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Research paper

Impact of miscanthus yield on harvesting cost and fuel consumption

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ABSTRACT

Miscanthus is emerging as a potential bioenergy crop because of its high yield and ability to reduce greenhouse gas emissions. However, there is a lack of data on harvesting machinery performance for the USA conditions, and influence of yield on harvesting cost and fuel consumption. This study quantified performance of a mower-conditioner and a large square baler for Illinois conditions, and investigated influence of yield on fuel consumption and harvesting costs. To calculate performance parameters, a field area was segmented from which a bale was formed. Then in the segmented field area, yield and machine performance parameters were determined. The mower-conditioner's field capacity was 1.8 ha h^{-1}, and diesel consumption was 19.2 L ha^{-1}. The baler's field capacity was 1.4 ha h^{-1}, and diesel consumption was 19.7 L ha^{-1}. The mowing cost was 4.8 \$ Mg^{-1}, and baling cost was 6.8 \$ Mg^{-1}. An inverse correlation ($R^2 = 0.62$) was found between miscanthus yield and harvesting cost (\$ Mg^{-1}), and a direct correlation ($R^2 = 0.67$) was found between miscanthus yield and fuel consumption (L ha^{-1}). It is expected that this study would help in more accurate assessment of environmental impact and economic feasibility of miscanthus, and may lead to further studies for quantifying crop yield and machine performance interactions.

1. Introduction

Depleting fossil fuel reserves combined with greenhouse gas emissions from these fuels has resulted in a growing interest in alternative energy sources such as biomass. Many biomass crops are being investigated, and *Miscanthus x giganteus* is emerging as an attractive crop because of its high yield [1]. Being a perineal crop, it requires fewer agronomic inputs than annual row crops. Once planted, it lasts for 10–15 years and requires annual harvests. Reduction in soil erosion and increased biodiversity are other environmental benefits [1]. Miscanthus holds promise as an optimal bioenergy crop in the temperate zone with its high yield, cold tolerance, low environmental impact, resistance to pests and diseases, ease of harvesting and handling, and non-invasiveness [2]. The substitution of fossil fuels by biomass from perennial grasses is a robust strategy to reduce fossil energy use and curb greenhouse emissions [3]. However, it can lead to overexploitation of fresh water reservoirs if not planned properly [3]. In Europe, miscanthus is being used for co-combustion with coal and for heat and power applications [4].

To reduce feedstock costs, research studies are underway to analyze and improve various aspects of miscanthus. The optimal practices for establishment of Miscanthus in the Midwestern USA have been to plant 60–75 g rhizomes to a depth of 10 cm, and to use rhizomes that have been stored for the minimum time possible [5]. Sensitivity analysis of miscanthus crop production costs showed that the pre-harvest and harvesting machinery costs was the second most critical factor [6]. Baling and storage were significant components of the total delivered cost of biomass [7]. Compared to harvesting in December, the energy yields decreased by 14–15% when harvested between December and February and by a further 13% when harvested between February and March [8]. However, a desirable result of delayed harvest was the significant reduction in water content and in the concentrations of ash, nitrogen, chloride and sulphur of the harvested biomass [8].

Miscanthus can be harvested by employing traditional hay and silage machinery. In a single pass harvesting system, a self-propelled forage harvester cuts, chops and blows the crop into a trailer. In a two pass harvesting system, a mower-conditioner cuts the crop, conditions it and gathers it in a swath on the ground; a baler picks up the swath and densifies it in a rectangular or round

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bale. Harvesting methods: mowing-chipping, mowing-baling, and mowing-bundling affect harvesting cost [9]. Harvesting costs represented significant portion of the feedstock costs for all the eight combinations of harvesting methods studied [9], and minor differences in harvesting energy were observed between the mowing-chipping and mowing-baling systems [4]. There was major difference between baled and chopped miscanthus harvesting costs [10]. The mowing-chopping cost and mowing-baling cost have been shown to be comparable for the farmer owned machines, whereas the mowing-chipping cost was the least expensive for the contractor owned machines [11].

To reduce harvesting cost, modifications to existing hay and forage machinery were recommended such as improvements in cutterbar, baler pickup unit, and conditioning rollers [12]. Laboratory studies indicated that optimizing cutting speed, blade oblique angle, and design of cutting edge reduced cutting energy consumption [13,14]. Field studies confirmed that optimizing blade oblique angle and cutting speed reduced energy consumption [15,16]. A close correlation was found between miscanthus yield and mowing-conditioning cost [17].

