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# Net ecosystem production and carbon balance of an SRC poplar plantation during its first rotation☆

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ABSTRACT

To evaluate the potential of woody bioenergy crops as an alternative energy source, there is need for a more comprehensive understanding of their carbon cycling and their allocation patterns throughout the lifespan. We therefore quantified the net ecosystem production (NEP) of a poplar (*Populus*) short rotation coppice (SRC) culture in Flanders during its second growing season.

Eddy covariance (EC) techniques were applied to obtain the annual net ecosystem exchange (NEE) of the plantation. Further, by applying a component-flux-based approach NEP was calculated as the difference between the modelled gross photosynthesis and the respiratory fluxes from foliage, stem and soil obtained via upscaling from chamber measurements. A combination of biomass sampling, inventories and upscaling techniques was used to determine NEP via a pool-change-based approach.

Across the three approaches, the net carbon balance ranged from 96 to 199 g $m^{-2}$ $y^{-1}$ indicating a significant net carbon uptake by the SRC culture. During the establishment year the SRC culture was a net source of carbon to the atmosphere, but already during the second growing season there was a significant net uptake. Both the component-flux-based and pool-change-based approaches resulted in higher values (47–108%) than the EC-estimation of NEE, though the results were comparable considering the considerable and variable uncertainty levels involved in the different approaches. The efficient biomass production – with the highest part of the total carbon uptake allocated to the aboveground wood – led the poplars to counterbalance the soil carbon losses resulting from land use change in a short period of time.


## 1. Introduction

At the present day energy from biomass has gained interest as an alternative for fossil fuels and as a possibility to bring down greenhouse gas emissions [1,2]. Land use changes affecting the cycling and storage of carbon (C) in ecosystems [3] are one of the main causes of the increased greenhouse gas levels in the atmosphere [4,5]. However, afforestation of abandoned and marginal farmland can enhance ecosystem C storage and potentially counteract the processes of C loss [6]. Within this


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context the establishment of short rotation coppice (SRC) plantations for bioenergy production has potential for mitigating the rising greenhouse gas levels in the atmosphere [7]. It has been assumed that the net $CO_2$ emissions from bioenergy cultures are zero [8] or are so-called 'carbon neutral' by taking up as much C during the growth as released upon conversion to energy. However, bioenergy cultures as SRC plantations might act as a $CO_2$ source, particularly in the short to medium term [9] due to land use changes. During the consequent years they switch to C sinks [8,10–13]. The net C benefit of such plantations is fairly site specific [12]; it is, therefore, important to study and quantify the C cycle of these ecosystems in more detail and to assess their impact on regional C balances [14].

The net C balance of an ecosystem can be assessed by both NEP (net ecosystem production) and NEE (net ecosystem exchange). NEP is the difference between net primary production (NPP) and heterotrophic ecosystem respiration. NPP is the total amount of new organic matter produced during a certain period [15]. It is the difference of the total photosynthetic uptake of $CO_2$ by the ecosystem – or the gross primary production (GPP) – and the autotrophic ecosystem respiration. NEE is the net $CO_2$ flux from the ecosystem to the atmosphere [16], which corresponds to the net difference of photosynthetic carbon uptake and the respiration of autotrophs and heterotrophs [17]. NEE equals NEP disregarding sources and sinks for $CO_2$ not involving conversion to or from organic C [18]. To understand the dynamics of the ecosystem C sinks, it is important to estimate the size of each C pool and to quantify all C fluxes. Studies of the C balance of SRC plantations are rather scarce [19,14,12] and the simultaneous quantification of NEE with eddy covariance techniques, and of NEP with both C flux and C pool assessments were never done before for an SRC culture.

The present study is part of the large-scale POPFULL project [20] which aims to make a full greenhouse gas balance and to investigate the economic and energetic efficiency of an operational SRC culture with poplar. Within this context, the specific objectives of this study were: (i) to quantify the components of the carbon balance of an SRC plantation; (ii) to quantify NEP and determine the sink–source status and (iii) to compare the estimated NEP with NEE measured through eddy covariance techniques. All measurements were performed during the second growth year of the first rotation.

## 2. Material and methods

### 2.1. Site and plantation description

The operational POPFULL site is located in Lochristi, province East-Flanders, Belgium (51°06′44″ N, 3°51′02″ E). The region is subjected to an oceanic climate with a long-term average annual temperature and precipitation of 9.5 °C and 726 mm, respectively [21]. According to the Belgian soil classification the area forms part of the sandy region with poor natural drainage [22]. The 18.4 ha site was a former agricultural area consisting of croplands (62%; with corn as the most recent cultivated crop in rotation) and extensively grazed pasture (38%). On 7–10 April 2010 an area of 14.5 ha (excluding the headlands) was planted with 12 selected poplar (*Populus*) and three selected willow (*Salix*) genotypes, representing different species and hybrids of *Populus deltoides*, *Populus maximowiczii*, *Populus nigra*, and *Populus trichocarpa* and *Salix viminalis*, *Salix dasyclados*, *Salix alba* and *Salix schwerinii*. The present study focuses on the poplar genotypes only. Using a modified leek planting machine 25 cm long dormant and unrooted cuttings were planted in a double-row planting scheme with alternating distances of 0.75 m and 1.50 m between the rows and on average 1.10 m between trees within the rows (plant density of 8000 $ha^{-1}$). The plantation was designed in large monoclonal blocks of eight double rows wide that covered both types of former land use (cropland and grazed pasture). Each genotype has minimum two and maximum four replicated blocks with row lengths varying from 90 m to 340 m. After two years of growth (2010, GY1 (growth year) and 2011, GY2) the plantation was harvested for the first time on 2–3 February 2012 with commercially available SRC harvesters. Trees continue growing as a coppice culture with multiple shoots per stool in the following two-year-rotations. More details on site conditions, on poplar materials and on the plantation lay-out are found in Broeckx et al. [23].

### 2.2. Meteorological data and soil data

A complete set of environmental variables were recorded continuously from June 2010 till present as described in Zona et al. [24,25]. Soil temperature was monitored from the surface until 1 m depth; air temperature and relative humidity were collected at about 5.4 m above the surface. All sensors for these measurements were placed in the immediate proximity of an eddy covariance (EC) mast (see below). For more details on the instruments used we refer to Zona et al. [24,25].

### 2.3. Quantification of carbon pools

#### 2.3.1. Foliage pool (F)

Leaf litter was collected during leaf fall from early September to December of GY2 in two plots of 5 × 6 trees for each genotype within each former land use type ($n = 48$). In each plot three perforated litter traps (litter baskets) of 0.57 m × 0.39 m were placed on the ground along a diagonal transect between the rows covering the wide and the narrow inter-row spacings. Every two weeks the litter traps of each plot were emptied and leaf dry biomass was determined after oven drying at 70 °C. Successively collected leaf biomass was cumulated over time to obtain the yearly produced foliage. C mass fractions of the leaves were determined on a mixed subsample of three randomly selected mature leaves of different individual leaf area and from different tree heights per plot in September of GY2, at the time when maximum leaf area index was reached [23]. Leaves of plots with the same genotype × land use type combination were merged, yielding six leaves per mixed sample. Samples were ground and analysed by dry combustion with an NC element analyzer (NC-2100 element analyzer, Carlo Erba Instruments, Italy). These C mass fractions were used to quantify the foliage C production per plot. An average foliage C pool value was then calculated by weighing the averages per genotype × land use type combination with their proportional area in the plantation.