Journal of Cleaner Production 200 (2018) 28–38

Contents lists available at ScienceDirect

Journal of Cleaner Production

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

Can extensification compensate livestock greenhouse gas emissions? A study of the carbon footprint in Spanish agroforestry systems

A. Eldesouky [a], F.J. Mesias [b, *], A. Elghannam [c], M. Escribano [d]

[a] Department of Agricultural Economics, Faculty of Agriculture, Zagazig University, Sharkia, Egypt
[b] Department of Economics, Faculty of Agriculture, University of Extremadura, Avda. Adolfo Suarez, s/n – 06007, Badajoz, Spain
[c] Department of Agricultural Economics, Faculty of Agriculture, Damanhour University, Elbeheira, Egypt
[d] Department of Animal Production and Food Science, Faculty of Veterinary Medicine, University of Extremadura, Campus Universitario, 10003, Caceres, Spain

A R T I C L E I N F O

Article history:
Received 25 February 2018
Received in revised form
14 July 2018
Accepted 27 July 2018
Available online 30 July 2018

Keywords:
Carbon footprint
Life cycle assessment
Extensive production
Livestock
Soil carbon sequestration

A B S T R A C T

Dehesa agroforestry systems (rangelands located in Southwest Spain) are characterised by their semi-arid and often marginal conditions. These features are behind the low supply of pastures available for livestock use, which leads to proper management being based on the use of reduced stocking rates which imply minimal animal pressure on the territory.

In this sense, the study of the role of carbon footprint in extensive systems is of great interest by analysing, within a case study framework, the various production systems available in *dehesa* farms and providing the methodological adjustments required to generate results that are comparable with other livestock systems and species.

Results have revealed that beef farms with fattening calves are those with the lowest carbon footprint levels (8.62 kg of carbon dioxide equivalents (CO_2eq)/kg live weight), followed by meat production sheep farms and farms selling calves at weaning. Enteric fermentation accounts for 64.10%–43.63% of the total emissions, and it is linked to the extensification of these systems and to the grazing diet of the animals. The system's own emissions could reach up to 78% in meat production systems. Undoubtedly, feeding is the input that amounts for the highest percentage of off-farm emissions, as it can reach up to 44.60% of the total emissions in dairy sheep farms and 21.20% in the meat production sheep farms.

Soil sequestration has also been observed to range between 270.02 and 334.01 kg CO_2eq ha^{-1} y^{-1} in the extensive farms under study, which represents considerable carbon compensation. It should be noted that these systems cannot compete in product units with the more intensive ones and, therefore, carbon footprint in *dehesa* agroforestry systems should be referred to the territory.

1. Introduction

One of the challenges the world faces over the next decades is the preservation of its natural resources, at the same time as the production of sufficient food to satisfy the demand of the growing human population (Ibidhi et al., 2017). But with the growing concern about climate change and the already significant contribution of food production to the emission of greenhouse gases (GHG) (Herrero et al., 2013) there can be a need to compensate food production and GHG emissions.

In this context, calculating the Carbon Footprint (CF) of products has become increasingly popular. Carbon Footprint provides an estimate of the total GHG emitted during part or all of the life of a good or service (BSI, 2011), expressed as CO_2eq. It can be used to identify and assess environmental loads associated with a process, product or system, and this assessment allows for the examination of potential bio-physical trade-offs from proposed policies and other measures (Galli, 2015). Carbon Footprint is increasingly used in the food supply chain to determine the quantity of GHG emitted at each stage of the production process, and it may extend to the distribution and usage phases (Jones et al., 2014). Carbon Footprint also enables carbon labelling of products -therefore allowing sustainable consumer purchasing decisions-, and provides an

* Corresponding author. Francisco J. Mesias
E-mail address: fjmesias@unex.es (F.J. Mesias).

https://doi.org/10.1016/j.jclepro.2018.07.279
0959-6526/

emissions' benchmark against which mitigation targets can be set and progress measured.

The major reason for the widespread use of CF in food products is the attention that climate change has received on the global environmental agenda (Röös et al., 2011), as food production significantly contributes to the increasing human input to the GHG emissions. Thus, society has expressed concern about the environmental impacts caused by the growing need for food production to meet the global demand (Florindo et al., 2017).

The growing alarm over the environmental impacts and different characteristics of food has increased consumer interest in the production methods and other attributes of food products (Forsman-Hugg et al., 2008), also spurring a flurry of discussion in the popular media regarding the climate impacts of livestock production and the comparative performance of feedlot and grass-based production systems (Pelletier et al., 2010). Thus, the concerns about reducing GHG emissions to mitigate climate change have recently promoted the assessment of the CF for various activities and products (Luo et al., 2015).

1.1. The importance of using CF in animal production systems

The environmental impacts of agricultural production depend to a great extent on the production systems, which can be influenced by techniques, harvesting period and other technical issues. This primary phase is seen as the main contributor to the environmental impacts of food, related to biodiversity loss, GHG emissions and reduction of soil fertility (Mohamad et al., 2014).

