nature food

Matters arising

https://doi.org/10.1038/s43016-025-01116-z

Estimating low-opportunity-cost feed

Received: 14 November 2023

Accepted: 13 January 2025

Published online: 10 February 2025

Check for updates

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ARISING FROM Q. Fang et al. *Nature Food* https://doi.org/10.1038/s43016-023-00813-x (2023)

Global demand for animal feed, driven by growing meat consumption, has resulted in deforestation, carbon emissions and biodiversity loss, underscoring the need to improve the environmental sustainability of feed production[1]. Fang and colleagues[2] developed a linear feed allocation optimization model and estimated that feeding more low-opportunity-cost products (LCFs), such as food waste and by-products, to animals in China could have substantial land-use-related environmental benefits. While their study contributes to advance research on sustainable feed alternatives, we question some of the key assumptions underpinning their model and note important discrepancies between some of their predictions and observations.

Feed conversion ratio

The feed conversion ratio (FCR) from the model developed by Fang and colleagues[2] differs considerably from what has been observed in different countries. FCR is the amount of feed (dry matter) used per unit of live weight gain, an important determinant of the extent of commercial feed that LCFs can replace and the resulting land savings. Fang and colleagues[2] predicted FCRs in pig production for medium and industrial systems to be 26–42% lower than the ones observed in China during the same period as well as in other countries (Table 1). This discrepancy is notable and cannot be explained by typical variation, considering, for instance, that from 2000 to 2015 the FCR of China's medium and industrial systems decreased by only 7% (ref. 3), and from 2013 to 2019 the FCR of fattening pigs in the European Union decreased by just 1% (ref. 4).

The difference described above may result from simplifications of the model, which is set to meet animals' energy and protein requirements. Although Fang and colleagues[2] acknowledge that feed should meet the protein requirements for animal production and management, they only consider the crude protein content. Yet, the protein quality of feed depends on the content and digestibility of essential amino acids such as lysine and methionine, which are limiting factors for animal growth and development[5]. More importantly, this simplification may compromise the model's ability to simulate impacts of feeding more LCFs on animal productivity. For example, even with similar crude protein levels, a diet that includes LCFs can lead to reduced growth rates and feed efficiency due to deficiencies in essential amino acids[6].

Another reason for the FCR discrepancy may be the overestimation of feed amount and nutritional content by Fang and colleagues[2]. Supplementary Table 11 of their study shows that food waste added to animal diets further reduces the FCR, such as a 10% reduction in the industrial pig system; this may be partly because they assume that food waste from the distribution and consumption stages has the same nutritional content and quality as the original food types, making it comparable to commercial feed. This assumption needs to be made clear and its validity is debatable. In the food waste-to-feed chain, food waste is susceptible to fermentation, microbial (mould) growth and deterioration. These factors, along with the necessary conversion processes, can result in a reduction and alteration of its nutritional content, as well as a decline in quantity[7,8]. Additionally, the amount of fish meal used for terrestrial animals in China in Fang and colleagues' study[2] (approximately 9 Mt) seems overestimated, as global fish meal production is only about 5 Mt, with over 75% used mainly for aquaculture[9]. In fact, there may be other, more complex factors that can cause the model-predicted FCRs to differ from the observed FCRs, such as potential interactions between feeds[5] and the high fibre content of LCFs[10]. More experiments and empirical studies are needed to shed light on the impact of FCFs on animal productivity and help improve modelling work.

Land savings and food waste

Fang and colleagues'[2] estimates of 'land-saving benefits' might not be solely attributable to LCFs, as suggested in their paper, but also to structural optimization. This is because the business as usual (BAU) scenario and alternative scenarios in their model have different optimization objectives: the former aims to minimize the difference between the total feed supply during 2009–2013 and the calculated total feed usage (model results) through feed allocation, while the latter aim to minimize the cropland area used for feed supply through feed allocation. As a result, alternative scenarios involve not only feeding more LCFs but also a structural optimization of the entire feed system. Thus, even without increasing the use of LCFs, alternative scenarios may still demonstrate land-saving benefits. Hence, land savings in alternative scenarios must be described cautiously in order to avoid overestimating the potential of LCFs.

