BIOSYSTEMS ENGINEERING 133 (2015) 64–70

Available online at www.sciencedirect.com

ScienceDirect

journal homepage: www.elsevier.com/locate/issn/15375110

Research Paper

Effect of blade oblique angle and cutting speed on cutting energy for energycane stems

Sunil K. Mathanker [a], Tony E. Grift [a,*], Alan C. Hansen [a,b]

[a] Department of Agricultural and Biological Engineering, University of Illinois at Urbana-Champaign, 1304 West Pennsylvania Avenue, Urbana, IL 61801, USA

[b] University of KwaZulu-Natal, South Africa

ARTICLE INFO

Article history:
Received 20 December 2014
Received in revised form
4 March 2015
Accepted 8 March 2015
Published online 26 March 2015

Keywords:
Impact cutting
Harvesting
Energycane
Biomass
Bioenergy
Size reduction

Energycane is a promising bioenergy crop for warm south-eastern US regions and existing sugarcane machinery is being adapted for energycane cultivation. Because of energycane's comparatively higher fibre content and smaller stem diameters, the cutting blades must be optimized for energycane harvesting and size reduction. To optimize cutting blade designs, this study investigated the effect of cutting speed and blade oblique angle on cutting energy. An impact type cutting mechanism was used to determine the cutting energy cost of individual stems. The results showed that the specific cutting energy increases with cutting speed. The lowest average specific energy was 0.26 J mm^{-1} for a 60° oblique cut at an average cutting speed of 7.9 m s^{-1}, whereas the highest average specific cutting energy was 1.24 J mm^{-1} for a straight cut at an average cutting speed of 16.4 m s^{-1}. The specific cutting energy showed a close correlation with stem diameter and stem cross-sectional area. For a 30° oblique angle at 11.3 m s^{-1} average cutting speed, the cutting energy varied from 4.5 to 15 J as the energycane stem diameter varied from 11 to 17 mm. Comparisons with sugarcane studies indicated that optimisation of cutting speed and blade oblique angle can result in significant savings in cutting energy, whilst simultaneously improving the quality of cut. This study emphasises the need for further investigation of the energycane cutting process especially at higher cutting speeds with cutting devices with varying moments of inertia.

1. Introduction

Worldwide, renewable energy sources are being investigated as an alternative to fossil fuels. Biomass, a renewable energy source, has the potential to supply fuel and electricity compatible with existing transportation and power generation infrastructures. The energy consumed in the US is expected to increase to 120.8 EJ by 2034 from 105 EJ in 2008 (DOE, 2010). The expectation is that renewable energy sources will meet 10–40% of the demand being approximately 17 EJ by 2034 (DOE, 2010). A large portion will come from biomass sources and many alternative crops are being investigated. Energycane is emerging as one of the low-input high-yielding crops suitable for biomass production in warm south-eastern regions of the US (Knoll, Anderson, Strickland, Hubbard, & Malik, 2011).

* Corresponding author.
E-mail address: grift@illinois.edu (T.E. Grift).
http://dx.doi.org/10.1016/j.biosystemseng.2015.03.003

Nomenclature

A	Stem cross sectional area, m^2
a	Stem diameter in the cutting direction, m
b	Stem diameter in direction perpendicular to the cutting direction, m
E_c	Energy required to cut energycane stem, J
I	Moment of inertia of the cutting arm, kg m^2
ω_i	Initial speed of the cutting arm before cutting stem, rad s^{-1}
ω_f	Final speed of the cutting arm after cutting stem, rad s^{-1}

Most of the plants called energycanes are hybrid species within the *Saccharum* genus, usually with one *Saccharum officinarum* parent (Youngs & Taylor, 2009). Energycane is a perennial grass species that utilises the energy efficient C-4 photosynthetic pathway. Sugarcanes are also from *S. officinarum* species whereas the ratio of soluble sugar to insoluble fibre distinguishes 'sugarcanes' from 'energycanes' within the *Saccharum* species. The energycanes are further divided into Type I and Type II with a low and high sugar content respectively.

Energycane harvesting is similar to sugarcane harvesting, where the green tops are removed and left in the field. Some harvesters remove the green top and heap the canes that are burnt to remove trash representing about 15% of the total biomass (Youngs & Taylor, 2009). Other harvesters remove the green top, cut the cane approximately 50 mm above the soil, and subsequently cut the harvested stalk into billets which are loaded into a transport bin. The green tops and leaves (trash) are expelled onto the field.

