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Published in:
Journal of Agricultural Science

DOI:
10.1017/S0021859622000120

First published: 06/04/2022

Document Version
Peer reviewed version

Link to publication

Citation for pulished version (APA):
Zhou, Y., Jain, N., Jha, G. K., & Begho, T. (2022). Nitrogen pollution from cattle production in India: A review of the social, cultural and economic influences. *Journal of Agricultural Science*, *160*(1-2), 98-106. https://doi.org/10.1017/S0021859622000120

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Nitrogen pollution from cattle production in India: A review of the social, cultural and economic influences

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Received: 2 January 2022

Revised: 6 March 2022

Accepted: 29 March 2022

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Abstract

Livestock plays a crucial role in food and nutrition security. However, livestock production accounts for 0.18 of global greenhouse gas emissions. India has one of the highest livestock densities globally, mainly produced under traditional systems. Specifically, the emission and particularly nitrogen losses from cattle in traditional systems cannot be ignored. Nitrogen emission is substantial when cattle roam free and waste is not collected or managed efficiently. This paper reviews the literature to piece together the available information on nitrogen

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DOI: 10.1017/S0021859622000120

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emissions from cattle in India to synthesise the evidence, identify gaps, and contribute to further understanding of the problem. At the same time, the paper highlights the solutions to reduce nitrogen pollution from cattle production in India. The main findings are that most cattle in India are not reared to provide meat protein. The implication is that reactive nitrogen per capita consumption is lower than most developed countries. However, there are substantial inefficiencies in feed conversion, feed nitrogen use, and manure management in India. As a result, nitrogen losses and wastage are considerable in the different production systems. Furthermore, the review suggests that social, cultural, and economic factors such as convergent social behaviour, urbanisation, regulations, changing consumption patterns, the demand for cheap fuel sources, culture and religion influence the production systems and, consequently, the emissions from livestock. Suggested solutions to reduce nitrogen pollution from cattle production in India are improving livestock productivity, adopting better feeding, manure and pasture management practices and using behavioural nudges.

Key words: Environment, livestock, reactive nitrogen, emission, sustainable management, waste

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Introduction

Agriculture, including livestock farming, is one of the main contributors to human-induced climate change (Prasad *et al*., 2020). There are enormous benefits of agricultural intensification in terms of providing an adequate food supply for the growing population of developing countries. However, the flip side is that there are associated consequences with inefficiencies. Evidence suggests that agricultural emissions have increased over the past decades (Lassey & Harvey, 2007; Thomson *et al*., 2012). The Indo-Gangetic Plain has been reported to be an area high in gaseous nitrogen pollutants such as ammonia (NH_3) and nitrogen oxides (NO_x) deposition (Clarisse *et al*., 2009; Singh *et al*., 2016). In addition, an important (non-GHG)

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pollutant which is mainly from agriculture and has a significant effect on ecosystems is ammonia (NH_3). The majority of agricultural NH_3 is from livestock manure (Galloway *et al.*, 2008; Kavanagh *et al.*, 2019; Sommer *et al.*, 2019). Among the greenhouse gas (GHG) that contribute to climate change, nitrous oxide (N_2O) is one of the most potent. Per molecule, the global warming potential of N_2O is over 264-310 times more than that of CO_2 (IPCC, 2014). Of concern is that agriculture is the largest source of N_2O (Reay *et al.*, 2012). Besides the gaseous nitrogen emissions from livestock farming systems, agriculture contributes to methane (CH_4) emissions (Lassey, 2008). The global warming potential of CH_4 is more than 25-34, greater than CO_2 (IPCC, 2014). Livestock are responsible for 0.30 of global CH_4 emission, and about 0.36 of global emissions of enteric CH_4 is from Asia, and India is one of the main contributors (FAO, 2021).

India is the second-largest contributor out of the four countries responsible for 0.47 of the global reactive nitrogen (Nr) emissions (Oita *et al.*, 2016). The gradual accumulation of Nr due to increased human activities has impacted air and water quality, human health, soil health and biodiversity (Aneja *et al.*, 2009; Singh & Singh, 2008). Also, nitrogen pollution causes damage to the aquatic environment. There is evidence that anthropogenic emissions of nitrogen have resulted in ecological damage along much of India's coastline (Abrol *et al.*, 2017). Globally, there is increasing awareness of the polluting potential of nutrients when used inefficiently. However, this concern has not been sufficiently reflected in policies, particularly in developing countries (Kanter *et al.*, 2020a; Kanter *et al.*, 2020b).

India has one of the highest livestock densities globally but also has interesting peculiarities. For example, despite having the largest cattle herd of all countries, the human population consists of many vegetarians (0.31). Farmers in India mainly keep cows for dairy products (Kumar & Kapoor, 2014; Phillips, 2021). In India, the total emission from livestock is approximately 222.7 million tons of CO_2e (MoEFCC, 2021). Besides, the efficiency and

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productivity of cattle in India is reportedly among the lowest globally (O'Mara, 2011; Manoj, 2015). Hence, justifying the importance of addressing the livestock nitrogen pollution in India. This paper aims to piece together the available information on livestock nitrogen emissions, focusing on highlighting the solutions to reduce nitrogen pollution from cattle production in India. Specifically, the study reviews the literature on the scale of nitrogen pollution in India, the consequences of nitrogen pollution, nitrogen transaction related to different production systems, the factors that drive nitrogen losses and the sustainable solutions to the problem.

