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The role of farm animals in a circular food system

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ABSTRACT

If we use farm animals for what they are good at - converting by-products from the food system and grass resources into valuable food and manure - they can contribute significantly to human food supply, while at the same time reducing the environmental impact of the entire food system. By converting these so-called low-opportunity-cost feeds, farm animals recycle biomass and nutrients into the food system that would otherwise be lost to food production. Rearing animals under this circular paradigm, however, requires a transition from our current linear food system towards a circular one. Here we present a biophysical concept for the role of farm animals in a circular food system, essential for meeting dietary recommendations within the boundaries of our planet.

1. Introduction

Today's global food system has a major impact on the environment. It releases about a quarter of all human-induced greenhouse gases, is responsible for a third of global terrestrial acidification, the majority of global eutrophication, and covers 40% of the world's ice- and desert-free land (Godfray et al., 2010; Foley et al., 2011; Bajzelj et al., 2014; Pop et al., 2014; Crist et al., 2017; Springman et al., 2018; Willett et al., 2019). The world's animal sector dominates these human-induced emissions from the food system, being responsible for 56–58% of the total (Poore and Nemecek, 2018), and uses the majority of all agricultural land, including 40% of our global croplands (Mottet et al., 2017). This cropland is used to produce high quality feeds that we humans could also eat, such as cereals, resulting in a competition for land and other natural resources between feed and food production.

It is widely affirmed that the physical limits of the planet, albeit uncertain, set the ultimate boundaries for all human activity (Fisher et al., 2007; Steffen et al., 2015). A central question, therefore, is: what role, if any, do farm animals play in a planet-friendly food system? An increasing body of literature suggests that a reduction in consumption of animal-source food (ASF) in high-income countries is needed to reduce the environmental impact of our food system, which simultaneously would improve human health, (e.g. Springman et al., 2018; Willett et al., 2019). There is, however, no consensus about the degree in reduction of ASF. Some studies suggest that it would be best for the planet if we all become vegan (e.g. Poore and Nemecek, 2018), while other studies show that farm animals reared under a circular paradigm can play a crucial role in feeding humanity (Schader et al., 2015; Van Kernebeek et al., 2016; Röös et al., 2017; Van Zanten et al., 2018; Van Hal et al., 2019). These farm animals then would not consume human-edible biomass, such as grains, but convert by-products from the food system, that are inedible for humans, and biomass from grasslands into valuable food, manure and other ecosystem services (Van Zanten et al., 2018). Such farming requires a transition towards circularity in the food system and, therefore, a paradigm shift, as our current food industry is built around the linear extract-produce-consume-discard model. To enable a transition towards such circularity, we need a shared vision on what circularity in the food system entails (Termeer et al., 2017; O'Sullivan et al., 2018). Our aim here is to present the main principles of circularity in the food system, *with a special emphasis on the role of farm animals.* We acknowledge that biomass harvested from land or natural bodies of water can be used for many functions other than the growing of human food, such as the production of pharmaceuticals, functional biochemicals, fibre, or bio-energy. Here, however, we adopt the premise that food production will and must, in the short and medium term, have priority over other uses of biomass, such as the production of bio-energy, as energy can be generated also from the sun, wind, or running water, whereas biomass so far is the only source for food.