According to the FAO's report "*Livestock's Long Shadow*", the livestock sector is seen as a major contributor to some of the most serious environmental problems at local and global levels (Steinfeld et al., 2006). The livestock sector represents 12% of all human-induced GHG emissions, with the ruminant sector being responsible for 80% of these GHG emissions (Havlik et al., 2014). The report also implies that the livestock sector increasingly competes for scarce resources and causes severe impact on air, water and soil. Since its publication, public and scientific awareness about the impact of animal production on the environment has increased (Steinfeld et al., 2006).

Among livestock food products, meat causes the greatest environmental impact. This is due to the inefficiency of animals to convert feed to meat, as 75–90% of the energy consumed is needed for body maintenance or lost in manure and by-products such as skin and bones (Röös et al., 2013). There are many processes contributing to major GHG emissions during meat production, mainly: (i) production of feed, (ii) enteric fermentation from feed digestion by animals (mainly ruminants), (iii) manure handling and (iv) energy use in animal houses (Steinfeld et al., 2006).

Furthermore, GHG emissions associated with meat production can be effectively reduced through: (i) improvements in animal productivity and fertility; (ii) intensification of production as output/ha (provided that higher input requirements of feed and/or fertilizer are offset by higher levels of productivity); and (iii) soil CO_2 sequestration in grasslands (Beauchemin et al., 2008; Crosson et al., 2011).

Therefore, the analysis of the CF and the variables included in livestock production may identify procedures or techniques in which emissions can be reduced by improving efficiencies (Wiedmann and Minx, 2007). Table 1 shows the CF for various production systems and functional units (FU, the unit selected to express the results of the analysis, e.g. kg of meat or litre of milk produced) and reflects the inherent variability of this indicator.

Strangely enough, at least when it comes to environmental issues, intensifying animal production is generally advocated to mitigate certain environmental impacts, such as the GHG emissions associated with the production of foods of animal origin (Steinfeld and Gerber, 2010). In this regard, the intensification of animal production in feedlots or through changes in their diet allows an early slaughter and has been reported to be a strategy adopted in several countries to reduce GHG emissions in beef production (Ruviaro et al., 2016).

With that in mind, many consumers are still unfamiliar with CF information, which makes it difficult for them to evaluate and compare the different products which are on offer (Kemp et al., 2010). However, meat companies are interested in finding out how different product characteristics can influence consumer choice and whether there is a possibility for a price premium to be added if products are differentiated using the CF attribute (Koistinen et al., 2013). This topic is especially relevant for extensive systems, in which the environmental values associated to livestock production can be overshadowed by the comparatively higher emissions of these production systems, as carbon sequestration by the environment (soil, plants …) is usually not considered.

In this context, the study of the role of CF in extensive systems is of great interest through the analysis -within a case study framework- of the various production systems available in *dehesa* agroforestry systems[1] (Spanish rangelands) and through the provision of the methodological adjustments required to generate results that are comparable with other livestock systems and species.

2. Materials and methods

Among the various methodologies available to estimate the GHG emissions, Life Cycle Assessment (LCA) is an internationally accepted, standardised method used to identify and quantify the environmental impact of a product (Buratti et al., 2017), and it has therefore been selected for this piece of research. Through the entire life cycle of a product, LCA accounts resource consumption, energy, pollutant emissions, etc. (Goldstein et al., 2016).

The calculation of CF has been made in accordance with British Standard PAS 2050 and the IPCC guidelines for national GHG inventories (IPCC, 2006). An adaptation of the methodology quoted by the Spanish Ministry of Agriculture has also been followed regarding the characteristics of livestock in the analysed areas and manure management (MAPA, 2012). The methodological procedure followed in this piece of research consisted of an LCA analysis of the CF taking into account the soil's carbon sequestration.

2.1. Data collection

This study is based on the analysis of four case studies, which were selected as the most representative types of *dehesa* farms. Although global system information may be lost when we deal with technical-economic aspects, the choice of representative farms within a case study analysis allows us to delve more deeply into complex issues (Ripoll-Bosch et al., 2012) such as those related with inventory data collection that are necessary both for LCA and for the calculation of the CF in farms. This methodological choice can be found in other research on CF such as that of Stanley et al., (2018). The analysed farms are described below.

[1] The *dehesa* is an agroforestry system characterized by the presence of a low-density tree layer (30–40 trees/ha, mainly Quercus Ilex and Suber) together with an understorey of pastures, shrubs and crops. The system commonly includes a mixture of different livestock species (beef cattle, sheep, and Iberian pigs), which graze freely and are raised for extensive meat and live animal production. When resources are handled efficiently, the woodland (trees, shrubs, etc.) and the pasturelands provide most of the animal feed needed in the farm. At the same time, livestock grazing avoids shrub invasion and therefore the degradation of the system.