The review approach used in this paper is narrative. The goal is to present an overview, clarify present knowledge, draw attention to the issue and highlight the contributions of different studies towards a cumulative understanding of nitrogen pollution from cattle production in India. The rest of the paper is structured as follows. Section 2 discusses the agricultural sources of nitrogen pollution in India. Section 3 reviews the social, cultural, and economic dimensions. We discuss the solutions to reduce nitrogen pollution in section 4. Finally, sections 5 and 6 present the future perspectives and conclude the paper, respectively.

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The agricultural sources of nitrogen pollution in India

The scale of nitrogen pollution cannot be highlighted without a discussion of nitrogen losses that accrue from crop production. In India, just as it is globally, nitrogen is lost due to poor management of chemical fertiliser and livestock manure during crop production. In 2015-2016, India accounted for approximately 0.16 of the global nitrogen fertiliser production (Abrol *et al.*, 2017). At the same time, the country relies heavily on the use of fertiliser to increase crop yields (Andrews & Lea, 2013). Due to rapid population growth and the consequent increase in food demand, India's nitrogen fertiliser use is growing at a rate of 1.96%, almost equal to the population growth rate. This fertiliser use could continue to increase at current trends (Andrews & Lea, 2013). In addition, chemical fertiliser is also used to grow livestock fodder and feed.

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As with many countries globally, nitrogen fertiliser is used inefficiently for crop production in India. In India, the average nitrogen use efficiency (NUE) which broadly refers to as nitrogen harvested yield per unit of nitrogen input for cereal was 0.21 (Omara *et al*., 2019), full crops NUE was approximately 0.22, while the chain-wide NUE (including livestock) was 0.20 (Andrews & Lea, 2013).

In monetary terms, the huge cash subsidies (~0.75 in the case of urea) associated with nitrogen fertilisers place a strain on the country's financial resources. Because of the large subsidy on nitrogen fertilisers, Indian farmers tend to use more urea (Fishman *et al*., 2016). It is estimated that India loses Nr worth US$10 billion per year as fertiliser value (Ladha *et al*., 2020). However, substantial environmental and economic benefits could be derived by increasing NUE through moving from imbalanced nitrogen use to a more sustainable use across India.

Globally, livestock accounts for a significant proportion of anthropogenic GHG emissions (Gerber *et al*., 2013). The main activities contributing to GHG emissions in livestock farming are enteric fermentation and manure management. In India, seasonal variation has been observed in N_2O flux from manure. For example, Gupta *et al*. (2007) reported higher flux in the rainy season. They attributed such changes to both the feed of the animal and how the manure is stored in conjunction with the environmental conditions. Also, the bovine population of over 303 million in India can produce 995 million tonnes of manure. Therefore, livestock manure contributes substantially to NH_3 emissions. This could be as high as 0.56 from cattle in India (Aneja *et al*., 2012; Abrol *et al*., 2017). These statistics make India one of the largest sources of NH_3 emission globally (Rath & Joshi, 2020). Further, it highlights that manure mismanagement should be a major focal point in the discussion to reduce GHG emissions and climate pollutants from cattle production.

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Livestock Production Systems in India

The pathways for environmental emission from cattle production in India cannot be examined without understanding the livestock production systems. In India, the predominant system is traditional feeding and cattle management practices (Manoj, 2015; Deb, 2015). Traditional livestock production systems consist of grassland-based systems (traditional pastoral and agro-pastoral systems) and mixed or integrated farming systems. Pastoral systems are predominant in arid and semi-arid zones of India's e.g., Rajasthan, Gujarat, Haryana, and Ladakh regions. Pastoral systems are also prevalent in the humid and sub-humid regions of the Himalayas, including the North-eastern hills of India. About 0.04 of agricultural land is under these systems (Deb, 2015). Mixed livestock and crop production systems are also practised across India. There is the potential for these farming systems to be more environmentally beneficial and sustainable as the output from livestock and draught power could be an important input in crop production and vice-versa (Deb, 2015).

Depending on species, animal type, production system and management, the efficiency of these livestock production systems in converting feed protein into animal protein varies between 0.05 and 0.45 (Oenema, 2006). There are considerably higher livestock emissions in India due to a large number of indigenous low producing cattle (Chhabra *et al.*, 2013). As with many parts of the world, grazing animals are fed at barely subsistence levels, consuming rather than producing much (Akila & Chander, 2010). The inefficiencies associated with this process result in nitrogen losses in urine and manure of between 0.05 and 0.55 (Oenema, 2006). With the gradual increase in semi-intensive production systems witnessed (Khan *et al.*, 2016), nitrogen losses could decrease if there are better management practices.

The nitrogen losses from cattle in the predominant traditional systems in India cannot be ignored. The nitrogen losses to the environment are especially substantial when livestock roams free, and the waste is not collected and managed efficiently. Across many farms in India, the

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animals are either working on the field, grazing or tethering during the day. The night-time housing is basic sheds with thatched roofs and mud floors, lacking side walls in many cases (Akila & Chander, 2010). The system poses a challenge to manure management which we discuss.

