BIOSYSTEMS ENGINEERING 129 (2015) 112–126

Available online at www.sciencedirect.com

ScienceDirect

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

Research Paper

Cost of boundary manoeuvres in sugarcane production

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ARTICLE INFO

Article history:
Received 21 February 2014
Received in revised form
29 July 2014
Accepted 13 September 2014
Published online 22 October 2014

Keywords:
Saccharum spp.
Energy
Path planning
Mechanisation
Agricultural machinery

Machinery has direct and indirect costs associated with their work in field, with non-productive time spent in manoeuvres when machinery reaches field borders. Much work has been carried reducing the number of manoeuvres in complex field shapes and changing the type of manoeuvre in order to speed them up. Biofuel producing crops such as sugarcane (*Saccharum* spp.) besides requiring economic profitability demand positive energy output in their production chain. Sugarcane uses narrow width equipment which requires time-costly manoeuvres adding significant inputs particularly on short rows. Using a method and calculations that is applicable for other crops, this study takes operational, spatial, economic, and energy factors into account to observe the impact of manoeuvres at the headland of a sugarcane crop. Energy and economic costs were retrieved from the hourly use of machines for four main field operations and their respective manoeuvring costs. Crop parameters were retrieved with their data compared with operational costs to establish the dimensions of row-length benefits. Increases in row length and width has decreasing benefits that may conflict with the logistics of servicing auxiliary units. The impacts of turning patterns were obtained, it suggests changes to minimise time and space for manoeuvring in planting and cultivating operations, and using wider roads and more steerable carriers in harvesting operations. In standard scenarios of a production system it was found that the income from row lengths less than 50 m were less than the economic costs occurred in turning at the headland.

1. Introduction

There are environmental and economic costs associated with the operation of machinery in agricultural fields. Soil compaction, overlap of worked area and the acquisition and operation of the suitable machinery are among the factors that can negatively impact on the sustainability of the agricultural production. Generally, agricultural machines do not spend much time in a field fully carrying out the operation

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http://dx.doi.org/10.1016/j.biosystemseng.2014.09.007

Nomenclature

ARL average row length being cover by the operation (m)
CRME cost of manoeuvring in a row-edge (MJ or US$)
DBA distance between implement and front tractor axles (m)
DBT distance between turns within a U-turn (m)
D-MDS distance followed by the tractor parallel to the road to the manoeuvre dedicated space (m)
EFB_{area} energy or financial balance per area (MJ ha^{-1} or US$ ha^{-1})
$EFB_{metre\text{-}row}$ energy or financial balance per metre-row (MJ m^{-1} or US$ m^{-1})
Eh hourly energy input (MJ h^{-1})
EMCRL equivalent manoeuvre cost in row length (m)
Emw energy given per unit weight (N kg^{-1})
F yearly frequency of occurrence of the operation
fv, *rv* forward and rearward velocities (m s^{-1})
h length of the overlapping zone (m)
ICMA input cost of manoeuvring per area (MJ ha^{-1} or US$ ha^{-1})
LT hourly lifetime of the implement (h)
M mass of implement (kg)
MDS manoeuvre dedicated space, a wider width of the roads required for the P-turns.
NRC_{Oper} number of rows covered by the operation
Oper identifier of the field operation
Pm average power output of the tractor during its lifetime (kW)
Pn nominal power of the tractor (kW)
P-turn manoeuvre type executed by an agricultural machine operating in a headland pattern. The machine moves into a region which allows a full loop turn
q angle between machine direction and a perpendicular field border (in radians)
qme manufacturing and repair and maintenance energy per unit fuel consumption (MJ g^{-1})
qs specific mean consumption (g kW^{-1} h^{-1})
r turning radius (m)
RRM ratio of repair and maintenance energy to manufacturing energy
RTM_{Oper} relative time spent in manoeuvering (%)
TCMRE sum of manoeuvring operations costs in a headland (MJ or US$)
TC_{Oper} time cost of a manoeuvre (MJ h^{-1} or US$ h^{-1})
Ti hourly lifetime of the tractor (h)
TM_{Oper} time spent in a manoeuvre for the operation (s)
T-turn manoeuvre type executed by an agricultural machine operating in a headland pattern. Also known as reverse turn, the machine turns to one side and then reverses to be able to reach an adjacent machine track
U-turn Manoeuvre type executed by an agricultural machine operating in a headland pattern. The steering does not exceed 180° for turning to reach a next machine track
w width of the operation (m)
WMS, *UMS*, *TMS* and *PMS* respectively the W-turn, U-turn, T-turn and P-turn manoeuvring spaces required (equivalent to the road or headland width, in m)
WMT, *UMT*, *TMT* and *PMT* respectively W-turn, U-turn, T-turn and P-turn manoeuvring time cost (s)
WPR weight per power ratio (N kW^{-1})
WS working speed of the operation (m s^{-1})
Ω-turn manoeuvre type executed by an agricultural machine operating in a headland pattern. The steering exceeds 180° for turning in the shape of a lamp-bulb to reach a following machine track

they were designed to perform. Loading or offloading agricultural products and inputs and turning are the main non-working factors that contribute to overall efficiency (Witney, 1996); reducing these non-productive periods reduces production costs.

An increasing proportion of sugarcane production is shifting towards fully mechanised field operations. However, the high biomass harvested and the narrow width of machines makes highly demands per area leading mechanisation and increasing the initial cost of production (mechanisation is 40% of the cost, Milan, 2004).

In Brazil, ethanol for automotive fuel is derived from sugarcane and is used either pure or blended with gasoline (18–25% of ethanol). This ethanol is basically produced in sugarcane mills and distilleries, and the crop covers close to 9 million ha in the country (CONAB, 2013).

The energy balance for the sugarcane crop has been studied. As a bioenergy supplier it is expected that the energy produced by the crop to safely excel its inputs. Macedo, Seabra, and Silva (2008) found ratios of the output/input of sugarcane energy of 9.2 considering an input of 15.2 GJ ha^{-1}, while De Oliveira, Vaughan, and Rykiel (2005) obtained a ratio of 3.7 and an input of 36 GJ ha^{-1}. These studies were carried using a holistic approach focussing in the hectare as the research unit. Macedo et al (2008) calculated the embodied energy (per Mg) of sugarcane, from field production to the stage of energy products (ethanol and electricity). This latter approach gives a more accurate estimate, once the logistic costs of the production and processing are more specifically related to product quantity rather than area.

Coelho (2009) pointed that mechanisation of harvest operations in sugarcane can amount from 30 to 35% of production costs. Efficiency issues found that a sugarcane harvester spends only an average of 8.5 h of effective work in a continuous 24 h of work (three shifts each of 8 h).

Sugarcane is a row-crop where undesired machine traffic (i.e. across or in the rows) leads to damage of the ratoon which requires the crop has to re-establish and grow again. Around