sapwood > coarse roots > heartwood. While N and K concentrations increased with age in leaves and fine roots, concentration of Ca increased with stand age in all components. Dominant trees had higher N, K and Ca concentrations in leaves, and higher P, K and S concentrations in roots, compared with suppressed trees. Although the stands had similar biomass at different ages, there were important differences in nutrient accumulation per hectare from 979.8 kg ha^{-1} at the initial growth phase to 665.5 kg ha^{-1} at mature stands. Nutrient storage for mature and final growth stands was in the order Ca > N > K > P > Mg > S, and for regeneration stand was Ca > N > K > Mg > P > S. Belowground biomass represented an important budget of all nutrients. At early ages, N, K, S, Ca and Mg were about 50% in the belowground components. However, P was 60% in belowground biomass and then increased to 70% in mature stands. These data can assist to quantify the impact of different silviculture practices which should aim to leave material (mainly leaves, small branches and bark) on the site to ameliorate nutrient removal and to avoid a decline of long-term yields.

Keywords: Growth phase; Nutrients accumulation; Root/shoot ratio; Crown classes; Marginal forest

1. Introduction

The cool temperate forest of Patagonia is dominated by deciduous *Nothofagus* species which occurs from 46° to 56° S and ranges in elevation from sea level to more than 2000 m a.s.l. *Nothofagus antarctica* (Forster f.) Oersted (ñire) grows at sites that are harsh for most other species, thus on poorly drained or drier eastern sites in the ecotone with the Patagonian steppe. Within its natural distribution, tree growth rate is clearly site quality-dependent, reflecting the influence of soil, geologic, orientation and microclimatic factors. On the best sites *N. antarctica* trees can reach height of up to 15 m with straight trunks form but on rocky, dry and exposed sites trees only reach 2–3 m tall with a shrubby form (Veblen et al., 1996). Therefore, trees growing in better sites would store more biomass and nutrients (Palm, 1995) or increase nutrient concentrations in plant tissues (Diehl et al., 2003) than others developed in inferior site classes. Also, concentration of nutrients in leaf litterfall of trees may differ from those in live tissues due to a resorption from senescing tissues into perennial pools. Peri et al. (2006) reported that nutrient accumulation of *N. antarctica* varied according to the age, crown classes and components, but this study was carried out only in a middle site quality (total height of mature trees reached 7.8 m) and at an individual trees level in Southern Patagonia.

Most of the nutrient cycling researches in forest ecosystems have been focussed on aboveground pools (Caldentey, 1992; Santa Regina, 2000). However, net primary production, nutrient

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concentrations and fine roots turnover rates of belowground components in forest system can equal or even exceed those from aboveground pools (Caldwell, 1987; Ranger and Gelhaye, 2001). Therefore, research of belowground pools in trees is necessary to quantify nutrient sequestration in the underground woody structures.

As *N. antarctica* is often harvested mainly for wood products such as firewood and poles, data on biomass and nutrient accumulation at stand level in both above- and belowground components are essential for evaluating the impacts of silviculture practices on bioelement recycling and long-term effects on the mineral balance (Santa Regina, 2000). Also, *N. antarctica* forests are usually used as silvopastoral systems (trees growing with natural pastures in the same unit of land to feed cattle) where it is important to know the amount of nutrients up taken by the trees, the nutrients returned by leaves fall and the impact of the thinning on nutrients dynamic at a surface level.

The aim was to quantify the amount of biomass and nutrients in both above- and belowground components at different stands age and crown classes of *N. antarctica* forest growing in a dry and windy marginal site in South Patagonia, near the Patagonian steppe.

