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Energy performances of intensive and extensive short rotation cropping systems for woody biomass production in the EU

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ABSTRACT

One of the strategies to ensure energy security and to mitigate climate change in the European Union (EU) is the establishment and the use of short rotation woody crops (SRWCs) for the production of renewable energy. SRWCs are cultivated in the EU under different management systems. Addressing the energy security problems through SRWCs requires management systems that maximize the net energy yield per unit land area. We assembled and evaluated on-farm data from within the EU, (i) to understand the relationship between the SRWC yields and spatial distribution of precipitation, as well as the relationship between SRWC yield and the planting density, and (ii) to investigate whether extensively managed SRWC systems are more energy efficient than their intensively managed counterparts. We found that SRWC yield ranged from 1.3 to 24 t ha^{-1} y^{-1} (mean 9.3 $\pm$ 4.2 t ha^{-1} y^{-1}) across sites. We looked for, but did not find a relationship between yield and annual precipitation as well as between yield and planting density. The energy inputs of extensively managed SRWC systems ranged from 3 to 8 GJ ha^{-1} y^{-1} whereas the energy ratio (i.e. energy output to energy input ratio) varied from 9 to 29. Although energy inputs (3–16 GJ $ha^{-1}y^{-1}$) were larger in most cases than those of extensively managed SRWC systems, intensively managed SRWC systems in the EU had higher energy ratios, i.e. between 15 and 62. The low energy ratio of extensively managed SRWC systems reflected their lower biomass yield per unit area. Switching from intensively managed SRWC systems to extensively managed ones thus creates an energy gap, and will require more arable land to be brought into production to compensate for the yield loss. Consequently, extensification is not the most appropriate path to the success of the wide scale deployment of SRWC for bioenergy production in the EU.

Contents

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1. Introduction

In an attempt to lower the EU's reliance on fossil energy sources, to reduce emissions from fossil fuels, and to mitigate climate change, several renewable energy sources have been introduced into the EU market during the last few decades. Woody biomass represents one of the EU's largest potential sources of renewable energy, and the political objectives to increase the share of renewable energy sources in total energy consumption by 2020 are expected to lead to a long-term increase in the European wood demand [1]. Woody biomass comes from a number of sources, including forest residues, mill residues, and urban and municipal waste wood. Another potential source of woody biomass comes from short rotation woody crops (SRWCs) such as poplar (*Populus sp.*) and willow (*Salix sp.*) that are grown on sites that enable a higher productivity using agronomic techniques [2,3].

SRWCs can be grown under different farming systems, from intensively managed to extensively managed plantations. Poplar and willow are two of the few woody crops that have been commercially planted in SRWCs to a significant extent in the EU for the purposes of renewable energy production [4–6]. Currently there are about 50 kha of SWRCs established in the EU [7]. Compared to food crops, SRWCs require low inputs of fertilizers and herbicides, and they grow well on land that is less suitable for agriculture [8]. As there is no annual cultivation cycle, their energy balance is improved compared to traditional agricultural crops. SRWCs have the potential to not only ensure fuel security through the use of the derived biomass for renewable energy production, but also to provide other ecosystem services. When established on previous croplands SRWC plantations store carbon in the soil, improve water and nutrient retention, and decrease the runoff of both sediments and pollutants [9,10]. Other advantages of SWRCs include their increased flora, avian and invertebrate diversity [11–13]. But the overall impact of SRWC production on ensuring energy security and providing additional ecosystem services very much depends on the proper selection of genotypes [14], on the spatial scale of the planting in a specific locality, and on the management practices adopted.

Management practices influence both the final productivity and the energy balance of SRWC systems through the size and the efficiency of the applied farm inputs [15,16]. In the intensively managed SRWC systems, high capital inputs (machinery, agrichemical) and labor generate high yields per unit land area. In the extensively managed SRWC systems the yield is lower because the production methodologies require smaller inputs of labor and capital equipments. However, intensification of agricultural systems in the EU has led to reduced soil fertility, enhanced erosion, reduced wildlife habitats, as well as serious pollution problems [17]. Because of its positive ecological character, extensive farming systems are being portrayed as a way of solving these problems associated with intensive agriculture [18]. The current emphasis on extensive SRWC systems justifies the increased interest in reducing on-farm water and energy use, in protecting the environment, and enhancing the landscape and species diversity. However, it is unclear if extensively managed SRWC systems result in significant energy yields; a precondition that determines the potential for cultivating SRWCs.

A number of studies have compared the energy use in intensively managed and extensively managed food crop production systems [18–27]. These specific studies showed that extensively managed food crop production systems, while not without environmental impacts, are less polluting than intensively managed ones because their impact on the level of biodiversity is lower, and because they demand less energy per unit of area [23–27]. Only one study has so far compared the energy inputs and energy balances of intensively and extensively managed energy crops [28]. For food crops the energy balance is of limited importance since the harvested biomass is primarily determined by its nutrient content rather than by its heating value. But for energy crops like SRWCs the energy balance is of paramount importance [28]. To be a viable substitute for fossil fuels, SRWCs must yield significantly more energy than is required to produce them [28], regardless of the management system adopted. SRWC growers are challenged by the need to identify the management system that maximizes productivity, energy and water use, while maintaining high biodiversity. To evaluate how problematic this challenge is, we compiled all recent available data on SRWC plantations in the EU and used them (i) to review the obtained SRWC yields in the EU and how much they depend on precipitation, planting density; and (ii) to assess and compare the energy balance of intensively and extensively managed SRWC systems in the EU.

2. Database and data treatment

2.1. Database construction of SRWC plantations

We constructed a database of data from past and currently existing SRWC plantations in the EU. The plantations included in the database were identified by (i) doing a search for SRWC production data via the Web of Knowledge; (ii) identifying journal articles that cited original studies or topical reviews; (iii) tracing back papers cited in the bibliographies of the identified studies through (i) and (ii); and (iv) contacting farmers who established and managed commercial SRWC plantations in the EU, or scientists who have worked or are currently working on SRWC production in the EU. We limited our assessment to the EU and selected studies or sites according to the three following criteria: (i) poplar or willow was the main crop; (ii) productivity was measured in the field; and (iii) details on the cultivation techniques and/or the energy inputs were available. An inventory of all data categories and of the key variables that were quantified is shown in Table 1. After the database was completed, the first three authors reviewed all entries in order to detect inconsistencies or insufficient data quality. When aberrant entries were found, we re-contacted the providers of the