European Journal of Agronomy 92 (2018) 133–140

Contents lists available at ScienceDirect

European Journal of Agronomy

journal homepage: www.elsevier.com/locate/eja

Research paper

Energy and economic efficiency in grazing dairy systems under alternative intensification strategies

Eduardo Llanos[a], Laura Astigarraga[b], Valentín Picasso[a,b,c,*]

[a] Departamento de Sistemas Ambientales, Facultad de Agronomía, Universidad de la República, Av. E. Garzón 780, Montevideo, Uruguay
[b] Departamento de Producción Animal y Pasturas, Facultad de Agronomía, Universidad de la República, Av. E. Garzón 780, Montevideo, Uruguay
[c] Agronomy Department, University of Wisconsin – Madison, 1575 Linden Dr., Madison, WI, 53706, United States

ARTICLE INFO

Keywords:
Farming systems
Grazing
Energy efficiency
Forages
Ecoefficiency

ABSTRACT

The intensification of dairy systems, or the process of increasing milk productivity per unit of land area, can be achieved through various strategies. However, it is debated whether intensification is associated with increased economic and/or environmental efficiency. The aim of this study was to identify alternative intensification strategies for grazing dairy systems and evaluate their economic and energy efficiency. A model for calculating energy inputs and outputs was applied to 30 dairy farms with reliable production and economic records in Uruguay, spanning a wide range of farm features. Milk productivity averaged 3819 l.ha^{-1} year^{-1} (ranging from 1512 to 6942), intake of concentrate averaged 0.25 kg l^{-1} of milk (ranging from 0.03 to 0.38), fossil energy use averaged 3.96 MJ kg^{-1} (ranging from 1.9 to 9.1) and farm net income averaged 317 U$D ha^{-1} year^{-1} (ranging from 136 to 748). Using a numerical classification procedure, four farm clusters that represent different technological, production, and efficiency situations for grazing dairy farms were identified, associated with the differential use of pastures and concentrates. Although increasing used of concentrates in diets was associated with higher milk productivity, and sometimes higher economic performance, it was consistently negatively associated with energy efficiency. Dairy farms with a higher proportion of pasture consumption achieved higher efficiency of utilization of feed concentrates (higher kg milk/kg concentrate) and thus used less fossil energy per liter of milk. These results suggest that sustainable intensification of grazing dairy systems should rely on efficient utilization of pastures rather than just increasing concentrate intake.

1. Introduction

The growth in global population and income has increased demand for food production and consumption, especially animal proteins (Ranganathan et al., 2016). The intensification of livestock systems is the process of increasing milk or meat productivity per unit of land area, and it has been proposed as the necessary path to sustain humanity (Herrero et al., 2016). Intensification can be achieved through various strategies. Conventional intensification of livestock production systems has been achieved by increasing the number of dairy cattle per hectare of land, the acquisition of genetically improved cattle, and the increase in concentrates in the diets (Caviglia-Harris, 2005) supported by use of inputs such as fertilizers, pesticides, and fuel to increase grain and forage yields (Alexandratos and Bruinsma, 2012). This intensification strategy based on inputs and high fossil energy use can result in serious environmental impacts. The emission of greenhouse gases by combustion of fossil fuels, emissions from nitrogen fertilizers, and enteric methane from cattle significantly contributes to climate change (Meul et al., 2007). Soil erosion, nutrient leaching, water contamination and eutrophication of water bodies, are other environmental impacts associated with conventional intensification based on higher use of annual crops and inputs (Modernel et al., 2013; Picasso et al., 2014).

The rising costs of livestock inputs and low prices of products entailed a lower profit margin for producers. Increased productivity through investment in technology (inputs and capital) was the way to increase production and improve the profitability of farming systems (Dartt et al., 1999; Somda et al., 2005). In response to environmental and social problems generated by this model, ecological intensification (Tittonell, 2014), appears as a sustainable alternative, integrating environmental indicators and adding value to the products, through exploiting ecological mechanisms that underlie the productivity, stability and resilience, including the balance between feedstuff (grains) and pasture management (Hanson et al., 1998; Parker et al., 1992). This alternative seeks to develop sustainable production systems that reduce consumption of fossil energy and generate better economic results

---

[*] Corresponding author at: Agronomy Department, University of Wisconsin – Madison, 1575 Linden Dr., Madison, WI, 53706, United States.
E-mail addresses: ellanos@fagro.edu.uy (E. Llanos), astigarr@fagro.edu.uy (L. Astigarraga), picassorisso@wisc.edu (V. Picasso).

http://dx.doi.org/10.1016/j.eja.2017.10.010
Received 20 August 2016; Received in revised form 13 October 2017; Accepted 18 October 2017
1161-0301/ Published by Elsevier B.V.

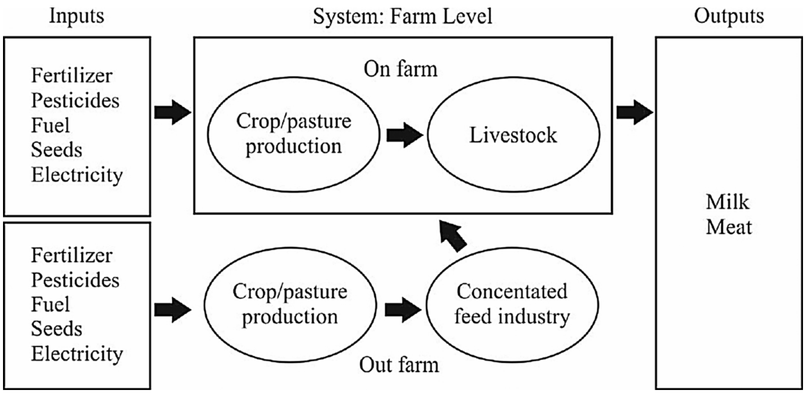

Fig. 1. Model of the system used to quantify the energy inputs and outputs at the farm level.

