Giant reed (*Arundo donax* L.) harvesting system, an economic and technical evaluation

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Abstract

The giant reed is a herbaceous energy crop that demonstrates a good adaptability for areas of central-northern Italy. However, its size and stem resistance to cutting pose problems for harvesting in relation both to the availability of suitable machinery and costs of the operation. A technical and economic evaluation has been conducted of a harvesting system based on an experimental machine, the biotriturator, developed by University of Bologna in collaboration with the Nobili Company (Bologna, Italy) and adapted to field operating conditions.

The harvesting system consists of cutting-shredding and baling in a single pass. The system was evaluated by performing a winter harvest when the crop was in quiescence and had a low moisture content.

The total harvesting costs were evaluated as 11.6 € Mg^{-1} dry biomass. Given that the estimated area that can be covered by the harvesting system was 123 hectares per year the system represents an effective solution for not very large areas and is therefore suitable for the Italian environment where average farm sizes are slightly over seven hectares (ISTAT, 2011).

Introduction

Dedicated energy crops can play a key role in providing substantial amounts of lignocellulosic feedstocks required for the second-generation biofuel production chain as well as heat and electricity production (JRC EC, 2011). The main barrier to the diffusion of crops for bioenergy is cost competitiveness with fossil fuels. To create a reliable supply chain it is necessary to achieve efficient and sustainable cultivation.

The perennial grass giant reed (Arundo donax L.) is considered as particularly promising for Mediterranean regions, because of high yields in lignocellulosic biomass, a good adaptability to these environments and its very low soil tillage, pesticide and fertilizer requirements (Lewandowski et al., 2003; Angelini et al., 2005, 2009)

The harvesting can be a critical phase of giant reed cultivation mainly due to the lack of harvesting machines (Venturi and Bentini, 2005). As well as being very tall and having a high cutting resistance, Arundo is a rhizomatous grass that is not laid out in regular rows and is also sometimes partially lodged (Yitao et al., 2007). It is therefore necessary to design a specific machine or adapt machines developed for other crops.

The harvesting process requires mow-conditioning, raking and baling or loading of loose chopped biomass for delivery to the energy plant. Depending on the moisture content of the biomass a partial drying in the field may be necessary prior to baling or delivery (Trebbi, 1993). The giant reed can also be harvested in winter, with partial drying of the plants in the field improving the characteristics of the biomass in terms of specific energy and reducing the storage and handling costs.

In this paper, a prototype for the cutting and chopping of giant reed has been evaluated. A technical economic analysis has been conducted of a cutting-shredding-baling system that can harvest the crop in a single operation.

Material and methods

Harvesting trials were done on a 7-year-old giant reed crop with a 1 x 1 m planting layout obtained from rhizomes of an ecotype selected at the University of Catania. The crop was harvested at the end of February when plants were in winter quiescence and had a low moisture content. A prototype biotriturator RM 280 BIO was used, which combines cutting, shredding and crop windrowing. The equipment was developed by the Agricultural and Food Sciences Department of the University of Bologna, in collaboration with Nobili S.r.l. (Bologna, Italy). The machine was composed of a cutting shredding chamber surmounted by a dividing conveyor, constituted by a frame to channel the plants into the shredding chamber. The shredding system consisted of a horizontal rotor with 64 half Y-shaped flail blades, the eight rows of flails were staggered. A double auger conveyor situated in the rear of the shredding chamber allowed the biomass to be raked. The biotriturator was front-mounted with a three point hitch on a 4-wheel-drive tractor CNH T6090 (147 kW) (CNH Corporation), with a Kuhn VB2160 round baler (Kuhn S.r.l., Italy) rear-mounted on the same tractor. The baler was a variable chamber that wrapped the bales in nets (Figure 1, 2).

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Table 1. Implement and tractor cost data

		Tractor	Biotriturator	Baler
Purchase price	€	84000	7500	24000
Estimated life	h	8000	1000	1000
Annual use	h	800	200	200
Remaining value	C1	0.976	0.756	0.852
coefficient	C2	0.119	0.067	0.101
	C3	0.0019		
Insurance and housing	%	1	1	1
RF1		0.019	0.44	0.43
RF2		1.3	2.0	1.8

Table 2. Crop characteristics

Plant age	years	7
Average density	shoots m^{-2}	15
Stem length m	3.7	
Moisture at harvest (wet)	%	41
Average yield (dry)	Mg ha^{-1}	20.1

Table 3. Operative characteristics of harvesting systems

Field speed	km h^{-1}	4.0
Machine working width	m	2.80
Field efficiency		0.55
Effective field capacity*	Mg h^{-1}	12.5
Area covered per year	ha	123

*Referred to dry biomass

Bales were measured and then weighed directly in the field suspended by belts on an electronic dynamometer (Figure 3). The bulk density and moisture content on a wet basis were determined.