In general, previous studies investigated harvesting machinery performance to compare the machine components and machinery systems. A literature survey also indicates that there are limited studies examining the influence of yield on harvesting machinery performance, and there is a lack of data on machinery performance for USA conditions. However, miscanthus yield and harvesting cost vary widely [4,6,18,19], and this study was conducted to investigate this interaction for a mowing-baling system and to quantify its performance for Illinois conditions. The first specific objective was to quantify the performance of a disk mower-conditioner and a large square baler, and the second specific objective was to investigate the influence of miscanthus yield on fuel consumption and harvesting cost.

2. Material and methods

The miscanthus crop planted in 2008 at the Bioenergy Farm (40.0685 N, 88.2000 W), University of Illinois at Urbana-Champaign was harvested after 2011 and 2012 crop growing seasons. Total area of the plots harvested was about 6 ha. In the 2011 harvesting season, the ground was frozen; whereas in the 2012 harvesting season, the ground temperature was above 0 °C. It was generally observed that frozen ground provided better traction compared to unfrozen ground. For both seasons, the crop was harvested during January–March, and average moisture content varied from 15 to 20%. A self-propelled disk cutterbar mower-conditioner (New Holland model H8080, 168 kW, 750 HD Specialty Head with 4.7 m cutting width, New Holland, PA) was used for cutting and conditioning the miscanthus crop (Fig. 1). Disk cutters modified for cutting tough miscanthus stems and slatted-steel conditioning rolls for aggressive conditioning were used to implement some of the recommendations from previous studies such as [12]. An RTK GPS (Real Time Kinematic, Global Positioning System) unit was used to record latitude and longitude of the mower-conditioner at 1 s intervals using a program written in LabVIEW (National Instruments, Austin, TX). The program also recorded engine speed, percent engine torque, and field speed available on the mower-conditioner CAN (controller area network) bus. The mower-conditioner was considered stationary when its field speed was less than 0.2 km h^{-1}, and those data were not used in calculating mower-conditioner performance. Performance parameters were calculated by following the procedures described in the ASABE standards [20,21].

A large square baler (New Holland model BB9080, New Holland, PA) collected the crop windrowed by the mower-conditioner (Fig. 2). The baler was pulled by a 164 kW tractor (John Deere model 7930, Moline, IL), capable of generating 134 kW PTO (power take off) power. Another RTK GPS unit was used to record latitude and longitude of the tractor at 1 s intervals. Engine speed, percent engine torque, fuel consumption and baler field speed available on the tractor CAN bus were recorded. The baler was considered stationary when its field speed was less than 0.2 km h^{-1}, and those data were excluded from the baler performance calculation. In addition, the baler was equipped with an on-the-go bale weighing and moisture content measuring systems with an average accuracy of 5%. It was also equipped to record GPS coordinates of a location where a bale was tied and released. Typically, such a recorded GPS location was the finish point of a bale and the start point of the next bale. These features were part of a commercial yield monitor (Harvest Tec. model 479, Hudson, WI) fitted to the baler (Fig. 2). In this study, the yield levels are reported on a dry basis.

Fig. 1. A self-propelled mower-conditioner (New Holland model H8080: 750 HD specialty rotary disc head, New Holland, PA) used in mowing miscanthus.

Fuel consumption and harvesting cost as influenced by the miscanthus yield were determined by employing the bale-specific method [17]. A bale was selected to determine the correlations when it was formed in a single row. The distance between the start point and finish point of the selected bale was determined using the GPS locations. The distance between the start and finish point and the effective cutting width were multiplied to calculate the field area from which the selected bale was formed. Typically, the segmented field area varied from 150 to 500 m^2. In the segmented field area, machine performance parameters, fuel consumption and harvesting cost were determined.

Costs of use per hour were calculated following the procedure described in the ASAE D497.7 [20] and ASAE EP496.3 [21] standards. For the mower-conditioner assumptions were: list price $125,000; annual use, 250 h; repair and maintenance cost over the

Fig. 2. Large square baler (New Holland model BB9080, New Holland, PA) used in harvesting experiments.