Manure mismanagement as a key leakage source

Manure is a valuable underutilised resource that, when properly managed, can significantly reduce the emissions from livestock production (Nautiyal *et al*., 2015). But poor manure management result in wasted resources and have the potential to emit environmental pollutants. Besides, over-application of manure in fields can also lead to toxicity, odour, water pollution and pose a risk to human health (Dominguez & Edwards, 2011; Nautiyal *et al*., 2015). In India, the three most common types of manure use include (1) producing dry cakes from manure for use as fuel in rural households, (2) storing in heaps for composting as organic fertiliser for crops where traditionally, manure has been allowed to be composted with bedding and residual crop straw and (3) when animals are kept outdoors, the manure is not recycled and is generally allowed to decompose in the fields/pastures (Abrol *et al*., 2017). It is estimated that in India, 0.36 of the manure is used to make fuel cake, 0.27 is used for composting, and the remaining 0.37 is left in the field when the animals are allowed to graze outdoors (Mohini *et al*., 2016). However, the proportion may vary with seasons.

In India, for farmers who collect manure daily, up to 0.90 of the manure is collected stored in heaps, either taken to the farms during the crop season or put to alternative uses such as for the preparation of dung cakes (Gupta *et al*., 2017). In producing dung cakes, the manure is spread on the floor or stuck to walls in the open resulting in substantial nitrogen emissions. Also, when dung is collected as organic fertiliser, it is stored for long periods in the open or partially covered stores before application in the field (Webb *et al*., 2012; Gupta *et al*., 2017).

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This practice can lead to the accumulation of greenhouse gases (GHG) and subsequent emissions to the atmosphere (Kulling *et al*., 2001).

As much as 0.48 of excreted nitrogen is lost depending on the management practice of solid manure (Webb *et al*., 2012). Nitrogen losses from manure are mainly in the forms of NH_3 and N_2O (Ndegwa *et al*., 2008). NH_3 losses may account for 0.92 of total ammoniacal nitrogen (TAN), depending on the manure mixture and the compost management employed (Eghball *et al*., 1997). Estimates of nitrogen loss through manure from all livestock in India suggest approximately 4017.52 million tonnes (Abrol *et al*., 2017). Specifically, it is estimated that 70 tons of N_2O from manure management is emitted yearly in India (Sharma, 2020). In addition, the manure from approximately 0.14 of livestock that graze rangelands in India is also not put to use (Gupta *et al*., 2017). Notably, urine is not collected as it is difficult to collect and store. Nitrogen losses from urine are between 0.30-1.00 (Snijders *et al*., 2009). This finding is a concern as urine in livestock production systems is a major source of NH_3 volatilization and indirect N_2O emissions. NH_3 volatilization from urine deposited to grassland, pastureland, and cropland may range from 0.07 to 0.41 depending on the climate and soil (Whitehead *et al*. 2004, Zaman *et al*. 2013, Fisher *et al*. 2016). Figure 1 summarizes the discussion.

[Figure 1 here]

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Social, cultural, and economic determinants of nitrogen pollution from cattle production

In India, several economic, socio-demographic, cultural and religious factors directly or indirectly influence the livestock production and management systems and, consequently, the level of N emission from cattle production. We discuss the factors as follows.

Economic factors

Livestock production contributes considerably to improving the economic status of the rural

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poor in India, especially small and marginal farmers who own more than 0.70 of the livestock wealth. For example, smallholder dairy farming has become a livelihood option for 0.44 of rural households and contributes to reducing poverty in rural India (Rajendran & Mohanty, 2004). Typically, the smallholder farmer has a small herd of 1 to 3 cattle (Thimnavukkarasu *et al.*, 2019). These smallholders are usually landless or have small landholdings. The implication is that they graze their cattle in open access grazing land, limiting the potential for reducing nitrogen losses from manure to the environment. Also, the cost of maintaining the animal impacts the management method. About a decade ago, the number of stray cattle in India was estimated to be only 5 million. However, about 40 million unproductive cattle are currently in danger of being abandoned (Khan *et al.*, 2020). The main reason for this is the financial requirement to keep cattle beyond the age of productivity, and it is beyond the capacity of the small and marginal farmers. Therefore, these cattle, bulls, heifers and cows with low productivity add to the stray cattle population (Times of India, 2021).

Changing consumption patterns have also impacted production via the increased cattle numbers. In 2018-19, India's annual milk production was approximately 188 million metric tonnes (Government of India, 2020). The majority of this came from smallholder dairy farming as approximately 70 million farm families are engaged in dairy production (Thimnavukkarasu *et al.*, 2019; Lindahl *et al.*, 2020). Since the implementation of "Operation Flood", there has been a major increase in milk production and the per capita consumption of milk. While this program had a significant impact on the economic sustenance and livelihood of dairy farmers, it also holds the potential to reduce environmental pollution from cattle rearing through an increase in production efficiency, particularly when technology is involved (Thornton, 2010).

