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Power requirements and field performance in harvesting energycane and sugarcane

S.K. Mathanker [a], H. Gan [a], J.C. Buss [b], B. Lawson [c], A.C. Hansen [a,d,*], K.C. Ting [a]

[a] Department of Agricultural and Biological Engineering, University of Illinois at Urbana-Champaign, Urbana, IL, USA
[b] John Deere, Thibodaux, LA, USA
[c] United States Sugar Corporation, Clewiston, FL, USA
[d] University of KwaZulu-Natal, South Africa

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ABSTRACT

Energycane is emerging as a candidate bioenergy crop, and it resembles sugarcane in stature and cultivation practices. Preliminary trials indicated that sugarcane billet harvesters have insufficient power to harvest energycane. This study quantified the power requirements of selected harvester components and field performance of harvesters for sugarcane and energycane. The elevator pour rate for energycane was lower (43.3 Mg h^{-1}, wet weight) than for sugarcane (132.7 Mg h^{-1}, wet weight). At the observed pour rates, power consumption of the basecutter, elevator, and the entire harvester was comparable for energycane and sugarcane. However, the power requirements of the chopper were 1.65 times higher for energycane than for sugarcane. Greater stem damage and higher stubble heights were observed for energycane compared to sugarcane. Overflowing of the elevator was observed for energycane because of lower bulk density of the biomass (billets and trash, 143.8 kg m^{-3}) compared to sugarcane (predominantly billets, 349.4 kg m^{-3}). The field capacity of the harvester for energycane (0.32 ha h^{-1}) was lower than for sugarcane (0.61 ha h^{-1}), and the harvesting cost for energycane (5.91 \$ Mg^{-1}) was considerably higher than for sugarcane (1.87 \$ Mg^{-1}). Design modifications to the existing sugarcane harvester models would be needed to adapt them to harvest energycane.

1. Introduction

Many potential bioenergy crops are being investigated to produce cellulosic ethanol, and possibly other chemicals or burn as fuel, so energycane is emerging as a candidate bioenergy crop [1,2]. However, high harvesting cost is one of the challenges in producing cellulosic ethanol at competitive prices. Energycane harvesting costs for a mowing and baling system were 38.4% of total production costs [3] compared to 32.5% for sugarcane [4]. A literature survey indicated that limited studies of energycane harvesting are available, however, many studies investigated different aspects of unburnt

* Corresponding author. 360S, Agricultural Engineering Sciences Building, 1304 W, Pennsylvania Avenue, Urbana, IL, 61801, USA. Tel.: +1 217 333 2969; fax: +1 217 244 0323.
E-mail address: achansen@illinois.edu (A.C. Hansen).
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(green) sugarcane harvesting which closely resembles energycane harvesting except for the collection of trash.

Design modifications to harvester components were the emphasis of many studies on unburnt sugarcane harvesting. The harvesting rate of a modified harvester in unburnt sugarcane was twice that of the original harvester design [5]. The single-spiral design of the crop dividers improved the harvester's performance compared to the twin-spiral design [6]. The harvester speeds were 2 and 3 km h^{-1}, while the elevator pour rates were 109 and 156 t h^{-1} for the single-spiral design and the twin-spiral design, respectively [6]. A chopper designed for whole crop harvesting was developed to reduce losses and improve quality of the harvested material [7]. A trash shredding and collection system, attached to the primary extractor fan assembly and which discharged shredded trash into the elevator, was developed to improve whole crop harvesting [8]. The effects of reducing billet length, vibration, compaction and crop topping were evaluated to improve the efficiency of whole crop harvesting and transport [8].

The influence of operational parameters on harvester components was another feature emphasized in many studies on harvesting unburnt sugarcane. An automatic height control system of the harvester basecutter resulted in reduced stool damage, lower stubble height, and fewer crop losses [9]. Bulk densities about 35% lower than burnt sugarcane were recorded when harvesting unburnt sugarcane [10]. Analysis of video captured, while harvesting unburnt sugarcane, revealed that harvester performance could be enhanced by optimizing machine-crop interactions [11]. Chopper performance was affected by the pour rate and sugarcane cultivars [12]. The ground speed of the harvester did not influence the amount of sugarcane harvested or its quality when it was harvested green [13]. A fiber optic yield monitor performed well in both unburnt and burnt sugarcane [14].

