Ecological Indicators 77 (2017) 304–313

Contents lists available at ScienceDirect

Ecological Indicators

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

Original Articles

Water, land and carbon footprints of sheep and chicken meat produced in Tunisia under different farming systems

Ridha Ibidhi[a,b,*], Arjen Y. Hoekstra[c,d], P.Winnie Gerbens-Leenes[e], Hatem Chouchane[c]

[a] Laboratoire des Productions Animales et Fourragères, Institut National de la Recherche Agronomique de Tunisie (INRAT), Université de Carthage, 2049 Ariana, Tunisia
[b] Faculté des Sciences de Bizerte, Université de Carthage, 7021 Zarzouna, Tunisia
[c] Twente Water Centre, University of Twente, P.O. Box 217, 7500 AE Enschede, The Netherlands
[d] Institute of Water Policy, Lee Kuan Yew School of Public Policy, National University of Singapore, 259770 Singapore, Singapore
[e] Center for Energy and Environmental Studies (IVEM), University of Groningen, The Netherlands

ARTICLE INFO

Article history:
Received 23 July 2016
Received in revised form 12 February 2017
Accepted 15 February 2017
Available online 1 March 2017

Keywords:
Environmental footprint
Water
Land
Carbon
Sheep and chicken meat
Tunisia

ABSTRACT

Meat production puts larger demands on water and land and results in larger greenhouse gas emissions than alternative forms of food. This study uses footprint indicators, the water, land and carbon footprint, to assess natural resources use and greenhouse gas emissions for sheep and chicken meat produced in Tunisia in different farming systems in the period 1996–2005. Tunisia is a water-scarce country with large areas of pasture for sheep production. Poultry production is relatively large and based on imported feed. The farming systems considered are: the industrial system for chicken, and the agro-pastoral system using cereal crop-residues, the agro-pastoral system using barley and the pastoral system using barley for sheep. Chicken meat has a smaller water footprint (6030 litre/kg), land footprint (9 m^2/kg) and carbon footprint (3 CO_2-eq/kg) than sheep meat (with an average water footprint of 18900 litre/kg, land footprint of 57 m^2/kg, and carbon footprint of 28 CO_2-eq/kg). For sheep meat, the agro-pastoral system using cereal crop-residues is the production system with smallest water and land footprints, but the highest carbon footprint. The pastoral system using barley has larger water and land footprints than the agro-pastoral system using barley, but comparable carbon footprint.

1. Introduction

One of the challenges the world faces over the next decades is to preserve its natural resources and at the same time produce sufficient food to satisfy the demand of a growing human population. Between 1950 and 2015, the world population has quadrupled and global resource consumption and waste emissions have grown beyond the Earth's carrying capacity. Food production significantly contributes to the increasing human appropriation of the world's limited freshwater and land resources (Steinfeld et al., 2006; De Vries and De Boer, 2010) and to the emission of greenhouse gases (Herrero et al., 2013). The resulting increase in water and land scarcity in turn affects food security. The accumulation of human pressure is the main cause of many environmental issues and world leaders face the challenge of selecting appropriate policies and investments to prevent further detrimental effects. In order to monitor the pressures humanity exerts on the environment, different impact categories should be measured through a set of appropriate indicators, for example using the family of footprint indicators, including the water, land and carbon footprint (Galli et al., 2012, 2013). The footprint indicators have the potential to provide a comprehensive picture of environmental pressures (Hoekstra and Wiedmann, 2014; Fang et al., 2014). The multi-indicator approach is important in order to measure the pressure on water, land and climate. The water footprint (WF) measures the freshwater appropriated to produce goods or services, expressed as a water volume per unit of product (Hoekstra, 2009; Hoekstra et al., 2011). The WF includes three components: the green WF (evapotranspiration of rainwater from the field to produce for example a crop); the blue WF (net withdrawal of water from surface water or groundwater); and the grey WF (the volume of freshwater required to assimilate pollutants). The land footprint (LF) is the amount of land used to produce goods and services and is expressed in area per unit of product. The LF of a product reflects the real amount of land, wherever it is in the world, that is used to produce the product (Borucke

* Corresponding author at: Laboratoire des Productions Animales et Fourragères, Institut National de la Recherche Agronomique de Tunisie (INRAT), Université de Carthage, 2049 Ariana, Tunisia.
E-mail addresses: ibidhi_ridha@hotmail.fr, ibidhi.ridha1@gmail.com (R. Ibidhi).

http://dx.doi.org/10.1016/j.ecolind.2017.02.022
1470-160X/

et al., 2013; Giljum et al., 2013). Both WF and LF can be used to show the dependency of consumption in one place on natural resources (water or land) in another place, since products are traded, and with them the water and land virtually embedded in this product trade (Čuček et al., 2012). The carbon footprint (CF) refers to the greenhouse gas (GHG) emissions, expressed in CO_2 equivalent units (CO_2e), associated with a product process or service (Ruviaro et al., 2015). The CF includes the three main gases included in the Kyoto protocol: carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). The conversion of the gases to CO_2-eq is done using the global warming potential (GWP) of each gas, where GWP values for CO_2, CH_4 and N_2O are 1, 25 and 298 CO_2-eq/kg, respectively, assuming a 100-years time horizon (IPCC, 2007).