The economic purpose for which the animal is kept also influences the breeding and management practices. Most small and marginal farmers keep cows for milk production and bulls as work animals (Akila & Chander, 2010). The financial cost of keeping draught cattle

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reduces priority in terms of feeding and housing compared to dairy cattle (Akila & Chander, 2010). In addition, the production systems have implications for environmental pollution. Livestock production is shifting towards intensive production systems to meet the growing demand for animal products. In India, the increase in intensive production is attributed to limited open land for cattle grazing, urbanization and the change in consumers' food preferences (Manoj, 2015). These changes have affected livestock numbers, feed requirements, feeding and manure management practices and associated GHG emissions (Pierre & Harald, 2006). Under intensive production systems, animals are often fed more protein, phosphorus, and micronutrients to achieve higher yields, resulting in increased excretion of excess nutrients and consequently environmental pollution from the nutrient wastage (Abrol *et al.*, 2017). For example, Reichenbach *et al.* (2021) investigation of resource use efficiency of dairy production in Bengaluru showed a low feed efficiency among semi-intensive and intensive dairy production systems. As a result, the per-area footprint is usually higher under an intensive system, considering that more cattle are kept per land area compared to extensive systems. In other words, an intensive system produces higher overall GHG emissions but lower emissions intensity. However, this paper does not delve into the debate on GHG emissions from intensive versus extensive systems but highlights the common point of agreement that emissions can be reduced with better management irrespective of the systems.

For economic reasons, the use of manure cakes as fuel in rural households is widespread. The cheap fuel source is an additional motivation to keep cattle (Khan *et al.*, 2013). Manure contributes to 0.78 of residential energy from burning biomass (Council on Foreign Relations, 2021). However, the methods of processing and storing manure cakes are mostly not environmentally friendly. The manure is mixed with crop residue and sun-dried in the form of mid-size pellets (Sfez *et al.*, 2017; Prasad *et al.*, 2019). According to Stewart *et al.* (2021), manure cake had a higher emissions factor than fuelwood and liquefied petroleum gas,

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suggesting that the contribution to environmental pollution from burning manure cake is substantial.

Institutional factors also play an important role in mitigating agricultural pollution. Breeding programmes such as the National Project for Cattle and Buffalo Breeding, which is aimed at genetic improvement in cattle and buffalo across India, have increased the conception rate by 15% (Department of Animal Husbandry & Dairying, 2019). This increase holds positive benefit for efficiency through reducing wastage from empty calving intervals and replacement rates.

Social factors

The societal influences on livestock farmers also play a role from the perspective of farmers understanding their action to be either 'right' or 'wrong' in the light of the wider expectations. This social influence can make farmers behave in a particular manner (Fish, 2014). Herding, i.e., a convergent social behaviour, is also responsible for livestock management practices in India. Cattle farmers may be influenced by group behaviour. As such, farmers abandon their information and beliefs to align their behaviours with others in the group. Besides economic reasons, there are reports of some farmers letting their cattle roam free because others do the same (Katiyar & Layak, 2019).

Membership of milk cooperatives indirectly influences pollution mitigation via regulating milk quality. Kumar *et al*. (2013) suggest that the membership of milk cooperatives provides a distinct advantage in milk yield, productivity, and quality. Conversely, achieving better food safety measures is correlated with an increased milk yield (Kumar *et al*., 2020). Specifically, improvement in yield through productivity gains, improving feed efficiency and maintaining a high health status which is a prerequisite for better milk quality and food safety measures, also have the potential to reduce inefficiency-driven environmental pollution. However, there are

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herd size barriers and cost implications of compliance with these standards.

Urbanization in India impacts livestock production efficiency in India. Reichenbach *et al.* (2021) find that within an urbanizing environment, the distinctly different feeding strategies that dairy producers follow result in differences in resource use efficiency. Efficient feed systems are important for reducing GHG emissions. Besides, due to urbanization, common pastures are being transformed from their previous use, which has reduced options for publicly available feed and pasture (D'Souza & Nagendra, 2011). Consequently, cattle owners have to compete for degraded quality feed on the available common making the cattle vulnerable to many diseases and, in severe cases, resulting in losses for the farmers (Vij & Narain, 2016).

Rearing cattle serves as a visible status symbol and as a store of wealth. Households with a large number of cattle are considered wealthy (Mohan, 2019). There are no studies that directly examine whether there is a correlation between the management of cattle owned mainly to store wealth and livestock emissions. However, one can postulate that there will arguably be less motivation to reduce the environmental impact of cattle reared for status purposes. Other important factors are education and environmental awareness. Several studies suggest that Indian cattle farmers' awareness of best management practices is limited (Singh, Singh & Jaiswal, 2004; Paul & Chandel, 2010). Low environmental awareness could drive preference for certain traditional cattle management practices with questionable environmental sustainability.

Cultural and religious factors

Cows are considered sacred animals in the Hindu religion in India, and all the products such as milk, urine, dung are highly valued (Agoramoorthy *et al.*, 2012). Because of the sacred status, the consumption of cow meat is taboo in the Hindu religion. In India, there is a national ban on cow slaughter and in most states, slaughtering cows is illegal (Kennedy *et al.*, 2018). This ban

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contributes to the approximately 5 million stray cattle population in India. These stray cattle are, in general, unproductive or low yielding animals, which increases the financial burden of the farmer with no returns. The farmers are not interested in rear the unproductive cattle, and there is a decline in their use on the farm due to increased mechanisation. Since these cattle become a liability for the farmer, they are left free to roam around for their feed during the daytime and in some cases are kept in (publicly or privately funded) animal shelters. Not only do these stray cows contribute to a large amount of greenhouse gas emissions, but the manure they produce leads to loss of nitrogen as N_2O and NH_3. Also, cow urine is used for religious rituals (Daria & Islam, 2021). How the urine is stored, processed and used could be pathways for nitrogen losses. A summary of the factors that influence the livestock production and management systems and the level of N emission from cattle production is presented in Figure 2.