Comparison of harvesting rates or throughput rates for unburnt and burnt sugarcane was the objective of many studies. The harvesting rate for unburned sugarcane was 45% of that for burnt sugarcane [15]. Like a previous study [15], the throughput rates in unburnt sugarcane reported in Ref. [16] decreased by 43% compared to burnt sugarcane harvesting. Over 10% reduction in harvesting rates were reported when trash and billets were collected compared to when only billets were collected [17].

It appears that harvesting energycane is a similar process to unburnt and whole crop sugarcane harvesting, and therefore could face similar challenges: less efficient operation of critical harvester components, reduced field speed, and reduced harvesting rates. Preliminary energycane harvesting trials in Lorida, Florida confirmed that the inferences drawn from the literature survey, and this study was conducted to quantify the limitations affecting energycane harvesting and to identify critical components of a typical sugarcane billet harvester that would require design modifications. Sugarcane harvesting was used as a baseline for contrasting with energycane harvesting. The specific objectives of this study were to: a) measure power and energy requirements at the basecutters, chopper mechanism, elevator, and for the entire harvester for sugarcane as well as energycane, and b) record field performance of harvesters as influenced by sugarcane and energycane yield.

2. Materials and methods

A twin-row sugarcane billet harvester (Model 3522, John Deere, Thibodaux, LA; Fig. 1a) was employed to harvest energycane crop (variety: Ho 02-113 (second ratoon); row spacing: 1.5 m; row length: 250 m; location: Lorida (27.34330 N, 81.22120 W), Florida) following green (unburnt) harvesting practices. The topper and extractor fan were turned off, and both billets and trash were collected in a calibrated weigh wagon. The volumetric capacity of the calibrated weigh wagon was 27.70 m^3. The crop weight was recorded at the end of each row. The row length and row spacing were used to calculate the field area from which the weigh wagon was filled. The crop weight divided by the field area gave the energycane yield per unit area for that row. The bulk density of harvested biomass was calculated by dividing the wagon weight by its volume after the wagon was completely filled. In this study, a row was treated as a data point for energycane data analysis.

Similarly, a single row sugarcane billet harvester (Model 3520, John Deere, Thibodaux, LA; Fig. 1b) was employed to harvest sugarcane (variety: CP841198K (plant-cane); CP961252 (first ratoon); row spacing: 1.5 m; location: Clewiston (26.8113 N, 80.6075 W), Florida). The sugarcane crop was burnt before harvesting following recommended practices. The extractor fan was operated to remove trash, and cleaned billets were collected in a calibrated weigh wagon. The volumetric capacity of the calibrated weigh wagon was 17.39 m^3. A Global Positioning System (GPS) unit (1-EGPS-200-P-2, Hottinger Baldwin Measurements Inc., Marlboro, MA), and a digital on-off switch were used to mark the start and finish point of a wagon load similar to Carbonell et al. [18]. The weight of a filled wagon was divided by the corresponding field area to calculate the sugarcane yield per unit area. In this study, each load in the weigh wagon was treated as a data point for data analysis.

Stem characteristics were recorded at six randomly selected locations for both energycane and sugarcane. At each location, a one meter long section of row was selected to record stem characteristics. Stem diameter at cutting height (50 mm above ground), stem height and stalk density were measured before harvesting the rows. After harvesting, stubble heights and stool (stem) damage were recorded. Stem damage was categorized into three levels: undamaged, partially damaged, and severely damaged (Fig. 2).

The first part of the study consisted of measuring power and energy requirements of selected harvester components when harvesting either energycane or sugarcane. The operating parameters of hydraulic motors fitted to each of the two harvesters were similar (Table 1). The base-cutter disk diameter was 0.84 m for the 3522 John Deere harvester, to accommodate twin-row planting geometry, and was 0.61 m for the 3520 John Deere harvester designed for single row planting geometry. The chopper drum of the 3522 John Deere harvester had three blades, and the chopper drum of the 3522 John Deere harvester had four blades. However, the feed train or feed roller sizes of the chopper units were similar for each of the harvesters. The elevator of the 3522 John Deere harvester was 10% faster than the elevator of the 3520 John Deere