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Human food vs. animal feed debate. A thorough analysis of environmental footprints

Arianna Di Paola[a,*], Maria Cristina Rulli[b], Monia Santini[a,c]

[a] Euro-Mediterranean Center on Climate Change (CMCC) Foundation, Impacts on Agriculture, Forest and Ecosystem Services (IAFES), Viterbo, Italy
[b] Department of Civil and Environmental Engineering, Politecnico di Milano, Milano, Italy
[c] Far East Federal University (FEFU), Ajax St., Vladivostok, Russky Island, Russia

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ABSTRACT

Currently, a large portion of grain production is funneled into animal feed despite widespread hunger and undernutrition. In the present work we: (i) estimated the area, water and carbon footprints of animal-source proteins (AP) obtained from intensive farming systems and compared them with those from producing an equivalent amount of plant-source proteins (PP); (ii) postulated a set of straightforward hypotheses to recover environmental resources by cutting down a surplus in the per capita protein intake from three representative regions where intensive animal farming systems account for a great share of animal food production.

Our major findings revealed that AP from intensive farming were approximately 2.4 to 33 more expensive in terms of area and water demand and 2.4 to 240 more pollutant in terms of greenhouse gas emissions when compared with PP. Environmental recoveries varied widely according to the hypothesized scenarios, but even the lowest estimates suggested remarkable results.

Whether additional proteins supply would be required, crops with large protein content as peas, chickpeas, soybeans, and lupins could help to meet food security, while better compromise between dietary habits and environmental protection could be reached in rich countries by a moderate consumption of meat produced with non-feed grain systems.

1. Introduction

Proteins are essential constituents of human nutrition (Day, 2013; World Food Programme (WFP), 2012) and one of the major benefits of consuming animal-source food lies in the protein content they eventually incorporate (Smil, 2014; Sanders, 1999). Currently, an excessive vs. inadequate proteins intake in rich vs. malnourished countries yields to an imbalance in the world's food system (Smil, 2002a), and for the coming decades, emerging countries are expected to increase the demand for animal-source food (Ehui et al., 1998; Kastner et al., 2012; Ranganathan et al., 2016; Tilman and Clark, 2014).

The production of animal-source proteins (AP) is highly inefficient (Smil, 2002a; Aiking, 2011): about 75% of global human-driven inputs of reactive nitrogen are used for agriculture and only 30% of these inputs are converted into plant-source proteins (PP) to feed livestock, with the non-recovered fraction mainly lost to the environment, causing degradation and pollution. Then, about 15% of PP from feed crops are estimated to turn into AP for human consumption, while 85% are wasted (Smil, 2002a; Aiking, 2011).

From the fifties, industrialized countries intensified the efficiency of animal-source food production shifting from extensive, grazing, small-scale, subsistence animal farming systems towards intensive, large-scale, geographically-concentrated, specialized production units (Robinson et al., 2011; Delgado et al., 2001), broadly known as Intensive Animal Farming Systems (IAFSs).

Even if IAFSs are mostly located in industrialized, large and quickly emerging countries, they represent a global issue accounting for more than 40% of the global animal-source food (FAO et al., 2014), being a relevant source of greenhouse gas (GHG) emissions (Tubiello et al., 2013) and sharing a significant portion of the global crop production to feed livestock (Foley et al., 2011; Smil, 2001; Steinfeld et al., 2006; Manceron et al., 2014) that, paradoxically, could be also devoted to human consumption. Indeed, 40 to 70% of animal diets IAFSs is composed by cereals and legumes, which provide high levels of energy and protein intake for animals (FAO et al., 2014), whilst locally produced roughage represents the major constituent of animal diets extensive small-scale grazing systems. In turns, the Milan Protocol (http://www.milanprotocol.com/), promoted at the 2015 EXPO in Milan, highlighted the great food paradox that "*a large portion of crop and food production is funneled into animal feed or biofuels despite the widespread hunger and undernutrition*".

* Corresponding author.
E-mail address: arianna.dipaola@cmcc.it (A. Di Paola).

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Over a decade ago, Smil (2002b) argued that the replacement of a relatively modest but cumulatively significant share of AP with PP in human diets could have great economic, nutritional and environmental benefits. Indeed, several works paved the promising path of a dietary shift, raising the issue of the sustainability of animal- vs. plant-source foods (Kastner et al., 2012; Pimentel and Pimentel, 2003; Baroni et al., 2007; Wirsenius et al., 2010; de Ruiter et al., 2014; Jalava et al., 2014) and exploring less resource-demanding animal products maintaining the relative contribution of non-feed systems (Davis and D'Odorico, 2015). However, these studies are mostly based on the metric of calories, despite the major source of inefficiency arises in the production of AP (which is expected to increase). Moreover, although a general consensus that IAFSs cause strong impacts on the environment (Aiking, 2011; Steinfeld et al., 2006; Pimentel and Pimentel, 2003; Thornton, 2010; Eshel et al., 2014), the question of feeding livestock with feed grains still remains controversial: on one hand it represents the most efficient feed (Herrero et al., 2013); on the other hand, it acts as the farming system that should not be promoted (Smil, 2014; Aiking, 2011) because of the food paradox and the strong environmental impacts.

In this study, we explicitly addressed the global costs of producing AP from intensive, highly efficient, grain-fed livestock in terms of area demand, water consumption and GHG emissions (hereinafter *environmental footprints*), and compared them the with costs of producing an equivalent amount of PP. Based on the global scale focus and the data availability, we confined the analysis to the agricultural production components.