[Figure 2 here]

Solutions to reduce nitrogen pollution from cattle production

India can improve its shortcomings by learning from other countries, e.g., New Zealand that produces cattle sustainably. Reducing nitrogen emissions in cattle production can be achieved by changing manure management practices (Rees *et al.*, 2013). In line with the nitrogen loss pathways identified in this review, mitigation options can broadly be considered in three ways. First, improving livestock productivity and thus ensuring better nitrogen balance. Second, addressing feed-related practices aimed at improving nitrogen use efficiency. Third, implementing effective interventions related to manure and pasture management. The relevant mitigation options for sustainable livestock management and, specifically, reducing nitrogen pollution are discussed in the present paper.

Improving livestock productivity

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The implementation of "Operation Flood" has resulted in a major increase in milk production and per capita milk consumption. However, with current volume-oriented production, which relies on large numbers of animals and low productivity, the livestock industry in India will struggle to meet the growing local and global demand for livestock products. The desired production level can be achieved in the future by increasing productivity. This can be achieved by maintaining optimum livestock numbers during the production phase and increasing productivity through scientific breed, feed and herd management. Breeding methods that improve herd performance and better management can reduce non-productive animals and help to reduce emissions (Gerber *et al*., 2013). In India, increasing the average productivity of milk from 3.6 kg to 6 kg per day could reduce the number of dairy animals by 40% and feed requirements by 27% without reducing milk production, thus providing a significant advantage in reducing nitrogen pollution (Blummel *et al*., 2009). At the same time, the demand driven by the changing consumption patterns and preference for better quality milk will have a greater likelihood of being met.

Despite a large number of cattle in India, the quality of India's indigenous cattle is generally considered to be poor. Since the beginning of the last century, India has initiated several cattle development programmes to promote quality breeds throughout the country. In addition to this, in recent years, the national policy for animal husbandry has been directed towards optimising the quality of indigenous cattle through crossbreeding, selection and breeding (National Livestock Policy, 2013). There is a need for breeding technologies such as sexed semen to be encouraged and made affordable to reduce the number of unwanted cattle (Rao *et al*., 2016). Improving the health of cattle is also an important prerequisite for increasing productivity. However, many environmental and resource constraints affect the health of cattle. For example, the use of contaminated water sources may negatively impact the health and production of dairy cattle (Giri *et al*., 2020).

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Improving feed production systems and management practices

Measures taken during the production of feed can also reduce nitrogen emissions. These measures can be reduced nitrogen application in the bovine feed production process. Reducing the amount of nitrogen fertiliser applied to produce feed for bovines reared intensively is widely considered an effective measure to reduce N_2O and NH_3 emissions. In addition, the use of biological nitrogen fixation as an alternative to chemical fertilisers in the production of forage can also provide the required nitrogen input (Cassman *et al*., 2002; Erisman *et al*., 2007). Nitrogen-fixing legumes crops such as Sesbania, Leucenea contain symbiotic bacteria in their root nodules that convert atmospheric nitrogen into forms that plants can take up (Rees *et al*., 2013).

Additionally, the use of nitrification and urease inhibitors along with urea and other ammonium compounds in rangeland fertilisation can reduce reactive nitrogen emissions (Di & Cameron, 2003). More recently, the use of neem-coated urea instead of urea has been implemented in India for the slow release of nitrogen in the soil (Dinesh Kumar, 2015). Globally, there is empirical evidence of reductions in nitrogen emissions from nitrification inhibitors in pasture and cropland fertilisation (Di and Cameron, 2003; Malla *et al*., 2005). However, since its efficiency is dependent on external factors such as soil temperature, its effect may vary from region to region. The use of cost-effective decision support tools such as the soil health card for site specific nutrient management and demand-based nitrogen application using the leaf colour chart is gaining popularity among farmers in India. The benefit of such tools is that they can help optimize the timing of nitrogen fertilizer application and reducing the nitrogen losses (Móring *et al*., 2021). In addition, farmers can also download free software on their mobile phones to calculate the amount of nitrogen fertilizer required. This

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method has already proved effective in the production of several crops (Móring *et al.*, 2021).

The types of feeds and feeding regimes of cattle determine feed efficiency and emission intensity. Approximately 0.25 to 0.35 of the nitrogen consumed by dairy cows is secreted in milk, while the excess nitrogen from feed proteins is excreted in manure (Ishler, 2004). Adopting nutritional management and manipulation of diet composition can increase the efficiency with which feed is converted into live weight gain or milk. For example, adjusting the crude protein in the diets has been reported to be effective in reducing NH_3 emissions from manure (Sajeev *et al.*, 2018).

