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Harvesting systems for poplar short rotation coppice

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ABSTRACT

The harvesting of wood species intended for energy production is one of the critical steps for the establishment of an economically viable supply chain. The review examines the state of the art of the main systems for collecting the short rotation coppice (SRC) by referring to poplar (*Populus* spp.), one of the main energy species for southern Europe. Starting from the early experiences of willow (*Salix* spp.) in Sweden, over time two approaches have established: the cut-and-chip and the harvest-and-storage system. In the work, the *pros* and *cons* of the two systems are analyzed and their efficiency compared, giving also some indication about the next evolution of the machines. Emerging systems showing an interesting future potential as bales production or the development of small-scale tractor-powered harvesters are also described. Finally, some economic considerations on differences between harvesting cost for the cut-and-chip and harvest-and-storage system are reported.

1. Introduction

The main objectives of EU policies on energy savings and reduction of greenhouse gas emissions are based on renewable forms of energy from agriculture. The use of dedicated crops for energy purposes has been recognized to provide some environmental, economic and social benefits like low input requirement, reduced environmental impact, positive role on soil health, re-utilization of marginal lands, improvement of GHG balance, opening of additional opportunities for farmers revenues (Alexopoulou et al., 2011; Valentine et al., 2012; Zegada-Lizarazu et al., 2010). The forecast of the increasing production of energy crops in the next 20 years (Cosentino et al., 2012; Krasuska et al., 2010) call for an effort for their integration into traditional production systems (Zegada-Lizarazu et al., 2010). The task is challenging since involves the optimization of their production while ensuring the economic, environmental and social sustainability of the bio-energy chain (Gold and Seuring, 2011).

The harvesting is the connecting point among the crop management and the supply system leading to the industrial transformation. Its key role is to assure the removal of the raw material safeguarding, simultaneously, the sustainable production of a feedstock complying the technical specification required for an efficient handling during the following stage of storage, transportation and energy conversion.

The manuscript analyzes the specific issue of mechanized harvesting of short rotation coppices (SRC). To our knowledge reviews on this topic are lacking. Using keywords like "SRF harvesting", "SRC harvesting" or "Poplar harvesting" on a citation database (www.scopus.com) the system returns almost three hundred results. Of these, about a dozen are reviews, but none matches exactly the specific topic of our manuscript. The present effort, gathering the information available on the status of art of harvesting systems and describing them in an ordered form, attempts to fill this gap.

2. Short rotation coppice

As summarized by Spinelli (2011), three main sources of agricultural and forestry wood biomass can be recognized: forest products, agricultural wood residues and dedicated plantations. The latter are utilized for the production of lignocellulosic biomass that, by means of different processes, produces bioenergy starting from cellulose and other cell wall polysaccharides. SRC refers to the managing of wood plantations as perennial energy crops and is the main wood production recently regarded as a promising renewable source for energy biomass. Starting from Sweden in the earlier 1900's where large areas were planted with willow (*Salix* spp. L.), the SRC cultivation has spread in South Europe. Here the poplar (*Populus* spp.) was frequently used because of its better adaptability to the climatic conditions. Other species with an interesting potential for energy use are black locust (*Robinia pseudoacacia* L.) and eucalyptus (*Eucalyptus* spp.). Physiological and morphological traits of each species may influence to some extent the harvesting performance. For instance, the wood consistency is lesser in poplar than in wil-

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low, but the latter has a better resprouting capacity compared to poplar as well as the black locust (Spinelli et al., 2009, 2011a).

The most widespread cropping system is based on high density plantations harvested every 1–5 years and include (Verani et al., 2008):

- Very short rotation system: the plant density exceeds 10,000 plants ha^{-1}. The harvesting is carried out every years on plants having a stem diameter at the point of cut of 2–3 cm.
- Short rotation system: 6–7,000 plants ha^{-1} harvested at 2–3-year intervals. The plants may have an average diameter of 5–8 cm.
- Medium rotation system: the harvesting is delayed until the 5th years on plantation with 1100–1500 plants ha^{-1}. At this stage, the tree may reach a diameter of 15–20 cm at cut level.

The attractiveness for the farmer resides in the highest surface yield and the short return time with acceptable economic results. Moreover, the SRC can be grown on surplus agricultural land, but also on abandoned and/or contaminated soils (Djomo et al., 2011; Spinelli et al., 2011a).

Considering its diffusion and importance as dedicated tree crop for the energy aims, poplar can be assumed as a "model specie". In this paper, the state-of-the-art of the mechanized harvesting of SRF poplar species will be synthesized and discussed.

Before discussing the data, for the sake of clarity a premise is highly desirable. Reader should be aware that the units of measure of machine performance can vary among authors, making the comparison a tricky task. In general, the machine performance can be evaluated following two different conceptual approaches. Machine rates can be expressed as productive (pmh) or scheduled (smh) machine hour. This one is the time during which equipment is scheduled to do productive work and the productive time is that part of scheduled time during which a machine actually operates. Generally, both the times are related to the worked area (ha smh^{-1} or ha pmh^{-1}). The ratio between productive and scheduled time is the utilization rate of the machine (Brinker et al., 1989; Miyata, 1980; Spinelli and Visser, 2009).

