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Mechanized harvesting of bamboo plantations for energy production: Preliminary tests with a cut-and-shred harvester

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ABSTRACT

Bamboo plantations can help expanding biomass production to marginal lands, while requiring limited chemical and labour inputs. However, the development of a modern industrial bamboo energy chain requires an adequate level of mechanization. The study presents the preliminary test of a new single-pass cut-and-shred harvester, designed for application to a powerful farm tractor. The machine is especially suited to negotiating disorganized crops, which offer challenging conditions for the more efficient forager-based harvesters. The results show that productivity may exceed 6 fresh t h^{-1}, which is close to the assumed theoretical limit for this machine type. Fuel use is over 3 l fresh t^{-1}, while harvesting cost varies around 33 € t^{-1}. Fuel use and harvesting cost are still relatively high, but they are likely to decrease as operators gain experience with the new system, and as the system itself is further improved. In any case, cost reduction is only one of the benefits accrued by mechanization, which also plays a major role in improving worker safety and overall supply chain efficiency.

Introduction

Bamboos are woody-stemmed perennial grasses that occur naturally in most tropical regions of the world. There are over 1200 species of bamboos, capable of occupying a large number of different habitats. Bamboos are frugal, adaptable and fast-growing, which makes them ideal for biomass production on marginal land (Liese, 1987). In fact, bamboos have remarkable technological qualities, and are already used for a range of different purposes, including construction, paper-making, food and medicinal preparation (Adhikari et al., 2015). Adaptability, effective reproduction strategy and human interest have resulted in a remarkable expansion of bamboo plantations, which currently cover more than 14 million ha, primarily located in Asia, Africa and South America (Maoy and Banik, 1996). The economic role of bamboos is especially important in South Asia, but it is increasing worldwide, to the point that the popular press is already talking about an alleged "bamboo boom" (Nijhuis, 2009). Whether or not the increased global interest for bamboo can be defined a boom, it is certain that the potential of bamboo is enormous. Already ten years ago, Brazilian scientists indicated bamboo as the second largest potential source of energy biomass in Brazil, right after sugar cane and way ahead of municipal solid waste, which was also a very large quarry of energy biomass (Filho and Badr, 2004). In fact, industrial bamboo plantations already cover 30,000 ha in Northeastern Brazil (Lobovikov et al., 2005), and they achieve high growth rates, due to the favourable soil and climate conditions, and to the availability of over 200 native species to select from (Shanmughavel and Francis, 1997; Viana et al., 2013). These plantations are exclusively grown for fibre production, but their surface and their role are likely to expand dramatically in the next decades (Li and Kobayashi, 2004). The increasing demand for renewable feedstock has raised interest in growing bamboo for the production of fuel chips (Guarnetti, 2014) pellets (Liu et al., 2016), liquid fuel (Dwivedi et al., 2009) and a variety of new bio-based products (Lee and Wang, 2006). At the same time, solutions must be found for reducing production cost, because industrial energy feedstock is a low-priced commodity, and competitive supply requires that all operations be conducted with the utmost efficiency (Spinelli et al., 2009). At present, bamboo harvesting is performed manually with bush knives (El Bassam, 2013; Obiri and Oteng-Amoako, 2007). That also accounts for Brazil, where mechanization is well established in most production systems (Bonilla et al., 2010). Bamboo harvesting techniques resemble the traditional manual methods used for harvesting sugar cane. However, sugar cane harvesting is becoming increasingly mechanized, through the introduction of single-pass cut-and-chop harvesters. Transfer of mechanized sugar cane technology to bamboo stands is made difficult by the very different characteristics of the two crops: bamboo stems are much larger than sugar cane stems and cannot be handled with conventional sugar cane technology, even if the harvesting technique could be the same

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cut-and-chop single-pass type. One possibility is offered by the modified foragers used for harvesting short-rotation coppice (SRC), but such machines perform best when the crop is laid down in regular rows, which is not the case with bamboo plantations (Spinelli et al., 2011). Furthermore, foragers are expensive specialised machines and farmers may prefer versatile equipment, based on the ubiquitous farm tractor. A few manufacturers do offer farm tractor attachments designed for the single-pass cut-and-shred harvesting of small trees and brushwood, and these machines may fit the bill. Among available models, those produced by Prinoth (Prinoth, 2016) have attracted considerable attention in Europe and North America, where they have been the object of several tests (Hannum, 2009; Lazdiņs, 2011). However, no one has yet considered using these machines for harvesting bamboo plantations, which seem to offer ideal conditions for the new equipment.