Adopting better manure and pasture management

Animal manures consists of beneficial components. If effectively recycled, it can be used as fertiliser for crops, feed animals, and produce energy (Parihar *et al.*, 2019). However, whole-farm management is necessary to reduce nitrogen loss in the cattle production system. The nitrogen loss can be decreased by frequent removal of manure and by avoiding storing in open heaps - a common practice by farmers. In intensive production systems, the best options are to minimise losses through closed tanks or, where that is not viable, maintain natural crusting in open tanks. Anaerobic composting of manure and lime acidification can help minimise nitrogen emissions (Samer, 2015). Other reliable manure management methods include biogas production, rotational composting, and vermicomposting (Parihar *et al.*, 2019). Although biogas production is used in India, there is a need to scale up the technology. Biogas plants recycle animal waste and produce CH_4 under anaerobic conditions. The CH_4 is used as an energy source for cooking, while the slurry left over after CH_4 extraction is used as farm manure. This method is a sustainable approach as it reduces the emission of manure pollutants and converts valuable waste into energy and farm waste (Gautam, 2006). The animal urine should be collected in closed tanks and can be applied as a deep injection into the soil to reduce

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the likelihood of nitrogen leakage. Notably, this practice may lead to more leaching and denitrification losses from the soil if not managed properly and integrated with practices such as efficient crop rotation and need-based application (Rotz *et al*., 2004).

In terms of pasture management, controlled grazing can reduce N_2O and NH_3 emissions by reducing intensive use of grassland (Luo *et al*., 2010). Also, controlling the moisture in grazing soils or forage production field soils through land drainage can reduce emissions of N_2O to the atmosphere. Such changes could address the finding and concerns in previous studies in India e.g., Shankar and Gupta (1992) that the carrying capacity of semi-arid grassland is 50 more Adult Cattle Unit (ACU) per hectare than recommended.

Future perspectives

Regarding the environmental impact of dietary structure, the typical Indian diet has a relatively low per capita environmental impression compared to high-income countries (Pathak *et al*., 2010). Still, there are also significant differences between dietary patterns (Green *et al*., 2018). India's diet is changing rapidly, with consumption of dairy products in particular growing (Abrol *et al*., 2017). As incomes increase, Indian diets are likely to become more diverse. Also, there may be greater demand for meat among the religious groups that eat meat. Given the size of India's population, the environmental impact of such a change could be significant (Green *et al*., 2018; Pathak *et al*., 2010).

Cubbing the practice of abandoning cattle due to old age, which results in a high number of stray cattle, makes sustainable practices in cattle management more difficult and consequently increases emissions. Therefore, ensuring these stray cattle can be properly housed and sustainably managed is an issue that needs attention in the future as it is an important step in reducing environmental pollution from cattle. Although India has over 3000 Gaushala (cow shelters), the increasing cattle population means that not all can be accommodated with the

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current capacity. Moreover, the increasing population of these animals also has implications for forage and feed demand. Crucially, the competition for land water and the challenges associated with the changing climate will also determine how environmentally friendly livestock production systems in India will be in the future.

In terms of national policy, the Indian government has introduced bioenergy policies and programmes to promote the safer, more efficient and environmentally friendly use of bioenergy (Kothari *et al*., 2020). For example, the new National Biogas and Organic Fertiliser Programme (NNBOMP) introduced in 2018 aims to establish, operate, and maintain many biogas plants to produce biogas and organic fertilisers to meet the demand for sustainable energy. Besides supplying energy and manure, biogas technology can provide an excellent opportunity to mitigate nitrogen emissions (Pathak *et al*., 2009). However, regulation for manure under a single directive may be needed if multiple laws or state regulations on manure management are less efficient. Notably, controlling unwanted reactive nitrogen releases through policy initiatives alone is difficult because in India, as in other countries, most Nr releases come from various sources such as agriculture, industry, transport and energy, and waste. Therefore, management strategies to reduce Nr releases into the environment require an integrated approach.

Crucially, increasing farmers' awareness of the problem of nitrogen mismanagement can create the desired change. Access to information often improves farmers' decision-making skills (Panda, 2015). Without sufficient knowledge, it is not easy for farmers to think of the potentially serious consequences of environmental pollution. The importance of educating farmers on best management practices cannot be overemphasised. Such effort may focus, for example, on areas where there are findings that over 0.90 have no urine drainage facilities in animal sheds (Manohar, Goswami & Bais, 2014).

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Conclusion

The nitrogen cycle has undergone large-scale transformations in its structure and function over the last six decades. From a human perspective, it is the most disturbed biogeochemical cycle. Human activities have a huge impact on the global nitrogen cycle through activities aimed at meeting the food and energy needs of a rapidly growing population, ranging from intensive agricultural activities to increased consumption of fossil fuels. Overall, nitrogen pollution from livestock in India is relatively serious due to the large number of cattle, unsustainable livestock production systems, poor manure management and surging population pressure. In addition, the increase in the number of stray cattle is creating significant pressure for the management of cattle and their waste. The sustainable solutions to reducing nitrogen pollution in the Indian cattle industry include improving livestock productivity, better feed-related practices to improve nitrogen use, and interventions related to manure and pasture management. Also, with increased knowledge and awareness of environmental protection and advances in science and technology, India's livestock industry will perhaps move in a more sustainable direction.

The limitation in the narrative of this paper is that, across the different studies reviewed, no further distinction is made regarding how different cattle types, sizes, and breeds differ in their emissions of GHG and environmental pollutants. Also, the paper did not discuss other non-nitrogen GHG and environmental pollutants. However, the recommendations made in this paper have a direct impact on the holistic reduction of pollution from cattle production in India.

