Biomass and Bioenergy 94 (2016) 209–219

Contents lists available at ScienceDirect

Biomass and Bioenergy

journal homepage: http://www.elsevier.com/locate/biombioe

Research paper

Woody biofuel production from short rotation coppice in Italy: Environmental-impact assessment of different species and crop management

Jacopo Bacenetti [a, *], Sara Bergante [b], Gianni Facciotto [b], Marco Fiala [a]

[a] AgriFood LCA LAB, Department of Agricultural and Environmental Sciences, Production, Landscape, Agroenergy, Università degli Studi di Milano, Via Giovanni Celoria 2, 20133, Milano, Italy

[b] Consiglio per la ricerca in agricoltura e l'analisi dell'economia agraria (CREA), Unità di ricerca per le Produzioni Legnose fuori Foresta (PLF), Strada Frassineto 35, 15033, Casale Monferrato, AL, Italy

ARTICLE INFO

Article history:
Received 27 January 2016
Received in revised form
16 July 2016
Accepted 5 September 2016

Keywords:
Chips wood
Poplar
Willow
Woody biomass
Renewable energy
Experimental trials

ABSTRACT

Short Rotation Coppices (SRC) can be a suitable solution for the production of biomass, mainly due to the easy-to-harvest good-quality feedstock. Besides technical, social and economic aspects, environmental issues are important to be taken into account when developing SRC. Although some studies focused on environmental sustainability of SRC were carried out only few compare different arboreous species using primary data.

In this study, the environmental evaluation of SRC plantations carried out with 14 poplar and 6 willow clones was performed using primary data collected during experimental field tests over 12 years.

Twelve impact potentials were evaluated using the characterization factors reported by the ILCD method: climate change (CC), ozone depletion (OD), Human toxicity, cancer effects (HTc), Human toxicity, non-cancer effects (HT), particulate matter (PM), photochemical ozone formation (POF), acidification (TA), freshwater eutrophication (FE), terrestrial eutrophication (TE), marine eutrophication (ME), freshwater ecotoxicity (FEx) and mineral, fossil and renewable resource depletion (MFRD).

Both for poplar and for willow, among the different clones the environmental performance greatly vary mainly due to the yield. The choice of the most productive clones involves a reduction of the environmental impact of the produced biomass of about 35% (respect to the average results both for poplar and willow). However, biofuel production from willow SRC achieves lower environmental burdens respect to poplar SRC considering both the average biomass yield and the most productive clones.

1. Introduction

In Europe, energy policies are increasingly promoting the generation of energy from renewable sources (i.e., the European Union [EU] target of 27% renewable energy by 2030 and 40% of greenhouse gas [GHG] emission reduction) [1]. Among the different renewable sources, woody biomass is an interesting solution for energy generation in rural areas for both electricity [2] and heat production [3,4]. Woody biomass can be produced from forestry management but also from dedicated plantations in which woody species are grown for energy purposes [5–7]. In more detail, regarding the latter, the Short Rotation Coppice (SRC) plantations are cultivations of woody crops (poplar, willow, black locust, and other fast-growth species) characterized by short cutting cycles (1, 2, or 5–6 years), high plant density (from 1000 to 12,000 trees per hectare), and a crop cycle ranging from 10 to 15 years, over which several harvests take place [7–11].

Over the years, thanks to public subsidy frameworks, in Italy, about 10,000 ha of SRC were realized mainly in northern regions (Lombardy and Veneto) [7,8,12–16]. Poplar clones (*Populus* spp.) are the most used for SRC, but experiences were also carried out with new clones of willow (*Salix* spp.) and provenances of *Robinia pseudoacacia* L. in Central and Northern Europe [8,9,16–21], as well as clones of *Eucalyptus* spp. in Southern Europe [22,23]. Some studies highlighted that the biomass yield of willow clones can be higher than that of poplar [8,11,17]; nevertheless, SRC based on poplar clones is the main solution performed at the commercial level.

* Corresponding author.
E-mail address: jacopo.bacenetti@unimi.it (J. Bacenetti).

http://dx.doi.org/10.1016/j.biombioe.2016.09.002
0961-9534/

With regard to clones, many genotypes of poplars and willows are in study and evaluation at CREA-PLF and in other private farms and public Institutes. Some new genotypes have been selected for biomass production at SRC plantations: They show resistance to principal poplar diseases, good rooting, and re-sprouting ability and rusticity. The most important and commercialized clones are *P.* × *canadensis* as "Orion" and "Imola" or "AF2," while others are *P. deltoides*, such as "Baldo." Between willows, the new clones selected for biomass purposes are *S. babylonica* (previus *S. matsudana*) hybrids, such as "Drago" and "Levante."

SRC plantations can be managed with different cutting cycles: plantations with short cutting frequency (1 or 2 years) and plantations with medium cutting frequency (>5 years). Two- and five-year cutting cycles are the most widespread in Italy; the annual one, which initially foresaw extremely high planting density, although originally used (mainly due to issues related to harvesting mechanization) [24], has not been adopted more due to low coppice survival, low material quality (high ash content), and high planting costs [18–20].

