CLIMATE CHANGE

Manure management benefits climate with limits

Improving manure management can reduce nitrous oxide (N_2O) emissions, but its impacts on indirect N_2O emissions and other greenhouse gases need to be assessed. Structural changes that address livestock demands and spatial planning are needed.

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Livestock is one of the most important sources of protein for humans, but has profound impacts on climate change — contributing 15% of anthropogenic greenhouse gas (GHG) emissions[1]. A considerable fraction of livestock emissions comes in the form of nitrous oxide (N_2O), a potent GHG and a major cause for ozone depletion, ranging from 12% to 29% in the literature[1,2]. However, quantifying these sources and associated mitigation opportunities is challenging given the large spatial and temporal heterogeneity in N_2O emissions and technical difficulties in measurement[3].

Writing in *Nature Food*, Xu and colleagues[4] report that they have leveraged recent progress in region- and practice-specific emission factors, activity data on manure management, and nutrient flow modelling. The authors provided what is, so far, the most detailed, spatially explicit and long-term account of N_2O emissions from livestock manure in China (from 1978 to 2017). Although N_2O emissions continue to increase, the study reveals a promising sign that the increase is slowing, mostly attributable to lower population growth and decelerated shifts towards meat-dominant diets.

With the detailed N_2O inventory, Xu and colleagues quantified mitigation potential using several manure management technologies, namely low crude protein feed (LCP; reducing manure nitrogen by 13%), anaerobic digestion (AD), composting, and combined AD and composting. These technologies can reduce N_2O emissions by 23–71 Gg yr^{-1} by 2030, representing important opportunities for climate change mitigation. However, this reduction is still less than the projected 111 Gg yr^{-1} increase in N_2O between 2017 and 2030, which is mainly driven by increased livestock production. These findings resemble the Jevons paradox[5], according to which efficiency improvements to reduce emissions are not sufficient to offset emissions rise due to the increase in total production.

Xu and colleagues found that the cost of these mitigation opportunities varies widely