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Author Contributions

Y. Zhou - Conceptualization, Methodology, Investigation, Resources, Writing - Original Draft

N. Jain - Validation, Investigation, Resources, Writing - Review & Editing

G. K. Jha - Validation, Investigation, Resources, Writing - Review & Editing

T. Begho - Conceptualization, Validation, Investigation, Writing - Review & Editing, Visualization, Supervision, Project administration

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Financial Support

This paper results from research funded by UKRI under the title ‘South Asian Nitrogen Hub [SANH]. The project team includes partners from across South Asia and the UK. Neither UKRI nor any of the partner institutions is responsible for views advanced here.

Conflicts of Interest

None

Ethical Standards

Not applicable

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https://doi.org/10.1017/S0021859622000120

References

Abrol, Y. P., Adhya, T. K., Aneja, V. P., Raghuram, N., Pathak, H., Kulshrestha, U., Sharma, C. & Singh, B. (Eds.). (2017). The Indian nitrogen assessment: Sources of reactive nitrogen, environmental and climate effects, management options, and policies. Elsevier.

Agoramoorthy, G., & Hsu, M. J. (2012). The significance of cows in Indian society between sacredness and economy. Anthropological Notebooks, 18(3).

Akila, N., & Chander, M. (2010). Management practices followed for draught cattle in the southern part of India. Tropical animal health and production, 42(2), 239-245.

Andrews, M. & Lea, P.J. (2013) Our nitrogen "footprint": the need for increased crop nitrogen use efficiency. Annals of Applied Biology 163, pp. 165-169.

Aneja, V.P., Schlesinger, W. & Erisman, J.W. (2009) Effects of agriculture upon the air quality and climate: research, policy, and regulations. Environmental Science and Technology 43, pp. 4234-4240.

Aneja, V. P., Schlesinger, W. H., Erisman, J. W., Behera, S. N., Sharma, M., & Battye, W. (2012). Reactive nitrogen emissions from crop and livestock farming in India. Atmospheric environment, 47, 92-103.

Blummel, M., Anandan, S. & Prasad, C.S. (2009) Potential and limitations of by-product based feeding systems to mitigate greenhouse gases for improved livestock productivity. In: 13th Biennial Conference of Animal Nutrition Society of India, 17-19 December Bangalore, India, pp. 68-74, pp. 168.

Cassman, K. G., Dobermann, A., & Walters, D. T. (2002). Agroecosystems, nitrogen-use efficiency, and nitrogen management. AMBIO: A Journal of the Human Environment, 31(2), 132-140.

Chhabra, A., Manjunath, K. R., Panigrahy, S., & Parihar, J. S. (2013). Greenhouse gas emissions from Indian livestock. Climatic Change, 117(1), 329-344.

Accepted Manuscript

Downloaded from https://www.cambridge.org/core, IP address: 143.234.194.201, on subject to the Cambridge Core terms of use, available at https://www.cambridge.org/core/terms.
https://doi.org/10.1017/S0021859622000120

Clarisse, L., Clerbaux, C., Dentener, F., Hurtmans, D., & Coheur, P. F. (2009) Global ammonia distribution derived from infrared satellite observations. Nature Geoscience 2, pp. 479-483.

Council on Foreign Relations. (2021) A Matter of Particular Concern: India's Transition From Biomass Burning. [online] Available at: <https://www.cfr.org/blog/matter-particular-concern-indias-transition-biomass-burning> [Accessed 10 August 2021].

Daria, S., & Islam, M. R. (2021). The use of cow dung and urine to cure COVID-19 in India: a public health concern. The International Journal of Health Planning and Management.

D'Souza, R., & Nagendra, H. (2011). Changes in public commons as a consequence of urbanization: The Agara lake in Bangalore, India. Environmental management, 47(5), 840-850.

Deb, S.M (2015) Traditional Livestock Production and Growth Opportunities in India. [online] Uknowledge.uky.edu. Available at: <https://uknowledge.uky.edu/cgi/viewcontent.cgi?article=1017&context=igc> [Accessed 24 July 2021].

Department of Animal Husbandry & Dairying (2019). National Project for Cattle and Buffalo Breeding. Retrieved on 14 November, 2021 from https://dahd.nic.in/related-links/national-project-cattle-and-buffalo-breeding.

Di, H. J., & Cameron, K. C. (2003). Mitigation of nitrous oxide emissions in spray-irrigated grazed grassland by treating the soil with dicyandiamide, a nitrification inhibitor. Soil use and management, 19(4), 284-290.

Dominguez, J. & Edwards, C.A. (2011) Relationships between composting and vermicomposting. In: Edwards, C.A., Arancon, N.Q., Sherman, R. (Eds.), Vermiculture Technology Earthworms, Organic Wastes, and Environmental Management. CRC Press, Boca Raton, pp. 11-26.

Accepted Manuscript

Downloaded from https://www.cambridge.org/core, IP address: 143.234.194.201, on subject to the Cambridge Core terms of use, available at https://www.cambridge.org/core/terms. https://doi.org/10.1017/S0021859622000120

Eghball, B., Power, J. F., Gilley, J. E., & Doran, J. W. (1997) Nutrient, carbon, and mass loss during composting of beef cattle feedlot manure. Journal of Environment Quality, 26 (1), pp. 189-193.