2. The biophysical concept of a circular food system and the role of farm animals

The concept of circularity originates from industrial ecology, which

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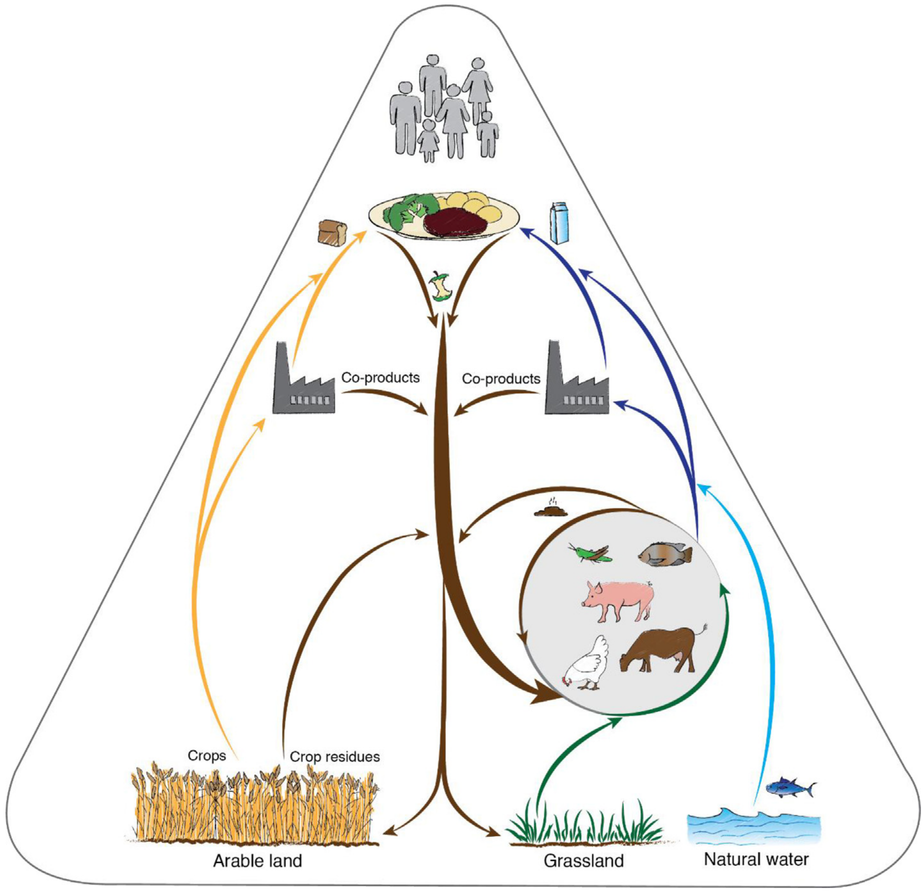

Fig. 1. The biophysical concept of circularity: arable land is primarily used for food production; biomass unsuited for direct human consumption is recycled as animal feed; by-products and manure are used to maintain soil fertility. In this way, nutrients are recycled and animals contribute to a circular food system, while sustainably feeding the future population.

aims to reduce resource consumption and emissions to the environment by closing the loop of materials and substances (e.g. Ghisellini et al., 2016; Jurgilevich et al., 2016). Under this paradigm, losses of materials and substances should be prevented, and otherwise be recovered for reuse, for remanufacturing, and recycling. In line with these principles, moving towards circularity in the food system implies searching for practices and technology that minimize the input of finite resources (e.g. phosphate rock and land), encourage the use of regenerative ones (e.g. wind and solar energy), prevent leakage of natural resources from the food system (e.g. nitrogen (N), phosphorus (P)), and stimulate reuse/recycling of inevitable resource losses (e.g. human excreta) in a way that adds the highest value to the food system (Ghisellini et al., 2016; Jurgilevich et al., 2016). A completely circular food system, however, may be a utopia, as our food system is, due to its openness and complexity, inherently associated with material and nutrient losses, which are partly impossible to recover, and will remain so in the foreseeable future.

Fig. 1 illustrates the biophysical concept of circularity in the food system. Below we explain this concept and explain why plant biomass is the basic building block of a circular food system, and why we can make most effective use of farm animals by using them to unlock biomass inedible for humans into valuable food, manure and other ecosystem services.

2.1. Plant biomass is the basic building block of a circular food system

In a circular food system arable land is used primarily to produce nutritious foods from plant biomass that fulfil the nutritional requirements of humans (not only proteins and calories but also essential micronutrients such as vitamin B12, iron and zinc). During the production and consumption of foods from plant sources several by-products are produced, such as crop residues, co-products from industrial food processing, food waste, and animal and human excreta. These by-products can be edible or inedible for humans. If we consume bread, for example, we also produce straw and husk (i.e. crop residues from cereal production), wheat middlings (co-product from flour production), bread waste and human excreta. As our first priority, we should prevent human edible by-products, such as food losses or food waste. Unavoidable human edible by-products should be reused as human food wherever possible (i.e. use wheat middlings in muesli). Only once such options have been exhausted should they be recycled in the food system – together with by-products inedible for humans (e.g. straw, husk and human excreta) – in order to maintain or improve the soil and fertilise crops, or to feed animals. All these products contain carbon and valuable nutrients, albeit in very different ratios, which makes them valuable as a source of energy or protein, micronutrients or structural material. The choice of our future crops and their rotations should thus be based on their main and by-products and their food value for humans and non-food value for the soil or farm animals.