We then moved the spotlight toward the actual per capita protein intakes in three representative regions (Northern America, Western Europe, and Eastern Asia) where IAFSs account for a great share of animal food production (Robinson et al., 2011; Steinfeld et al., 2006). In these regions, we found that the protein intake was higher than those recommended by the World Health Organization (WHO). Hence we postulated a set of straightforward hypotheses to shorten the average protein surplus (AP produced from IAFSs) and assessed the resulting amounts of area demand, water consumption and GHG emissions that could be virtually recovered.

Since our study is based on the metric of protein and considers the most efficient animal-source food production (i.e. from feed grains), we believe that our contribution would provide an additional insight into the human food vs. animal feed competition debate.

2. Methods

2.1. Environmental footprints

Fig. 1 summarizes the stepwise approach adopted to estimate the environmental footprints of both PP and AP. The whole procedure and the involved dataset are presented in detail in the Supplementary information (Sect. S1.1 and S1.2). Data sources (all available online) and their features are also reported in Table 1.

Overall, we hypothesized several feed mixtures and for each of them we estimated the Feed Area Demand (HA_F), Feed Water Footprint (WF_F) and Feed GHG Emissions ($GHG_{feeding}$) for unit mass by tracking back to the average yields, average water consumption and average GHG emissions related to the crops composing the feeds, on global scale (Fig. 1, big red box). Footprints of PP and AP obtainable from feeds were then derived from feed protein content (FPC) and feed conversion efficiencies (FCEs) of livestock, respectively. GHG footprints of AP were considered as the sum of the $GHG_{feeding}$ (i.e. the indirect sources due to crops composing the feed) plus the direct release from livestock management ($GHG_{farming}$, see Sect. S1.2 for details), because of the well assessed high impact of the latter (Robinson et al., 2011).

Global average yields were taken from FAOSTAT database (FAO, 2015) which provides values ($t \cdot ha^{-1}$) for around 160 crops and 14 crops' categories for several decades up to 2014 at country, regional and global level. Water consumptions were taken from the comprehensive work by Mekonnen and Hoekstra (2011), which quantified country to global scale green (from rainfall), blue (from irrigation) and grey (virtual polluted volume) water footprints ($m^3 \cdot t^{-1}$) of 126 global crops over the period 1996–2005 (data available on Water Footprint Network, WFN; www.waterfootprint.org). The total water footprint of selected crops is given by the sum of all three components (i.e. green, blue and gray). Data on average crop yields and water footprints are given in Table S1. Sources of GHG emissions associated with both feed production and livestock management (from FAOSTAT) are deeply presented is Sect. 1.2.

Feed Conversion Efficiency (FCE; Table 2) expresses the animals' ability to convert a generic feeding requirement of entire breeding, having about 15–21% of proteins (Smil, 2002b), into edible animal-source proteins. FCE is generally considered an intrinsic feature of the animal species, and it is related to the animal diet (Herrero et al., 2013). Generally, the composition of feeds varies depending on the livestock type to which it is intended for and the countries where it is produced (Herrero et al., 2013; Archimède et al., 2011). However, qualitatively similar mixtures of cereal grains and legumes (Sanders, 1999) are used in intensive animal farming: maize, barley, wheat or sorghum for energy needs, i.e. giving calories and having specific crop protein content (CPC) less than 15% (Table S1), and soybean or lupins for the protein requirements, having CPC above 35% (Table S1).

To be consistent with the definition of FCE, the protein content of a unit of feed mass should be somewhat constant and equal to approximately 20% (Smil, 2002b). Hence, we investigated eight possible feed mixtures (Table S3, see also legend in Fig. 2) composed of one energy and one protein crop (hereinafter C1 and C2, respectively), using a constant C1 to C2 ratio of 7:3. Due to the specific crop protein content (10–13% and 38%, for C1 and C2, respectively), such ratio provides a feed mass having about 20% of PP (i.e. 200 kg of PP per tons of feed mass).

The assumption of constant feed protein content (FPC) allowed us to approach the human food vs. animal feed debate from a new perspective. Instead of estimating the footprint for specific foods here we estimated the footprints for food categories under similar conditions (i.e. from qualitatively similar feed mixtures) making them comparable. Again, since the higher the quality of the livestock diet, the higher the efficiency of the feed conversion into AP (Herrero et al., 2013), the feed mixtures here investigated allowed us to focus only on intensive, highly efficient, livestock production (as done in IAFSs).

In this first analysis, we assumed that the area occupied by the farms as well as the direct water consumption for livestock activities (e.g. drinking of animals, maintenance of livestock farms etc.) are small enough when compared to the feed water and area demands so that they could be neglected (Mekonnen and Hoekstra, 2012).

Environmental footprints were estimated (see Sec. S1.1 and S1.2 in SI) as average values for the period 1996–2005 to maximize comparability among the reference periods of the involved dataset (see Table 1). Area and GHG footprints were also estimated for the period 2006–2012, but this was not possible in case of the water footprint due to the lack of updated data on water consumptions.

Environmental footprints of PP and AP were then compared showing their relative costs.

2.2. Opportunities for land recovery, water saving, and GHG emission reduction

Despite IAFSs represent a global issue, so that the impacts' calculation asks for the worldwide view, they are mostly located in industrialized, large and quickly emerging countries where they provide a great share of animal-source food (Robinson et al., 2011; Steinfeld et al., 2006). Thus, we analysed the actual daily per capita protein intakes (from *vegetal products total* and *animal products total* items in the Food Sheet Balance of FAOSTAT) for three representative regions defined by the FAO as: Northern America (United States of America;