2. Materials and methods

2.1. Study area

This study was carried out in four naturally pure stands of *N. antarctica* in the southern west of Santa Cruz province, Argentina (51° 40′ 59″ SL, 72° 15′ 56″ WL) corresponding to different growth phases (mature phase 140–180 years, final growth phase 80–100 years, initial growth phase 40–60 years and regeneration phase 8–20 years) growing at a low site quality where total height of mature trees reached 5.3 m. Climate is cold temperate with a mean annual temperature of 6.2 °C and a long-term annual rainfall of 280 mm. Soils were classified as Molisols. Thirty bulked soil sample cores from the four stands to different depths (0–5, 5–21 and 21–50 cm) were taken at random (Table 1). The soil pH and minerals was higher in the upper layer. Increasing the quantity of cations (mainly Ca^{+}, Mg^{+} and K^{+}) in soil solution (or increasing the base saturation) in the upper layer leads to higher pH. The declines in exchangeable soil minerals (particularly Ca^{+}) in the lower layers (where most of roots are distributed) could have resulted from an increase in nutrients uptake by trees. The mean dasometric characteristics of the four sampled stand are given in Table 2.

Table 1
Soil properties in sampled marginal sites of *N. antarctica* forest

	Organic horizon	Mineral horizon I	Mineral horizon II
Depth (cm)	0–5	5–21	21–50
Clay (%)	–	26	25
Silt (%)	–	22.5	19.9
Sand (%)	–	51.5	55.1
pH	5.6	4.7	4.5
N total (ppm)	5190	2810	1890
P Truog (ppm)	66	25	6
K^{+} (cmol/kg)	1.3	0.9	0.5
Mg^{+} (cmol/kg)	6.3	2.3	2.1
Ca^{+} (cmol/kg)	24.6	8.5	5.1

2.2. Biomass

Three randomly replicate sample plots for each growth phases stands were selected. These plots had a hierarchical design according to trees size which differs between growth phases stands. Thus, trees in mature phase stands were sampled in 150 and 50 m^2 for final growth phase, 10 m^2 for initial growth phase 40–60 years, and for 2 m^2 regeneration phase. Similar hierarchical designs according to trees size or trees age were used previously for trees biomass sampling (De Castilho et al., 2006; Laclau et al., 2000). Within each plot four *N. antarctica* trees were selected, felled and sorted in four crown classes: dominant, codominant, intermediate and suppressed trees, depending of their crown position.

Total height and diameter at breast height were measured, and the stem was cut at 0.1 m (stump), 1.3 m and every 1 m up to an end diameter of 10 mm after the harvesting to calculate wood volume for heartwood, sapwood, bark and rotten wood components using Smalian formula. Each tree was separated into the following components: leaves; small branches (diameter < 10 mm); sapwood, heartwood and bark from the main stem and coarse branches (>10 mm); and roots with bark classified as fine (diameter < 2 mm) medium (<30 mm) or coarse roots (>30 mm).

Three samples of each component in every tree were taken for biomass calculations and nutrient analysis. For coarse branches, stem and roots, three cross-sectional discs of 30 mm at different lengths were taken and separated into their component pool (heartwood, sapwood and bark) to determinate density for biomass calculations. All small branches, leaves and dead branches from each sampled tree were separated and weighed in fresh. Roots from individual tree were excavated to a depth of 0.5 m (maximum rooting depth for all crown classes) in circular plots centred on the stump of the selected trees minimizing the loss of the fine root fraction. These roots were sorted in 3 diameter classes (<2 mm, from 2 to <30 mm and >30 mm) and weighed in fresh.

At each sampled stand, four litter traps (1 m^2 collecting surface) were placed randomly under the canopy and collected at the end of the growing season (autumn). From total litterfall leaf litter was separated to estimate nutrient resorption.

Sub-samples from all components and leaf litter were taken to estimate biomass and for nutrients analysis.

2.3. Chemical nutrient analysis

Samples from all age classes were dried in a forced draft oven at 65 °C to constant weight and ground in a mill containing 1 mm stainless steel screen for nutrient analysis. Nitrogen (N) was determined using the Kjeldahl technique. Phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg)