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Research paper

Nutrients and energy in proleptic branches and leaves of poplar under a short-rotation coppice

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ABSTRACT

Renewable energy is often generated from biomass, produced in short-rotation coppice (SRC) cultures. These cultures are frequently established on former agricultural land with ample availability of plant nutrients as nitrogen, phosphorous, potassium, calcium and magnesium. Nevertheless, little is known about the annual recycling of these nutrients through the leaves, as well as about the amounts that are removed at harvest. We therefore quantified soil nutrient concentrations, as well as nutrient concentrations and the gross calorific value of the proleptic branches and of the leaves of 12 poplar (*Populus*) genotypes in the second rotation of an operational SRC (with two-year rotations). For the produced leaf biomass, we also quantified the standing energy stock and the nutrient stock of each genotype. After four years the P, K, Ca and Mg soil concentrations had not significantly changed, while the N concentration at 30–60 cm of soil depth had significantly increased. On average, the standing aboveground woody biomass of the 12 genotypes in 2013 was 13.75 Mg ha^{-1} and the total leaf biomass was 3.54 Mg ha^{-1}. This resulted in an average standing energy stock in the leaves of 64.8 GJ ha^{-1}. Nutrient concentrations were lower in the proleptic branches as compared to the leaves, but the proleptic branches and leaf nutrient concentrations significantly varied among the genotypes.

1. Introduction

Although coppice forests have existed for a long time in Europe [1], short-rotation coppice (SRC) cultures are not yet widely implemented as a component of European land use [2,3]. Nevertheless, SRC cultures are of increasing importance in countries with a temperate climate [4] and afforestation on agricultural land is often encouraged through grants or subsidies [5]. Poplar (*Populus* spp.) is one of the most suitable species for SRC cultures because it grows fast, it achieves high yields, and many (disease resistant) selected genotypes are commercially available [6]. SRC poplars planted on converted agricultural lands can benefit from the usually intensive fertilisation that was previously applied. The soil likely contains high amounts of macronutrients, i.e., nitrogen (N), phosphorous (P), potassium (K), calcium (Ca) and magnesium (Mg) [7–9]. However, the nutrient recycling in, and the nutrient losses from, SRC are not yet fully established. This is of great importance if we are to manage long-term SRC plantations sustainably.

SRC cultures are generally coppiced every 2–5 years, with all the aboveground biomass being removed from the site. After each harvest, a multitude of resprouting shoots emerges from every stump (Fig. 1); these gradually undergo self-thinning during the following rotation [10]. As a consequence, and because the relative amount of bark increases with decreasing shoot diameter, the proportion of bark to wood is much higher in SRC than in traditional forestry [11]. As bark contains much higher nutrient concentrations than bole wood [4,12,13], this leads to a relatively larger nutrient removal and, consequently, to a higher nutrient requirement for trees grown as SRC [4,7,14]. In traditional forestry, managers strive to achieve the lowest amount of bark in the harvested wood, because bark also reduces the combustion quality of the fuel wood [13]. Coppicing of leafless shoots is usually done in winter; this facilitates the mechanised

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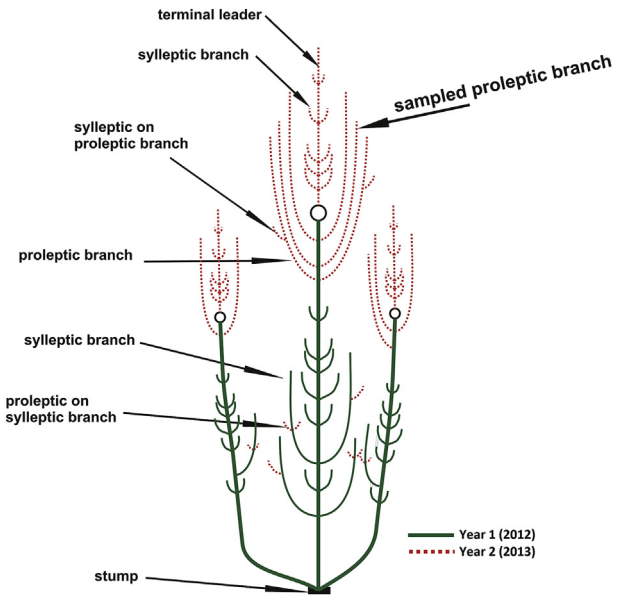

Fig. 1. Schematic representation of a two-year old poplar stool in November 2013. Stumps were four years old at the time of sampling (November 2013). Parts below the circles (full lines) present the stem wood formed in 2012 (first year of the second rotation), parts above the circles (dashed lines) present the current-year shoots formed in 2013. The term shoot refers to the combination of the main axis and all proleptic and sylleptic branches (modified after [45]).

process of coppicing and increases the combustion quality of the woody biomass into the burner. In this way, foliar nutrients are returned to the roots or to the soil [14,15]. On the other hand, leaves could also be considered as a source of harvestable energy [16]. In winter, soils are more likely to be frozen, thus minimising soil compaction [17].