Therefore, the goal of this study was to determine the performance of a tractor-based single-pass cut-and-shred harvester applied to industrial bamboo plantations. In particular, the study aimed at determining productivity, fuel consumption and harvesting cost, in order to assess the technical possibility and the financial benefit of replacing manual harvesting with mechanized harvesting.

Materials and methods

The test was conducted with a 276 kW Valtra S353 four-wheel drive tractor, equipped with the new AHWI H600 Bioharvester attachment, designed and built in Europe. The latter consisted of a powerful hammer shredder, coupled with a blower and designed to cut shrubs and small trees, comminute them and discharge the comminuted particles into containers through a curved spout. The AHWI H 600 was a very versatile machine, capable of handling a wide range of work conditions. For this reason, it could be deployed on other potential energy biomass sources beside bamboo plantations, including short-rotation coppice, native shrubs and logging residues. During the test, the tractor was supported by a dump truck with a capacity of 15 m^3, which drove along the harvester and received the comminuted bamboo particles (Fig. 1).

The harvester was tested on a second rotation bamboo plantation regenerated from rootstocks after a fire. The plantation was located near Tatuì, in São Paulo State, at an altitude of 610 m asl. The plantation had been established with punting pole bamboo (*Bambusa tuldoides* Munro) on a typical Nitisoil (Table 1). Mean annual precipitation and temperature were 1260 mm and 20.2 °C, respectively. At the time of harvesting the bamboo stems were 3.5 years old.

Plantation characteristics were sampled by conducting a typical forest survey on three 25 m^2 plots, randomly located within the plantation. In each plot, researchers determined the diameter at breast height (DBH) and the height of all stems, which numbered at least 120 units. Furthermore, ten stems were selected within each plot and 5 discs were cut from each stem at the following positions along the stem: 0%, 25%, 50%, 75% and 100% of total plant height. The dry density of discs was determined in the laboratory as the ratio between dry mass and saturated volume, in order to estimate dry matter yield.

Fig 1. The tractor-powered swathe harvester and the dump truck at work.

Table 1
Characteristics of the test plantation.

		Mean	SD
Age	years	3.5	–
DBH	cm	2.3	0.9
Height	m	7.1	2.1
Stem density	stems ha^{-1}	48,266	4636
Dry density	kg m^{-3}	320.5	52.9
Moisture content	%	47.8	2.5

Note: DBH = diameter at breast height, SD = standard deviation.

Harvesting performance was determined through detailed time-and-motion studies conducted at the cycle level (Magagnotti et al., 2013). The filling of a full load of chips was assumed as a cycle, which began with the forward motion of the harvester discharging chips into an empty dump truck, and ended when the truck bin was full to capacity. For each cycle, researchers determined the following parameters: surface area, biomass output, time input and fuel input.

The surface area covered with each cycle was determined by multiplying swathe width by total travel length, the latter recorded automatically on the tractor on-board computer. Resulting figures were double-checked with those obtained from a Garmin CSX GPS device.

Biomass output was estimated by taking all loads to a certified weighbridge. Moisture content of comminuted bamboo biomass was determined with the gravimetric method, according to ASABE S358.2 Standard (2010), on five 500 g samples randomly collected from each truckload.

Fuel inputs were taken from the on-board computer, whereas time inputs were recorded manually, with a conventional stopwatch. Productive work time was separated from delay time, but all delays were included in the study, and not just the delays below a set duration threshold, because such practice may misrepresent the incidence of downtime (Spinelli and Visser, 2009). However, delays caused by the study itself were removed from the data set. The distance between the field and the landing (i.e. truck dump site) was 1.2 km, and therefore the truck had to travel 2.4 km every time it was full and had to dump its load.

Machine cost was estimated with the method developed by the European COST Action FP0902 (Ackerman et al., 2014). Cost input data were obtained from the Brazilian Prinoth dealer and from the forest company providing the tractor and its driver (Table 2).

Results and discussion

Unfortunately, the machine was available for a short time only, and it was tested on a relatively small field, measuring 0.24 ha. Therefore, valid data were recorded over a time of about 2.5 h. This figure excluded tune-up and a few test runs conducted with the purpose of getting the operator acquainted with the new job. For this reason, the results obtained from this study are preliminary, and must be considered as merely indicative. Nevertheless, this is the only test of mechanized bamboo harvesting available so far, and any indications are quite valuable.

Plantation yield

Bamboo stools re-sprouted vigorously after the fire: three and half years later, the average number of stems per stool was 29, which offered abundant evidence to the capacity of bamboo stools to regenerate after cut, and supported the idea of coppice management (Darabant et al., 2016). The density of live stools reached 1660 units ha^{-1}. Field yield averaged 48 fresh t ha^{-1}, or 25.1 dry t ha^{-1} (Table 3). That corresponded