To secure soil quality, by-products could be used to feed the soil and fertilise the crop. But another option is to first feed these by-products to farm animals to produce ASF for humans, and subsequently recycle the animal and human excreta to the soil. In this way, we could produce ASF and also maintain soil quality. However, as long as animal production is associated with carbon and nutrients losses (e.g. methane and ammonia), we might want to feed some by-products, especially those with a low nutritional value for animals, immediately to the soil, and others to animals first. The precise value of each by-product for either the soil or the animal is a new and an evolving area of research.

It is also necessary to investigate the challenges of using organic instead of mineral fertilisers, as recycling of by-products as fertilizers is a condition and not an option for a circular food system. Unlike in mineral fertilizers, nutrients in organic fertilizers can only be taken up by roots after the organic material has mineralised and their release, therefore, might be poorly synchronised with crop demand, increasing the risk of losses. Moreover, the composition of organic fertilizers, certainly unprocessed ones, is highly variable across farms and seasons, and as such does not always match the requirements of the plants, which also results in risks of losses. Finally, nutrients are highly diluted in organic fertilizers, are available in fixed ratios which may not necessarily match crop requirements, and might be contaminated. Ultimately, to address these challenges, research and industry need to focus more on developing new strategies to improve the quality and composition of organic fertilizers. At the same time, we do know that by-products do not bring in new nutrients into the food system, and that zero-emission agriculture is not realistic, implying that additional nutrients from industrial processing or biological fixation are needed to sustain the food system. Using only nitrogen from biological fixation, by inclusion of legumes as food crop or as green manure in cropping systems, however, requires additional land. If we want to avoid this additional land use, why not use some mineral nitrogen produced with renewable energy?

2.2. Use animals for what they are good at

By recycling by-products and biomass from grasslands (further referred to as low-opportunity cost feeds) into the food system, farm animals can play a crucial role in feeding humanity. Initial estimates show that this route can provide up to one third (9–23 g) of the daily protein needs of an average global citizen (~50–60 g; Van Zanten et al., 2018), without using additional arable land, as arable land is used for the production of food instead of feed crops. The potential role of aquatic biomass in such a circular food system has not been studied so far. Schader et al. (2015), however, do give a first indication about the potential contribution of captured fisheries, which amounts to ca. 2 g of protein per person per day. The contribution of captured fisheries to the global protein supply, therefore, seems limited by the biophysical boundaries, but it can be extremely important in specific areas and in the provisioning of omega-3 fatty acids, such as docosahexaenoic (DHA) and eicosapentaenoic acid EPA. Similar to land, however, humans could move to harvesting biomass from water at a lower trophic level. We could shift our focus from consuming fish species, such as salmon and cod, to seaweeds, mussels, and clams.

In conclusion, although recent studies did show that farm animals can play a role in a circular food system, we do not know exactly how much food could be derived from farm animals fed solely with low-opportunity-cost feeds: this will depend on the quantity and quality of by-products and grass resources available for animals, the type of animals and how efficiently farm animal utilize these feed and the development of new technology. These factors are discussed below.

2.3. Which low-opportunity-cost feed costs are available for farm animals?

The volume of by-products available for farm animals depends on a number of factors. First, the type of food crops cultivated, which ultimately depends on the human diet and the potential to fundamentally change this diet. A shift from white to brown bread, for example, would change the quantity of wheat middlings available. Second, the availability of food losses and waste, which depends on the potential to avoid creating them altogether. Third, the use of by-products for other functions, such as soil quality, generation of bio-energy or production of pet food, which also includes normative decisions. An example of such a normative decision is the use of food waste as animal feed. Many countries, including the European Union, currently ban the use of food waste as animal feed due to potential risks for animal and human health. There is evidence, however, that feeding food waste to animals, especially to monogastric animals, can be safe when heat-treated (Zu Ermgassen et al., 2016).