The aim of this study was to quantify the amounts of energy and of nutrients in leaves and in the proleptic branches (Fig. 1) in 12 different poplar genotypes of an SRC. We focused on the proleptic branches to assess the average nutrient concentrations in the crown part. The quantification of nutrient fluxes in a managed ecosystem is very important for assessing the fertilisation requirements [4,14,18], because fertilisation is the most energy-consuming process in the life cycle of an SRC culture [9,19]. Reliable data on stand and nutrient dynamics are scarce [5,20] and they rarely take genotypic differences into account [21], although these differences are essential for making correct decisions about fertiliser application [15].

2. Materials and methods

2.1. Site description

This study was performed at an operational SRC plantation and fits within the framework of the POPFULL research project [22]. The plantation was established on 18.4 ha located in Lochristi (51°06′44″ N, 3°51′02″ E; East Flanders, Belgium), from which 14.5 ha were planted with poplar (*Populus*) and willow (*Salix*) cuttings. A detailed site description is given in Broeckx et al. [23]. The study focused on the 12 poplar genotypes planted; these are all commercially available (Table 1). Twenty-five cm long hardwood cuttings were planted at a density of 8000 ha^{-1}, in monoclonal blocks in a double-row planting scheme with alternating inter-row distances of 0.75 and 1.50 m, and 1.10 m between the cuttings in the row. The plantation was established in April 2010 and coppiced for the first time early February 2012 after a two-year rotation [24]. After the second two-year rotation the site was harvested for the second time mid-February 2014. The present study focused on the fourth year (2013) after plantation establishment, i.e. the second year after the first coppice (which took place in early February 2012 [24]). Site preparation, plantation management and coppice conditions have been previously described [25].

2.2. Soil nutrient analyses

To quantify the effect of coppicing on the total nutrient stock of the soil, we collected soil samples before the planting (March 2010) and after the second coppice (March 2014). Samples were taken at random in the middle of a mono-genotypic block of genotype Koster over two soil depths: 0–30 cm and 30–60 cm [26]. A gouge auger set for top soil layers was used (type 04.06, Eijkelkamp Agrisearch Equipment, the Netherlands). In the laboratory, samples were dried at 70 °C until constant dry weight, milled (with an ultra-centrifugal mill ZM200, Retsch, Germany) and sieved at 0.5 mm. From each sample 30 mg was used to determine the total N concentration (NC-2100 element analyser, Carlo Erba Instruments, Italy) and the rest of the sample was used for the analysis of P, K, Ca and Mg. The latter analyses were performed according to the standard procedures of the Belgian Soil Survey (Leuven, Belgium). There was not enough soil in every sample to allow for all nutrient analyses, thereby limiting the total number of samples (Table 2).

To test for differences in N concentrations between both sampling years (2010 and 2014) and between soil depths (0–30 cm and 30–60 cm) we used a generalised mixed effect model with gamma distribution of the errors and a logarithm link function. The mixed effect model (with sampling point as a random effect) was chosen because the different soil depths were sampled at the same point (Table 2). To test for differences in P, K, Ca and Mg concentrations we used repeated measures ANOVAs. The data were logistically transformed to stabilise the variance, because the variance increased with increasing element concentrations. All analyses were performed in R, with extension package lme4 [27]. Differences were qualified as significant when $p < 0.05$.

2.3. Standing aboveground biomass

The aboveground woody biomass (AGWB) of all genotypes was estimated by converting yearly diameter inventories with the allometric relations (per genotype) between shoot diameter and AGWB previously established for this site (described in detail by Broeckx et al. [28]). For this study we used the difference in AGWB between both years (2012 and 2013) as the AGWB increment for 2013.

The total leaf biomass (kg m^{-2}) produced per genotype in 2013 was obtained by dividing the maximum leaf area index (LAI_{max}) by the specific leaf area (SLA) [28]. The LAI_{max} (m^2 m^{-2}) was assessed by leaf litter collection between the time of LAI_{max} (15 August 2013) and the end of the growing season (6 December 2013) [25]. The genotype-specific SLA (m^2 kg^{-1}) was determined for four stumps per genotype [25]. The resulting total leaf biomass was further divided by the AGWB to obtain the relative amount (in %) of total aboveground dry mass (DM) allocated to the leaves.