The effective field capacity of the machine was evaluated considering the working times measured during the field trials on the basis of Standard ASAE EP496.3.

The total machinery costs are calculated including charges for ownership and operation and are based on buying a new machine and using a tractor for 10 years and implements for 5 years.

The ownership includes depreciation, interest on the investment, insurance and housing of the machine (Standard ASAE S495.1). The purchase price is based on the manufacturer's list price minus a percentage discount indicated by the dealers interviewed (20% for a tractor and 15% for implements). Other variables used in calculating costs are shown in Table 1.

Annual use was assumed as 200 h for implements and 800 h for tractors. The remaining value was calculated on the basis of Standard ASAE D497.7. The other ownership costs, insurance and housing were calculated as a percentage of the purchase price. For the interest charged on borrowing the money a rate of 5% on the average investment was applied.

Labour costs are based on 14.50 euros per hour labour charge, including taxes and social security contributions. Fuel costs are based on diesel fuel priced at 0.93 euros per litre. The total repair and maintenance charges take into account the amount of use and were calculated on the basis of Standard ASAE EP496.3. For the tractor, the repair and maintenance indices relative to the specific Italian situation were used (Calcante et al., 2011).

Figure 1. Baler during ejection phase

Figure 2. Harvesting system

Figure 3. Bale weighing

Results

Table 2 reports average values of the crop characteristics measured at harvesting. The average stem height was 3.7 m with values in the range 2.4-4.4 m, at a density of 15 shoots m-2. The yield represents the amount of biomass collected from the field, not the total amount of above-ground biomass.

For the evaluation of costs and machine performance reference was made to the data obtained in the field trial, which were comparable with average values obtained in other studies done in areas of central-northern Italy (Angelini et al., 2005, 2009).

The field speed was 4.0 km h^{-1}, with a field efficiency of 0.55 limited by the wrapping and ejecting times of the round baler. The effective field capacity was 0.62 ha h^{-1} that, on the basis of the hypothesized annual use, allows an area of 123 hectares per year to be covered (Table 3).

The average volume of the bales was 2.4 m3 (1.6 m diameter by 1.2 m wide) with a mass of 407 kg, moisture content on a wet basis of 41% and density 170 kg m-3.

The cost of the harvesting system amounted to 233.3 € ha^{-1}, due to 78.9 € ha^{-1} for the tractor (including fuel and oil costs), 130.9 € ha^{-1} equipment overheads and 23.5 € ha^{-1} labour cost for the tractor driver. The total harvesting cost per unit of dry biomass was 11.6 € Mg^{-1}.

The cost of net for the round baler was 0.81 euros for bale and was included in the total, while costs to transport the biomass from field to plant and for storage were not included.

The majority of implement costs were for interest and depreciation, corresponding to around 62% of the total cost for the baler and biotriturator and 74% for the tractor excluding the labour cost.

Discussion

The average speed of the harvesting system is 4.0 km h^{-1} and is always lower than 4.5 km h^{-1}, due both to the high cutting resistance of the culms of giant reed and the irregular crop distribution in the field, which over the years tends to invade the inter-rows.

The working capacity of the system is also limited by the baling phase, which has low field efficiency because of the need to stop the machine during the wrapping and ejecting.

Comparison of the biomass harvesting costs with other studies is difficult because of differences in assumption and methods. In addition, while analyses have been done on the harvesting costs of biomass crops such as sorghum and switchgrass (Cundiff and Marsh, 1996; Thorsell et al., 2004; Sokhansanj et al., 2009; Lychnaras and Schneider, 2011), to our knowledge no studies are available on the costs of the mechanised harvesting of Arundo.

Conclusions

The prototype is able to perform properly the harvesting of giant reed even if the crop is not laid out in regular rows but the high shear strength of the culms limits the machine speed. The machine can also used on other energy crops such as sorghum and switchgrass.

This system anyway showed reasonable harvesting costs for not very large areas (around 200 ha) and is therefore suitable for situations like that in Italy, where average farm sizes are slightly over 7 hectares.

In the future, with the expected diffusion of dedicated energy crops with winter harvest, the development of a combine is advisable that both shreds and bales without the feedstock coming into contact with the ground to reduce contamination by inorganic material, and consequently lower the ash content.

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