Finally, the extent to which global grassland can be used is important. If we would feed ruminants solely on biomass from current global grasslands, they could potentially produce about 7 g of protein per person per day (Schader et al., 2015; Van Zanten et al., 2016). Even though ruminants can create nutritional value from grassland, they also emit significant amounts of greenhouse gases, including methane. Some argue that at a local level methane emissions might be offset by the potential to increase carbon sequestration in grass-based ruminant systems. A recent comprehensive study found however that – although there is potential for significant sequestration in certain localized situations – at an aggregated global level, the potential benefits from sequestration are substantially outweighed by the animal's methane and other emissions (Garnett et al., 2017). As long as grass-based ruminant systems emit methane and nitrous oxide while grazing, there will be inevitable trade-offs between grassland use for food production and related greenhouse gas emissions. There may also be a trade-off between grassland use and biodiversity loss, depending on, among others, the grazing pressure. This discussion clearly demonstrates the opportunity costs implied when rearing animals on grasslands, and shows that not all grass biomass can be considered a free resource. What is lacking is a systems view on alternative uses of the world's grasslands with respect to food and bio-energy production, and the possibilities of rewilding (Newbold et al., 2016; Svenning et al., 2016).

2.4. Which farm animals use what feeds most effectively?

Different farm animals have different capacity to convert by-products and grass resources into valuable food for human consumption. Pigs, for example, were (and in some countries still are) used to convert food waste as they eat most foods which are also consumed by humans and can consume food with a high moisture content. But might feeding food waste to chickens, farmed fish or insects not result in relatively more animal product, pound for pound? Insects, for example, have potential to convert low-opportunity-cost feeds more efficiently into food than livestock, as they have higher reproduction rates and no energy allocation for the maintenance of a constant body temperature (Parodi et al., 2018).

Besides the species, the ability of various animals to efficiently convert low-opportunity-cost feeds into food for humans is also affected by the breed and their productivity level. There are animals which are bred to be highly productive on high-quality feeds that may be less suited to utilize low-opportunity-cost-feeds. This means we need to rethink the concept of resource-use efficiency in the feeding and breeding of animals, and consider a focus on conversion efficiency of biomass that is not edible for humans. We also need to explore the question of allocation: which low-opportunity feeds are available in a given setting, and which animals should receive these to maximise production of food from animal sources while minimising emissions that affect water, soil and air quality.

2.5. What potential role does technology play within a circular food system?

A hitherto underexposed potential is the contribution of technological development to circularity of food systems. The biological treatment of rice or wheat straw with fungi can, for instance, significantly improve the nutritional value for ruminants, and generally improve the quality of low-cost feeds (Khan et al., 2015). Moreover, microbes like bacteria, yeast, fungi and algae can also produce microbial proteins industrially. These proteins can replace conventional feed but also food, on a large scale and, thereby, save cropland area (Pikaar et al., 2018). Similarly, biorefinary can be used to segregate grass into protein and fibre. The resulting proteins can still be consumed by cattle, but are also highly suitable for pigs or poultry, or can even be processed directly into food suitable for humans. This leads to the question of whether we should feed those microbial proteins and grass protein to poultry, pigs, insects, dairy cattle or fish, or whether it would be better to invest in initiatives for making it directly edible for humans. Technological developments offer the potential to up-scale production levels of novel protein sources and can therefore increase our ability to produce significant volumes of underexploited protein sources. . A recent review showed that compared to ASFs novel protein sources such as insects, seaweed, mussels or cultured meat, have major environmental benefits while still safeguarding the intake of essential micronutrients (Parodi et al., 2018). The disadvantage of most novel protein sources is in general that their production requires a lot of energy, emphasizing the need of using renewable energy sources in food production.