The measuring of working time can follow the methodology adopted by CIOSTA (Comiteí International d'Organisation Scientificue du Travail en Agricolture) or the Italian Society of Agricultural Engineering (AIIA) (Bodria et al., 2006; Bolli and Scotton,1987; Fiala and Bacenetti, 2012). In this case, one of the main parameter is the field capacity of the machine expressed in ha h^{-1}. In particular, the effective field capacity (EFC) represents the actual working time of the machine. Work productivity (t h^{-1}) is derived from the product of EFC (ha h^{-1}) and the plantation yield (t ha^{-1}) (Fiala and Bacenetti, 2012).

Since the aim of present work is not the comparison of the systems of time measurement, the values of working time will be reported as in the original papers where the reference to each approach may be ascertained.

3. Harvesting systems

The high plant density and the relatively rapid growth allow to associate the poplar for SRC to an industrial crop rather than a conventional forest production. Consequently the integral mechanization assumes a central role for the development cropping system. The harvesting is one of the items with the greatest impact on economic balance, energy consumption and derived emissions of the dedicated woody energy crops (Manzone et al., 2009, 2014; González-García et al., 2012) and its extent is largely affected by the cropping system adopted. The harvesting of an SRC includes felling, chipping and transport of the feedstock to the storage point. Such steps can be carried out at the same time or felling may be physically and temporally separated by chipping. Indeed, since the 90's, two different approaches (Fig. 1) were suggested: the single-pass cut-and-chip system and the two-pass harvest-and-storage system (Berhongaray et al., 2013; Culshaw and Stokes, 1995; Mitchell, 1995; Schweier and Becker, 2012a). For the latter, the physical place for storage may be a dedicated site (Berhongaray et al., 2013) or within the windrow (Pari et al., 2013a,b,c).

The choice of the harvest system includes several variables (soil condition, length of harvest window, availability of auxiliary implements, type of storage facilities) that affect the final quality of the feedstock but also the cost-effectiveness of the supply chain. Both the harvesting systems present some *pros* and *cons* (Table 1).

Table 1
Pro and *cons* of the harvesting systems for SRC.

Harvesting system	Advantages	Disadvantages
Single-pass cut-and-chip	High harvesting yield	Wood chips with high moisture content at harvesting (55–60%)
	Possibility to operate also in traditional crops	Reduced harvesting window
		Soil compaction
Two-pass harvest-and-storage	Costless natural dehydration	Need of secondary handling for chipping
	Low moisture content (below 30%) of the wood fuel	Need of a transport if the chipping is performed at the end-use plant
	Better soil conditions	

3.1. Single-pass cut-and-chip system

The harvesting of SRC in a single-pass is preferentially performed with large-size modified foragers equipped with specific headers for woody biomass (Spinelli et al., 2009). The use of self-propelled forage harvesters (SPFH) in a single-pass is a high throughput system and the same type of mechanization can operate also in industrial crops, allowing the full integration of the SRC in traditional cropping systems. However, the harvesting period is limited to the winter months when the moisture content of wood chips is very high (50–60% on wet weight basis). Even if conditions are carefully controlled, the storage presents some risks of significant dry matter losses (Barontini et al., 2014; Manzone et al., 2013; Pari et al., 2013a).

During time, the weight of the machines used for the harvesting as well as their performance increased. The mass of a forage harvester ranges from 11 to 14 t and the addition of a header units leads the value at 15 t in total (Pecenka, 2014). The machines currently adopted may be self-propelled or tractors-mounted with the assistance of a tractor-trailer unit receiving the chips from the forager and moving them to a collection point (Schweier and Becker, 2012a). Owing to the specialized nature of the machines and the costs of purchasing and owning, the harvest is often subcontracted, a solution well suited for the forage harvester in case they are employed also for the harvesting of other crops. Pecenka (2014) esteemed that for a profitable economic return an area of at least 300 ha is required, maybe less if the harvester is used also for fodder.

The main component characterizing the SRC harvester is the cutting head. The most important versions developed till now are Claas HS1, HS2 and GB-1, Kemper and Krone headers and GBE1 and GBE2 (Fig. 2) produced by the Italian GBE company (Fiala and Bacenetti, 2012; Schweier and Becker, 2012a, 2012b). Various factors (soil conditions, state of the plants, wood characteristics, plant density) affect the performance and accordingly several authors reported variable results. If the harvesting conditions are appropriate, modified foragers may allow an yield ranging (on fresh basis) from 25 to 50 t_{fm} ha^{-1} (Fiala and Bacenetti, 2012; Schweier and Becker,