It is expected that sugarcane harvesters and forage equipment will work well for energycane (Mislevy & Fluck, 1992) but there is a great opportunity for efficiency improvement. Cutting forces and cutting speed required to cut plant materials play a significant role in designing energy efficient equipment. The initial knife penetration results in localised plastic deformation, followed by buckling and deformation as the knife advances (Person, 1987). As the knife continues to advance, the fibres in the stem are deflected and eventually fail in tension (Srivastava, Goering, Rohrbach, & Buckmaster, 2007).

Many studies investigated the effect of cutting speed on cutting energy and relevant studies are briefly summarized here. For maize stem cutting, a distinct minimum energy requirement was found at a cutting velocity of 2.65 m s^{-1} (Prasad & Gupta, 1975). This was not the case for forage grasses where the cutting energy monotonically decreased with cutting speed (McRandal & McNulty, 1978). The cutting energy required to cut sorghum stems showed a minimum at 2.9 m s^{-1} cutting speed and it increased as the cutting speed increased above 2.9 m s^{-1} (Yiljep & Mohammed, 2005). As with a maize study (Prasad & Gupta, 1975), cutting energy increased as the cutting speed decreased below 2.9 m s^{-1} (Yiljep & Mohammed, 2005). For harvesting sugarcane, the specific shearing energy was found to be proportional to the blade cutting speed and lower speeds were recommended to reduce the cutting energy requirement (Taghijarah, Ahmadi, Ghahderijani, & Tavakoli, 2011).

Many other studies examined the effect of blade angle and blade design on the cutting energy. A blade peripheral velocity of 13.8 m s^{-1}, oblique angle of 35°, and a tilt angle of 27° were optimum for a revolving knife-type sugarcane base cutter (Gupta & Oduori, 1992). The cutting force required for cutting sugarcane stem depended on the blade design and a difference of 26% was reported between the two designs tested (Clementson & Hansen, 2008). A cutting blade oriented parallel to a corn stalk (0°) compared to perpendicular (90°) resulted in a significant reduction in the specific cutting energy to one-tenth for internodes and about one-fifth for nodes (Igathinathane, Womac, & Sokhansanj, 2010). Optimum knife edge angle, shear angle, oblique angle, and rake angle were 25°, 40°, 40°, and 40°, respectively for *Kenaf* stems (Ghahraei, Ahmad, Khalina, Suryanto, & Othman, 2011). Hammer mills performed better than knife mills represented by various cutting mechanisms for energycane size reduction (Miao, Grift, Hansen, & Ting, 2011).

Many other studies examined the effect of stem diameter on cutting energy and relevant ones are described here. The cutting energy was found proportional to maize stem diameter (Prasad & Gupta, 1975). The cutting force and cutting energy increased with sugarcane fibre content and stem diameter (Kroes & Harris, 1996a, 1996b). The cutting energy increased from 15 to 20 J as the sugarcane diameter increased from 20 to 30 mm while cutting at a commercial harvester speed of 20 m s^{-1} (Kroes & Harris, 1996a, 1996b).

To avoid splitting of sugarcane stubbles which causes fungal and other diseases, it would be beneficial to keep the impact force less than the bending resistance of the remaining stem section for all depths of blade penetration (Kroes & Harris, 1996a, 1996b). The total cutting energy of dry corn stem internodes varied with the stem cross-sectional area and it ranged from 11.3 to 23.5 kN m^{-1} (Igathinathane et al., 2010). A serrated blade required 35% less cutting force than a flat blade while cutting miscanthus stems at 1.7 m s^{-1} cutting speed (Liu, Mathanker, Zhang, & Hansen, 2012).

Thus, this literature surveyed indicates that cutting speed, blade oblique angle, and stem diameter play a key role in the energycane cutting process. However, there are no studies investigating energycane cutting mechanics. To improve energycane harvesting and size reduction equipment, the objectives of this study were to investigate the effect of cutting speed, blade oblique angle, and stem diameter on the cutting energy required for individual energycane stems.

2. Materials and methods

Energycane stems (variety Ho 02-113) cut close to the ground were collected in July 2011 from a first year ratoon crop grown in Highlands, Florida. In the test assembly, the energycane stem was oriented vertically with its base firmly held in place to mimic the mechanical rigidity of the root structure of an energycane plant in the field (Fig. 1; Fig. 4b). The diameters of the stem in the cutting direction, and in direction perpendicular to the cutting direction were recorded at the expected