3. Discussion

Feeding farm animals primarily low-opportunity-cost feeds will affect the availability of ASF for human consumption. Initial studies show that farm animals fed solely with low-opportunity-cost feed can produce up to 23 g of protein per person per day (Van Zanten et al., 2018). The average protein supply from animal source food in Europe is 51 g per person per day, implying that moving towards circularity would require a substantial reduction in ASF consumption. The exact reduction in the consumption of ASF and the preferred ASF in high-income countries, however, needs more research, as this depends on the combination of factors described above. In low-income countries the consumption of ASF is still likely to grow. The average supply of animal protein in Africa, for example, is currently only 13 g per person per day. Increasing the consumption of ASF in Africa, especially in households where diet diversity is low and malnutrition is high, will make an essential contribution to human nutrition. Farm animals in these low-income regions, moreover, not only contribute to food security by supplying essential nutrients, but also by providing manure, traction, income, gender equality, insurance and financing (FAO, 2016). The need for decreasing the consumption of ASF in high-income countries while stimulating an increase in consumption of ASF in low-income countries is also recognised in other recent studies, such as Willett et al. (2019). A modest consumption of ASF across the world will benefit the environment and human health simultaneously.

To direct us towards animal farming that contributes to a circular food system, we are in need of (a smart combination of) new metrics. At present, product footprints are generally increasingly used by industry and society to reduce the environmental impact of food production. Product footprints, however, do not encompass the full complexity and circularity of food systems as they do not address interlinkages within the food system or the issue of feed-food-fuel competition. The current product footprint approach, therefore, does not direct us towards a circular food system, especially not in the field of animal farming. Feeding more concentrates instead of roughage to cattle, for example, would reduce the footprint of beef (De Vries et al., 2015), but at the same time increase feed-food competition and thus increase the land use of the entire food system (Van Zanten et al., 2018). Similarly, the use of animal manure in cropping is not necessarily more resource use efficient at the crop level (indeed, sometimes less efficient) than the use of mineral fertilizers (Schröder et al., 2010). Yet, at the level of the entire food system, it is efficient to utilize manure instead of mineral fertilization. To account for circularity in environmental impact assessments we therefore need a food systems approach to develop new metrics to get insight in e.g. feed-food competition, the use of new P in production chains, emission ceilings, or dietary recommendations (protein, carbon and essential nutrients) related to the consumption of ASF. Such metrics, however, should also account for eco-system services as livestock in low and middle-income countries often have multiple purposes contributing to different dimensions, such as gender balance, as well as to jobs and economic growth. Furthermore, metrics need to be developed at different scales (farm, region, product), to identify viable strategies to shape the role of animals in specific food systems. The scale at which we may target to close nutrient loops is determined by the interaction between various factors. Differences in agroecological and socioeconomic circumstances, for example, make some areas more suitable to producing certain types of food than others. These advantages may outweigh the emission impact of transport, implying that locally produced food may not always be the best choice from an environmental perspective. Closing nutrient loops also requires that new interactions are built between components of the food system, for example between cities and rural areas where food is produced. Cities are inevitably sources of large amounts of food waste and human excreta, which could be used as valuable nutrients for food production in urban farming systems that combine plant, insect and fish production. The optimal scale at which nutrients should be recycled in the food systems remains context specific, and requires an integrated analysis of the above mentioned factors.

Although nobody knows exactly how to move towards a circular economy, we most likely need a mix of socio-economic and institutional measures, such as true pricing, subsidising sustainable initiatives, increasing taxes on use of finite resources while lowering taxes on labour, labelling, legislation enabling safe recycling of food waste as animal feed, and clear emission ceilings. These measures must go hand in hand with education and transparent information to increase awareness of the unsustainability of our present food system and to change social norms and values in favour of more sustainable practices. We might even want to rethink our definition of economic growth. Should gross domestic product (GDP) remain the basic measure of our economy? Considering that we live on a planet with finite resources, we cannot increase our economic growth and associated material consumption indefinitely as this will eventually cause catastrophic changes to the Earth's ecosystem. Rethinking economic growth will clearly have implications for the prices paid to farmers, and most likely increase food prices, and the share of income we spend on food. Moving towards circularity in food systems may therefore require rethinking our definition of quality of life.

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