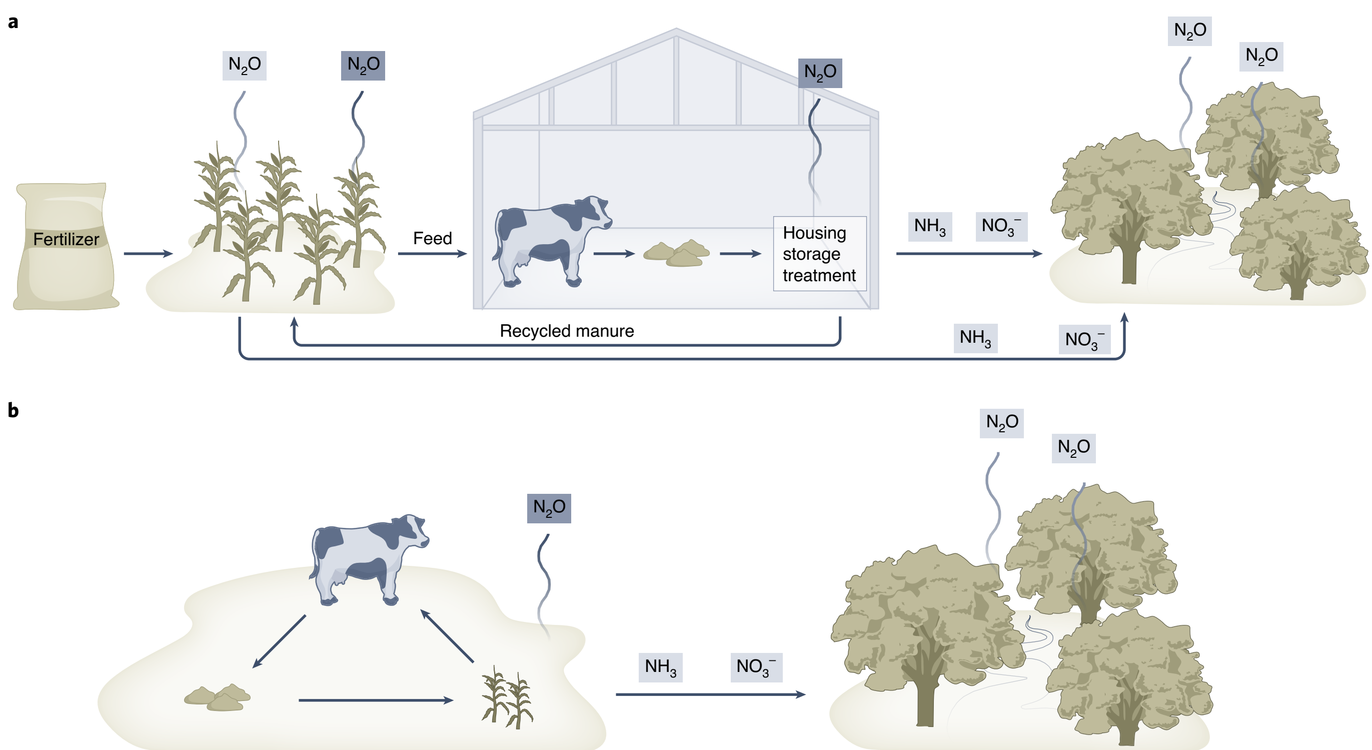

Fig. 1 | N_2O emissions associated with livestock production. a,b, N_2O emissions are shown in concentrated feeding operations (**a**) and in a grazing system (**b**). N_2O emissions highlighted in dark grey were quantified by Xu and colleagues[3], whereas N_2O emissions in light grey were not. On the left side of **a**, the N_2O in light grey denotes the N_2O emissions during the production and application of fertilizer. Other GHGs are not included.

among livestock types and technologies. About 19 Gg yr^{-1} of N_2O can be reduced without additional cost, mainly through implementing AD and composting for poultry, AD for sheep and goats, and composting and LCP for dairy cattle. However, moving beyond this 19 Gg yr^{-1} of N_2O mitigation opportunity, the unit cost for N_2O mitigation increases significantly. The overall implementation costs range from US$5.5 billion to 6.0 billion (ref. [4]), while the corresponding N_2O reduction could be valued at US$0.5–1.6 billion in the carbon market even with a target price at US$75 per ton (ref. [6]). Therefore, Xu and colleagues' assessment highlights the importance of prioritizing the implementation of existing technologies for different livestock types, and indicates the necessity for developing more cost-effective manure management technologies for climate impact reduction.

Overall, the analysis by Xu and colleagues focused on direct N_2O emissions from livestock manure, and demonstrated that related manure management technologies have a positive but limited impact on climate. However, this conclusion could change if indirect N_2O emissions and other GHG emissions were considered. In addition to the direct emissions accounted for by Xu and colleagues, manure management may affect N_2O emissions in two ways (Fig. 1). First, manure nitrogen emitted in other forms of reactive nitrogen (mostly ammonia (NH_3) and nitrate (NO_3^-)) may be converted to N_2O during denitrification or nitrification processes in the environment[7]. This part of indirect emissions can be affected by manure management technologies; for example, AD and composting both increase manure nitrogen emission in the form of ammonia by 50%. Second, a large fraction of the livestock-driven N_2O emission is from the use of synthetic fertilizer for feed production[8], and manure management technologies can potentially reduce this fraction if more manure nitrogen is recycled back to cropland instead of being wasted (thereby replacing synthetic fertilizer nitrogen input).

Besides N_2O emissions, manure management technologies may impact climate through other routes. For example, some technologies (such as LCP) affect methane (CH_4) emissions from ruminant animals, and the treatment of manure may generate CH_4 to be used as energy and/or reduce carbon dioxide (CO_2) emissions for transportation. Recycling manure to cropland may have added climate value when it reduces the use of synthetic nitrogen fertilizer, an energy-intensive product[9]. The increase in productivity may potentially relieve pressure on agricultural expansion and consequently reduce CO_2 emissions from land-cover change if the demand for livestock does not grow with improved productivity.

Indeed, conducting a comprehensive impact assessment of manure management on climate is challenging, especially as indirect emissions carry lots of uncertainties and are difficult to monitor. Yet it is a crucial next step to guide mitigation efforts in the livestock sector, and recent studies such as the one by Xu and colleagues are an important contribution in that direction.

Although the jury is still out for the scale of climate benefits from manure management, its co-benefits for mitigating air and water pollution have been made abundantly clear[10,11]. In China, livestock production has become increasingly dense and closer to population centres, resulting in the exposure of over a billion people to intense NH_3 and NO_3^- emissions[12]. Therefore, improvements to manure management must be motivated by the need to not only combat climate change but also, or even more strongly, reduce the damage to ecosystem and human health caused by nitrogen pollution.

Livestock is an inefficient system to convert nitrogen from vegetal into animal protein, and 50–90% of nitrogen taken by livestock will be excreted as manure. Therefore, the fate of manure nitrogen — that is, whether it is emitted to the atmosphere, leached to the water ways or recycled to cropland — governs the environmental impacts of livestock production, including the impacts on climate change. Technological improvements in manure management can reduce N_2O emissions per unit of livestock product, as demonstrated by Xu and colleagues, but the emission reduction and efficiency gain can be overwhelmed by continuous increase in livestock demand and disconnected crop–livestock production. Management may also have complex impacts on other GHG emissions and nitrogen pollution. Therefore, improving manure management is important to address the triple challenge of food security, climate change and environmental degradation, but must be accompanied by structural changes considering the production and consumption levels of livestock products, as well as better spatial planning to enable recycling. ❐

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Competing interests

The authors declare no competing interests.