Livestock, for the production of meat and milk, is the world's largest user of land resources, with pasture and land dedicated to the production of animal feed representing 70% of the total agricultural area (Steinfeld et al., 2006). Thus, the production of animal feed can be considered as one of the major hotspots in the environmental impact from livestock production (Ridoutt et al., 2014). Globally, grasslands cover about one third of the vegetated area and contribute about one fifth to the global carbon cycle (Goudriaan et al., 2001; Sala, 2001). Along a precipitation gradient, grasslands are located between forests and deserts. When annual precipitation is higher than 1200 mm per year, usually forests dominate, whereas when precipitation is lower than 150 mm per year, usually sites are dominated by deserts. Grasslands cover a broad range of environmental conditions with an annual aboveground productivity from 50 to 800 $g\,m^{-2}$ that is linearly related to precipitation (Sala et al., 1988). Grasslands are used to graze cattle, sheep, goats or other animals and in this way contribute to the production of food (Sala, 2001).

In this paper, we assess the WF, LF and CF of chicken and sheep meat produced under different farming systems in Tunisia. We then compare the water and land use efficiency and GHG emission between chicken and meat and across production systems for sheep. The period of analysis is 1996–2005. The livestock sector is one of the most important activities in Tunisia. It plays an important role, economically and socially, by contributing 35–40% to the agricultural gross domestic product (GDP) and 4–5% to total GDP (Ministry of Agriculture, 2013). Meat consumption in Tunisia increased substantially during the past few decades, especially the consumption of poultry. Consumer behaviour shows a shift from red meat to white meat consumption, which is partly explained from the low price of poultry compared to red meat. For a country with limited natural resources like Tunisia, climate change will have drastic repercussions. The country is increasingly experiencing extreme summer temperatures and periods of extreme drought and wetness. Water resources in Tunisia are already overexploited. The indirect effects of climate change, such as soil erosion and a decline in agricultural production, are impacting economically important sectors and threatening human habitats and ecosystems (Radhouane, 2013). The production of sheep meat in Tunisia relies on the availability of pasture and additional feed grown in Tunisia itself, while the dominant industrial production of poultry relies on imported feed, mainly from Brazil (Ministry of Agriculture, 2013). Mekonnen and Hoekstra (2010) estimated the WF of sheep meat in Tunisia using an average WF of pasture for Northern Africa and, by allocating all water consumption in crop production to the crop yield, assumed a zero WF for crop residues used for feed. Tunisia, however, shows distinct climatic zones, the North, Centre and South, with average annual rainfall and grassland productivity decreasing from North to South, resulting in three different sheep production systems. The current study takes the climatic differences into account and assumes that when crop residues are applied for feed, they have an economic value and thus a WF. The current study is the first to assess the three different types of environmental footprint of sheep and chicken meat production, expressed per unit of production to enable comparison.

Table 1
Land use and percentage of total land area in Tunisia.

Land use	Land area (1000 ha)	Percent of total land area
Total land area[a]	15536	100
Total agricultural land[b]	10079	65
Woodlands[b]	1039	8
Grasslands[b]	4830	31
Croplands[b]	4211	27

[a] FAO (2016a).
[b] Ministry of Agriculture (2013).

2. Environmental conditions and meat production in Tunisia

2.1. Climate and land use

The country has three climatic zones that divide the country into three regions: North, Central and South Tunisia (Chouchane et al., 2015). Due to its geographic position, Tunisia is under the influence of two climates, the Mediterranean climate in the north and the desert climate of the Sahara in the south. Central Tunisia shows characteristics of both climates. The annual average rainfall varies from less than 100 mm in the extreme South to over 1200 mm in the extreme North (Kayouli, 2006).

Tunisia is one of the Maghreb countries in North Africa. As the other countries in the region, it includes large areas of grasslands that vary quantitatively and qualitatively across bioclimatic zones (Kayouli, 2006; Le Houerou, 1975). Many are being destroyed by overgrazing and encroachment of agriculture (Puigdefabregas and Mendizabal, 1998). Tunisia as a whole suffers from high water scarcity, north Tunisia experiences moderate water scarcity, central Tunisia significant scarcity and South Tunisia severe water scarcity (Chouchane et al., 2015). Grasslands cover nearly one third of the total land area (Table 1). In Tunisia, grasslands are mainly applied for sheep grazing. Additionally, sheep get access to fallow lands; generally, croplands are fallow (not used for cropping) once every two years.

Climatic differences cause differences in crop water use (CWU) in the country's grasslands. Table 2 gives CWU per governorate as well as average CWU per region based on data from Mekonnen and Hoekstra (2010). CWU is largest in the North, averaging 4243 m^3/ha, and smallest in the South, averaging 2325 m^3/ha.

2.2. Productivity of grasslands

The second national Tunisian forest and grassland inventory (Ministry of Agriculture, 2010) made an inventory of plants that occur in the natural grasslands in the three regions in Tunisia. Table 3 gives an overview of the dominant grassland species in the North, Centre and South of Tunisia, the dry matter content (DM) per species and the average dry matter content for grassland species in the North, Centre and South of Tunisia.

The climate, including precipitation variation, causes different combinations of dominant grassland species among the Northern, Central and Southern part of Tunisia. Annual grassland yields vary as well. Table 4 shows indicative yields (in both tonne of dry matter and tonne of fresh weight per hectare) and average grassland dry matter (tonne/tonne) (FAO, 1985) for the three regions in Tunisia. North Tunisia has the largest grassland yields, about five times larger than yields in the South when expressed in tonnes DM per hectare, while the Centre finds itself in between the two extremes.