The sensitivity analysis conducted by Fang and colleagues[2] provides additional insights into the impact of key assumptions on model outcomes, showing that the amount and nutritional content of food waste have a small impact on the land-saving benefits of the LCFs.

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https://doi.org/10.1038/s43016-025-01116-z

Table 1 | Observed FCRs versus model-predicted FCRs for different pig production systems

Study	Method	Area	Year	Traditional (kg kg^{-1})	Medium (kg kg^{-1})	Industrial (kg kg^{-1})
Fang et al.[2] (scenario BAU)	Linear optimization model	China	2010	3.8	2.0	2.0
Fang et al.[2] (scenario S1)	Linear optimization model	China	2010	4.3	1.9	1.8
USDA[13]	CNDRC data	China	2006–2015	4.3	3.1	3.1
Wang et al.[3]	Nationwide sampling and survey	China	2012	3.0–4.0	2.7–2.9	2.7
Our calculation	CNDRC data	China	2020	3.2	3.0	3.0
National Pork Board[14]	Industry survey	United States	2020	NA	NA	2.6
ADHB Pork[15]	Industry survey	United Kingdom	2018	NA	NA	2.5

For consistency, all references reported production system classifications consistent with Fang et al.[2]. FCR is expressed as kilograms of feed dry matter per kilogram of live weight gain (kg kg^{-1}). China's National Development and Reform Commission (CNDRC) provides pig feed consumption data (excluding roughage) in ref. 16, based on provincial sampling surveys. AHDB Pork is a division of the UK Agriculture and Horticulture Development Board. NA, not applicable.

However, this might be an artefact of the nature of the optimization model rather than a reflection of the importance of key assumptions. In sensitivity analysis, any change in a single variable prompts the model to redesign the feed structure for each animal category and production system in the entire livestock industry to minimize overall cropland use. Consequently, this may obscure the true impact of changes in the amount and nutritional content of LCFs on animal production.

Finally, the assumption by Fang and colleagues[2] that a large fraction (~39%) of food waste—from the distribution and consumption stages—is currently used as animal feed, and that an even greater fraction would be plausible, seems questionable. The authors state that South Korea and Japan use food waste as feed at high rates, but neither country utilizes food waste to that extent. In Japan, only 7.6% of food waste from the distribution and restaurant stages, and virtually none from households, is converted to feed[11]. In South Korea, only 8.4% of food waste ends up as pig feed[8], and only 1% of pigs are fed with food waste[12]. Two reasons might explain this difference. First, the definition of food waste varies by region. In Japan, for example, food waste includes 'manufacturing stage waste like soybean meal', which, if included, would indeed mean 40% or more of its total food waste is repurposed as animal feed[11]. Yet, food waste in Fang et al.'s paper[2] is defined as only that from the distribution and consumption stages (retail, food services and households). Second, the availability of food waste as feed is low. For example, in South Korea, most food waste entering feed recycling facilities is discharged as food wastewater during treatment, with only 4% of the nation's food waste ending up as pig feed after processing, reaching 8.4% when including direct feeding[8].

In conclusion, Fang et al.'s[2] new approach to quantifying the environmental benefits of LCFs enriches current work on sustainable agriculture. However, modelling the application of LCFs is a complex task. Future analyses should focus on improving models' predictive accuracy and bridging the knowledge gap between LCFs and animal productivity, especially through more experiments and empirical studies. This will substantially enhance our ability to identify and implement effective policies and actions.

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Author contributions

Y.G. and Y.Y. designed the research, Y.G. conducted the analysis and wrote the first draft, and Y.Y. contributed to writing and editing.

Competing interests

The authors declare no competing interests.

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https://doi.org/10.1038/s43016-025-01116-z

Peer review information *Nature Food* thanks Marica Areniello, Ling Zhang and the other, anonymous, reviewer(s) for their contribution to the peer review of this work.