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Prototype for the harvesting of cultivated herbaceous energy crops, an economic and technical evaluation

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ABSTRACT

The scope of this study was to evaluate a multi-purpose prototype, the biotriturator, for the harvesting of biomass species cultivated in Northern Italy that would allow the baling of biomass to reduce the handling and storage costs. Harvesting trials were conducted on two herbaceous perennials: giant reed (*Arundo donax* L.) and switchgrass (*Panicum virgatum* L.), plus a herbaceous annual fiber sorghum (*Sorghum bicolor* L. Moench).

A technical and economic evaluation compared three harvesting systems in which the biomass was shredded with the biotriturator. The first system was a cutting-shredding-baling in the same operation. The second required two successive steps, the first was cutting and shredding with the biotriturator, the second was baling. The third harvesting system required three successive steps: cutting and shredding with the biotriturator, windrowing with star wheel rakes and baling. While the first and second systems were evaluated on the two perennial crops the third was evaluated on an annual crop.

Considering the hectares that can be covered by the biotriturator (170 ha of sorghum and 270 of switchgrass, with an average annual use of 200 h) and the total harvest cost (9.9–12.1 € Mg^{-1} dry biomass), the harvesting system represents an effective solution for situations like that in Italy, where average farm sizes are small.

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1. Introduction

Today some two-thirds of renewable energy in Europe is derived from biomass and this is expected to increasingly provide feedstocks for the different energy conversion routes, i.e., heat, electricity and (advanced second-generation) biofuels [1]. According to the NREAPs (National Renewable Energy Action Plans) submitted by the member states of the European Union, the use of biomass for electricity, heating and cooling and biofuels in transport is estimated at about 5860 TJ as final energy in 2020. In particular, the proposed target will mean an increase of 70% in the use of biomass for heating and cooling in 2020 [2].

Dedicated energy crops such as Short Rotation Forestry and energy grasses could provide substantial amounts of lignocellulosic feedstock for both the second-generation biofuel production chain as well as heat and electricity production. The main barrier to the diffusion of dedicated crops for bioenergy is cost competitiveness with fossil fuels, but a good operational level has been reached that has reduced the cost of biomass feedstock.

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To create a reliable supply chain it is necessary to achieve efficient and sustainable cultivation. In particular the phase of harvesting and pre-treatment of the biomass can improve its characteristics, increase energy density, and reduce storage, transport and handling costs [1].

In the southern areas of Europe some herbaceous energy crops have been indicated as promising for energy production. The perennial grasses giant reed (*Arundo donax* L.) and switchgrass (*Panicum virgatum* L.) are particularly interesting for the Italian situation due to their high yields in lignocellulosic biomass, good combustion quality and because they also display a good adaptability to these environments [3–6].

Giant reed is a native species to the area surrounding the Mediterranean Sea and is considered as an environmentally sustainable crop due to its very low soil tillage, pesticide and fertilizer requirements [5]. Furthermore, in April 2011, the Mossi & Ghisolfi Group (Chemtex) commenced construction of a commercial-scale 50 million liters per year cellulosic ethanol production facility in Vercelli, Italy that will use giant reed, so a strong demand is anticipated for this crop as feedstock.

Switchgrass is a perennial warm-season grass tolerating soil water deficits and low soil nutrient concentration, and shows promise as a perennial energy crop for bio-energy feedstock, but the techniques of harvesting, handling and storage must be improved with the aim of obtaining a suitable material for thermo-chemical conversion [7].

Some annual herbaceous species have been receiving increasing attention recently, such as fiber sorghum (*Sorghum bicolor* L. Moench), which has a growing cycle similar to that of traditional food crops and demonstrates a high potential energy related both to anaerobic digestion and second generation bioethanol production [8]. The characteristics of sorghum for electricity production have also been evaluated in different Italian areas, showing interesting potential [9].

The efficiency of the cultivation of dedicated energy crops depends, as well as on a correct energy and environmental evaluation, on farm cost-effectiveness. In relation to this latter aspect harvesting can represent a critical phase in relation both to the costs and technique used. Indeed, while many studies have been conducted on production techniques, research on the type of equipment for harvesting energy grasses is limited.

In general the harvest process for herbaceous energy crops requires mow-conditioning, raking and baling or loading of loose chopped biomass for delivery to the plant. Depending on the type of biomass and its moisture content a partial drying in the field may be necessary prior to baling or delivering [9].

Conventional forage equipment can be used to harvest and bale switchgrass when the yield is comparable to that for single-cut hay [10]. Although alternative systems are available, such as the combined mower-fodder-loader for giant reed [11] and an experimental machine for fiber sorghum [12], they cannot operate on lodged plants so it is necessary to develop specific machinery or adapt equipment designed for other crops [13].

The harvesting strategies can differ in relation to the type of conditioning planned for the biomass (loose, conditioned, chopped) and the type of storage (bale stack, loafing, wet chop ensiled) [10].

A prototype [12] has recently been developed in Italy, the use of which is limited to herbaceous energy crops such as fiber sorghum. However, this machine is only capable of harvesting crops laid out in rows and not lodged.

The harvesting phase still requires research and experimentation to develop and perfect machines with high working capacity and sustainable costs. Our objective in this study is to estimate the harvesting and baling costs of giant reed, switchgrass and fiber sorghum. A prototype has been evaluated that was developed to be utilized on different types of biomass crops and capable of harvesting the crop even if not laid out in regular rows or partially lodged.

2. Materials and methods

2.1. Experimental fields

Two perennial crops were considered, giant reed (*A. donax* L.) and switchgrass (*P. virgatum* L.) and the annual fiber sorghum (*S. bicolor* L.).

The crops were cultivated in the Po Valley, Italy. The experimental fields for the perennial herbaceous crops had an area of 7000 m^2 (Lat. 44°61′, Long. 11°72′, 9 m a.s.l.). The switchgrass, variety Alamo, at the seventh year of planting, was sown in rows 0.45 m apart at a rate of 600 PLS (pure live seed) per square meter. The giant reed was in a 7-year-old plantation obtained with rhizomes of an ecotype selected at the University of Catania, with a 1 × 1 m planting layout. The crops were harvested at the end of February 2011 when the plants were in winter quiescence and had a low moisture content and soil moisture conditions allowed the passage of the machinery in the field.

The harvesting trials of sorghum were conducted in experimental fields with an area of 2 ha, (Lat. 44°82′, Long. 11°12′, 14 m a.s.l.). The sorghum, Hybrid biomass 133, was sown with a layout of 0.75 × 0.07 m. It was harvested at the end of August 2011 when the amount of crop biomass was highest.

The principal crop characteristics were measured at harvest: average and maximum height, plant density, moisture content.

The yield used in this paper represents the amount of biomass collected from the field, not the total amount of above-ground biomass.

2.2. Prototype description

A prototype biotriturator RM 280 BIO was used, which combines cutting, shredding and crop windrowing. The equipment was developed by the Agricultural Economics and Engineering Department of the University of Bologna, in collaboration with the company Nobili S.r.l. Italy that provided the manufacturing support for the machine (Fig. 1).

The equipment is a development of a previous prototype [14,15] upgraded in size and structural characteristics. The specific organs of the biotriturator are as follows (Table 1):

- Cutting shredding chamber, composed of a crankcase that contains the rotor. The front part of the chamber has a movable hood, powered by hydraulic cylinders, which can

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