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Short Communication

Neglected carbon pools and fluxes in the soil balance of short-rotation woody biomass crops

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ABSTRACT

The cultivation of dedicated bioenergy crops is being stimulated because of their potential to replace fossil fuels and to maintain or to sequester carbon (C) in the soil, and thus help to mitigate the rising atmospheric CO_2 levels. There are, however, still a lot of inaccuracies with regard to the dynamics of C in the soil, and thus with the potential to sequester soil C in these bioenergy crops. Using experimental data observed at the intensively monitored short-rotation woody crops (SRWC) plantation of the POPFULL project, we demonstrate that frequently neglected C pools and fluxes can be of crucial importance for the soil C balance. We highlight three specific cases. First, C inputs into the soil due to weed roots may equal or exceed those due to poplar fine roots, especially during the establishment phase of the plantation. Secondly, harvesting influences the dynamics of above- and belowground C inputs, as well as the soil environment. Large amounts of C are stored in the belowground woody biomass, which represents a long-term C pool. Thirdly, spatial differences related to the planting design are an important source of error in the upscaling of soil variables. We call upon researchers to consider and measure these neglected C pools and fluxes.

1. Uncertainties associated with the soil carbon balance of short-rotation woody crops

Agriculture for food production and forestry for timber production have been human activities since millennia. Historic improvements in technical, mechanical, biological and management processes have led to higher food and timber yields, and to a more efficient production. In contrast to traditional agriculture and forestry, the cultivation of crops for the production of biofuels is of a more recent nature [1]. The culture of biomass for biofuels still represents a small proportion of both the agricultural and the energy sectors, and it is only applied at a small scale. In this contribution we focus on the soil carbon (C) balance of short-rotation woody crops (SRWC) for the production of bioenergy. Some management practices are still under development due to the relatively recent introduction of SRWC (since the 1970's). For example, appropriate and sustainable weed management remains a major

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issue, especially during the establishment years of any SRWC culture. SRWC cultivation is now fully mechanised, from soil preparation, planting and management till harvesting. Most mechanization comes from agricultural machinery that has been adapted for SRWC, and so it is somewhere in between forestry and conventional agriculture.

Bioenergy is being stimulated because of their potential to replace fossil fuels and to maintain or sequester carbon (C) in the soil. These features might help to mitigate the rising atmospheric CO_2 levels, and thus global climate changes. The soil C, or the soil organic matter, is an essential component of soil fertility. To maintain – or to increase – soil C levels the soil depends on the input of crop residues. In bioenergy crops most of the organic C aboveground is removed for the production of biofuels. So the question remains: how can we reconcile the competing demands for organic C products for biofuels with the C for soil fertility and for sequestration? [2]. In SRWC the weed management and the harvesting operation affect the C cycle by affecting productivity, C inputs into the soil from weeds, from harvest losses. As for conventional agricultural crops [3], the efficiency of SRWCs for soil C sequestration is highly uncertain [4].

The C mass balance approach is a suitable and frequently used technique for understanding C cycling and for proposing management options for increasing C sequestration. This approach accounts for the balance of all C inputs into and all C outputs out of the soil. The soil C mass balance approach also allows to evaluate whether a system is losing or gaining C, and to identify the main fluxes. Although all C fluxes should be considered, only the most evident inputs and losses are generally considered in the soil C balance [5]. This limits our understanding of the dynamics of the soil C of SRWCs.

In this communication (i) we describe and we quantify the impact of different management processes on the soil C balance of an SRWC; and (ii) we identify the principal sources of error associated with the quantification of the soil C balance. We illustrate and document our analyses and suggestions with experimental data observed at the intensively studied SRWC plantation of the POPFULL project (http://uahost.uantwerpen.be/popfull/).

2. Study case

The operational POPFULL site is a large-scale (18.4 ha) SRWC plantation of twelve poplar (*Populus* sp.) and three willow (*Salix* sp.) genotypes planted in April 2010 in monoclonal blocks in a double-row planting scheme. The distance between the narrow rows was 75 cm and that of the wide rows was 150 cm. The distance between trees within a row was 110 cm, yielding an overall density of 8000 trees per ha. The plantation in East-Flanders (Belgium) was managed in two-year rotation cycles, for two rotations (four years in total; 2010–2014). Manual and chemical weed control was applied during the first rotation, and during the first year after coppice. Neither fertilization nor irrigation was applied during the entire lifetime of the plantation. Table 1 provides a synoptic summary of the documented results from the plantation.

3. Management processes affecting the C balance

3.1. *Presence of weeds*

In agricultural crops and in SRWC plantations, spontaneous annual vegetations below the canopy are considered unwanted [6]. This explains perhaps why weed production is rarely reported in studies on C balances. Weeds do have an important function within any agro-ecosystem. Aboveground, weeds compete for light [7] and belowground they compete for water and nutrients [8]. Weeds, however, also provide a high annual input of C into the soil, especially in the first rotation [Fig. 1; 9]. In our plantation weed root biomass and root productivity during the first rotation were more than two times higher than those of the fine roots of the poplar crop [9]. Aboveground, these weeds reached up to 1.5 m height and accumulated up to 300 g C m^{-2} in biomass. The planting of annual 'cover crops' in periods of non-growth has been proposed as one of the most promising strategies to offset the

Table 1 – Range of carbon fluxes for the quantification of the soil C balance and their sensitivity to the use of different genotypes, former land uses, planting scheme and harvesting machines. Values rounded to the nearest unit. [Values adapted from 9, 18, 24] SRWC = short rotation woody crop; DOC = dissolved organic carbon. POPFULL project (http://uahost.uantwerpen.be/popfull/). Sensitivity expressed as change in the mean: (–) not applicable, (*) 1–5%, (**) 5–30%, (***) >30%.

Flux of C	Range ($g\ C\ m^{-2}\ y^{-1}$)	Sensitivity			
		Genotype	Former land-use	Planting scheme	Harvesting machine
Litterfall	70–175	**	*	*	–
Harvest losses[a]	1–145	***	***	–	***
Weed aboveground biomass	170–290	**	***	–	–
Weed belowground biomass	15–26	**	***	*	–
Tree fine roots	3–30	***	***	**	–
DOC	7	**	*	–	–
Pool of C	($g\ C\ m^{-2}$)				
Aboveground biomass	1820–2950	**	*	–	–
Root biomass	180–360	**	*	**	–

[a] Only for the year of harvest. For the annual value, the number should be divided by the length of the rotation (two years).