(Dalgaard et al., 2001; McLaughlin et al., 2000), which would also result in lower emissions of greenhouse gases (Dalgaard et al., 2001; Doucet, 2008; Meul et al., 2007) therefore mitigating climate change.

Grazing is the basis of the dairy production systems in South America, with varying levels of supplementation with conserved forages (Franzluebbers et al., 2014; Ostrowski and Deblitz, 2001). The intensification of dairy systems associated with the use of concentrates and reserves, has increased the productivity of milk with variable effects on the economic cost and energy efficiency. Identifying the best strategy for intensification in dairy appears to be difficult, because while some studies document improved environmental performance of low input systems, other studies contradict this. For instance, Meul et al. (2007) showed reduced energy input from a lower use of fertilizers and concentrates, with 25% increase in milk productivity per ha through a higher milk productivity per cow and a higher stocking rate. Several studies agree that fuel, electricity, fertilizer and animal feed together represent the main part of the total energy consumption (Cederberg and Flysjo, 2004; Cederberg and Mattsson, 2000; Kraatz, 2012; O'Brien et al., 2012; Rabier et al., 2010). Oudshoorn et al. (2011) concluded that minimizing local as well as global environmental impacts did not have an economic trade-off. On the other hand, Alvarez et al. (2008) showed that intensive farms produced at a lower average total cost and presented greater levels of efficiency than extensive farms. Basset-Mens et al. (2009) demonstrated that the high inputs systems can be more profitable when milk price is high and maize silage cost is low but the low inputs systems are more profitable when milk price is low and maize silage cost is high. Therefore, it appears from the previous literature that the relationship between environmental and economic efficiency depends on the dairy systems considered, the region, and the management practices analyzed. The aim of this study was to identify different intensification strategies for grazing dairy farms and evaluate the relationship between productivity, fossil energy consumption per kg of milk (FECK) and economic outcome, using a group of Uruguay dairy farms as a case study.

2. Materials and methods

2.1. Dairy systems database

In Uruguay, dairy cows are usually fed sown pastures of mixtures of grasses and legumes year round, supplementing the diet with corn grain and/or sorghum and silage to maintain milk production during winter when pasture production is poor. These silages are generally produced on the same dairy farm. During milking time, the cows are fed concentrates to satisfy the nutritional requirements of their expected level of production. Dairy cattle are predominantly Holstein breed. The 2009–10 average productivity of Uruguay was 4334 l cow^{-1} and 2410 l ha^{-1} per hectare (DIEA, 2010). and the average annual precipitation in the area was 1100 mm with a maximum temperature of 27° Celsius and minimum 4° Celsius (INIA, 2010).

The farms database for this study was obtained from the productive and economic records of 30 dairy farms remitting their milk to CONAPROLE, the major dairy industry of the country, for the 2009–2010 fiscal year, which was an average climate year. Farms were located in the southern region of Uruguay, in the departments of Colonia, San José, Canelones, and Maldonado. Farms were included in the study because they had reliable records and a broad range of milk productivity, in order to explore the diversity of production strategies. Data from milk productivity per hectare (MPH, l ha^{-1}), milk productivity per cow (MPC, l cow^{-1}), stocking rate (SR, cow ha^{-1}), herd efficiency (number of milking cows/total stock, HE, %), total dry matter intake per cow per year (DMI, kg cow^{-1}), concentrate intake per liter of milk (CL, kg l^{-1}), concentrate intake per cow per year (CC, kg cow^{-1}), proportion of the total intake from concentrate (PIC), proportion of the total intake from pasture (PIP), and proportion of the total intake from silage (PIS), were obtained from the records of each producer. Actual pasture yields were not recorded, and pasture intake per cow is estimated by difference.

2.2. Energy model

The Agroenergía model proposed by Llanos et al. (2013) was used for energy calculations. The model estimates energy inputs and outputs using energy coefficients from international literature and also local coefficients adjusted to the conditions of Uruguay. The model accounts for the input of fossil energy used in different activities within the farm (feed production in pasture or annual crops and feed purchased outside the farm, Fig. 1). The model uses the Hetz and Barrios (1997) methodology to quantify the energy costs of machinery operations per unit area (MJ ha^{-1}), with the coefficients presented by ASAE (1993) and Fluck (1985), for the use of machinery for feed production produced within the farm and bought off farm. For activities within the farm and feed purchased off-farm fossil energy from fuels and agrochemicals (fertilizers, herbicides, and pesticides) were added (Fig. 1). Fossil energy consumption per liter of milk (FECL, MJ.l^{-1}) was calculated.

As outputs the model considers the energy value of milk and meat. The energy value of milk (EM) was calculated from the equation based on the percentages of fat (%F) and milk protein (%P) for each farm: $EM = 40.72 (\%F) + 22.65 (\%P) + 102.7$ (Tyrrell and Reid, 1965). The energy value of the meat was calculated from the weight of the different tissues by animal category (García, 1997) and the tissue energy value proposed by Marletta and Carnovale (2000). The main energy parameters used in the Agroenergía model are presented in Table 1 (Llanos et al., 2013).

In order to compare alternative systems of production with previous studies in the literature, our results were transformed to the units of 1 kg energy corrected milk (ECM) and 1 kg fat and protein corrected milk (FPCM) by the following equations: $\text{kg ECM} = \text{kg milk} [0.25 + 0.122(\%F) + 0.077(\%P)]$ (Sjaunja et al., 1990) and $\text{kg FPCM} = \text{kg milk} [0.337 + 0.116(\%F) + 0.06(\%P)]$ (FAO, 2010).