Planting systems for different SRC models are different, too, with highly variable plant density: 10,000–14,000 plants ha^{-1} (annual SRCs), 5000–10,000 plants ha^{-1} (biennial SRCs) and 1000–1800 plants ha^{-1} (5-year SRCs). In SRC with short cutting frequency, regarding planting layout, a single-row or twin-row plantation can be realized. The single-row layout is currently the most widespread, but twin rows can be an alternative solution [8,17].

The cultivation practice is quite different in the two principal models. In SRCs with medium cutting time, the crop cultivation requires low inputs, and it is most similar to traditional poplar plantations. On the contrary, in annual and biennial SRCs, fertilization and weed control are more frequently carried out [13,14,17]. However, among SRCs with short and medium cutting times, the main differences are related to the harvest. The harvesting operations include the felling, chipping, and transporting of the chips to the collecting point where the biomass is temporarily stored before being sold or used. With medium cutting time, at the end of 4–6 years of growth, felling and chipping are performed separately because the stem basal diameters (0.20–0.25 m) are too big for foragers [24]. On the contrary, for annual and biennial SRCs, at the harvest time, the basal diameters are lower (<0.12–0.14 m) and can be felled and chipped simultaneously. For this purpose, different harvesting units are available: the tractor-based method or forager-based method [24–27]. The foragers are equipped with specific headers developed for harvesting SRC plantations [24,25].

In Italy, although better economic performances and a better quality of the biomass are related to SRC with medium cutting time, the SRCs with a 2-year cutting cycle are predominant (about 75% of the total area dedicated to SRC plantations) [16,28,29]. However, besides the economic aspects, the environmental ones also must be carefully evaluated to improve the environmental sustainability of this renewable energy source. In this regard, some studies were carried out at the end of the 1990s and at the beginning of new century, but most of them focused on the evaluation of a few environmental issues. They usually limited the analysis to energy and GHG or energy balance [13,15,16,30]. The most recently carried-out studies [6,22,23,32–36] only rarely used primary data regarding biomass yield and cultivation practice [6,22,32,33]. There is a lack of information about the environmental performance (benefits and/or impacts) of SRC carried out using different species and clones as well as considering different plant layouts.

In this context, the aim of this paper is to analyze the environmental performances of SRC plantations with 2-year cutting cycles, realized with different planting layouts (single and twin rows) using 20 clones of poplar and of willow. For this purpose, primary inventory data were collected by means of a 12-year experimental field test carried out in Piedmont (Northern Italy) with 14 poplar clones and 6 willow clones. In addition, to assess the environmental performances of SRC plantations, the environmental hotspots (processes most responsible for the environmental impact) were highlighted, and the impact of low water availability was evaluated using the life-cycle assessment (LCA) method. LCA is a holistic methodology that aims to analyze products, processes, or services from an environmental perspective (ISO 14040, 2006) [37]. Although originally developed for industrial processes, in the past few decades, it has increasingly become employed to analyze agricultural systems as well.

2. Materials and methods

2.1. Goal and scope definition

The goal of this study is to assess the environmental impact of SRC plantations characterized by poplar and willow clones, a short (2–3 years) cutting cycle, and different planting layouts. For this purpose, primary data regarding the biomass yield as well as all of the field operations carried out were collected over 12 years of experimental field tests. The two genera, the cutting cycle, and the planting layouts evaluated are the most widespread for SRCs in Europe.

In more detail, the research questions can be summarized as follows:

1) What is the environmental impact of SRC plantations performed with different poplar and willow clones?
2) What are the main environmental hotspots associated with SRC cultivation?
3) Between the single- and twin-row layouts, which solution has the lower environmental load?

The study outcomes can be useful for farmers and farmer associations involved in SRC plantation, for stakeholders involved in the woody biomass market and in energy generation from wood chips, and for local politicians involved in the woody-bioenergy process. Regarding the latter, the achieved results are important in view of the development of the new Rural Development Program; willow and poplar clones with better environmental performances should be favored inside the subsidy framework.

2.2. Functional unit

The functional unit provides the reference to which all other data in the assessment are normalized. With LCA's application to agricultural processes, different functional units (FUs) can be selected. In many LCA studies of agricultural production systems, the FU is the area (e.g., 1 ha) [36,38,39], in others, it is the energy produced [40–43]. Nevertheless, the mass-based functional unit is prevalent in LCA studies of agricultural systems [44–46]. Therefore, in this study, 1 t (tons) of dry-matter chipped biomass was considered as FU. However, considering that, although slightly, the lower heating value (LHV) of poplar and willow wood is different, the energy content of the biomass was taken into consideration (using the LHV of the two biomass) as additional FU for comparison among the most productive clones.

2.3. System description

The SRC trial was grown in Piedmont (Po Valley – Northern Italy) at the experimental farm "Mezzi" of Research Unity for Intensive Wood Production (CREA-PLF) at Casale Monferrato in the district of Alessandria. The climate of the Po Valley is a climate of