Erisman, J. W., Bleeker, A., Galloway, J., & Sutton, M. S. (2007) Reduced nitrogen in ecology and the environment. Environment Pollution, 150 (1), pp. 140–149.

FAO (2021). FAOSTAT. https://www.fao.org/faostat/en/#data/GE. Accessed on 16 Nov 2021.

Fish, R. (2014). Influencing farmers to engage in catchment sensitive farming: An introductory guide to behavioural research for CSFOs and their delivery partners.

Fishman, R., Kishore, A., Rothler, Y., Ward, P. S., Jha, S., & Singh, R. K. P. (2016). Can information help reduce imbalanced application of fertilizers in India?: Experimental evidence from Bihar (Vol. 1517). Intl Food Policy Res Inst.

Fischer, K., Burchill, W., Lanigan, G. J., Kaupenjohann, M., Chambers, B. J., Richards, K. G., & Forrestal, P. J. (2016). Ammonia emissions from cattle dung, urine and urine with dicyandiamide in a temperate grassland. Soil Use and Management, 32, 83-91.

Galloway, J. N., Townsend, A. R., Erisman, J. W., Bekunda, M., Cai, Z., Freney, J. R., Martinelli, L. A., Seitzinger, S. P. & Sutton, M. A. (2008). Transformation of the nitrogen cycle: recent trends, questions, and potential solutions. Science, 320(5878), 889-892.

Garg, A. & Shukla, P. R. (2002) Emission inventory of India, Tata McGraw Hill, New Delhi, pp. 84-89

Gautam, H. (2006) India Country Profile on Animal Waste Management for Methane to Markets. [online] Globalmethane.org. Available at: <https://www.globalmethane.org/documents/ag_cap_india.pdf> [Accessed 27 July 2021].

Gerber, P. J., Steinfeld, H., Henderson, B., Mottet, A., Opio, C., Dijkman, J., Falcucci, A. & Tempio, G. (2013). Tackling climate change through livestock: a global assessment of emissions and mitigation opportunities. Food and Agriculture Organization of the United

Accepted Manuscript

Downloaded from https://www.cambridge.org/core, IP address: 143.234.194.201, on subject to the Cambridge Core terms of use, available at https://www.cambridge.org/core/terms.
https://doi.org/10.1017/S0021859622000120

Nations (FAO).

Giri, A., Bharti, V. K., Kalia, S., Arora, A., Balaje, S. S., & Chaurasia, O. P. (2020) A review on water quality and dairy cattle health: a special emphasis on high-altitude region. Applied Water Science, 10, 79

Green, R. F., Joy, E. J., Harris, F., Agrawal, S., Aleksandrowicz, L., Hillier, J., & Dangour, A. D. (2018) Greenhouse gas emissions and water footprints of typical dietary patterns in India. The Science of the total environment. [Online] 6431411–1418.

Gupta, P. K., Jha, A. K., Koul, S., Sharma, P., Pradhan, V., Gupta, V., Sharma, C. & Singh, N. (2007). Methane and nitrous oxide emission from bovine manure management practices in India. Environmental Pollution, 146(1), 219-224.

Ishler, V. (2004). Nitrogen, ammonia emissions and the dairy cow. Nutrient Management College of Agricultural Sciences, Pennsylvania State University, 04-87.

IPCC (2014). Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, 151 pp.

Kanter, D. R., Bartolini, F., Kugelberg, S., Leip, A., Oenema, O., & Uwizeye, A. (2020a). Nitrogen pollution policy beyond the farm. Nature Food, 1(1), 27-32.

Kanter, D. R., Chodos, O., Nordland, O., Rutigliano, M., & Winiwarter, W. (2020b). Gaps and opportunities in nitrogen pollution policies around the world. Nature Sustainability, 3(11), 956-963.

Katiyar P. & Layak S. (2019).What made rural India abandon its cattle in droves. Retrieved on 13 October, 2021 from: https://economictimes.indiatimes.com/news/politics-and-nation/what-made-rural-india-abandon-its-cattle-in droves/articleshow/67604493.cms?utm_source=contentofinterest&utm_medium=text&ut

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m_campaign=cppst

Kavanagh, I., Burchill, W., Healy, M. G., Fenton, O., Krol, D. J., & Lanigan, G. J. (2019). Mitigation of ammonia and greenhouse gas emissions from stored cattle slurry using acidifiers and chemical amendments. Journal of Cleaner Production, 237, 117822.

Kennedy, U., Sharma, A., & Phillips, C. J. (2018). The sheltering of unwanted cattle, experiences in India and implications for cattle industries elsewhere. Animals, 8(5), 64.

Khan, N., Rehman, A., & Salman, M. (2013). Impact of Livestock Rearing on the Socio-Economic Development in North India. In Forum geografic (Vol. 12, No. 1, pp. 75-80).

Khan, A., Riedel, T., Hussain, R., & Patel, I. (2020). Beef Ban in India: A Multi-dimensional Issue. Journal of Pharmacy Practice and Community Medicine, 6(1).

Khan, M. H., Manoj, K., & Pramod, S. (2016). Reproductive disorders in dairy cattle under semi-intensive system of rearing in North-Eastern India. Veterinary world, 9(5), 512.

Kothari, R., Vashishtha, A., Singh, H. M., Pathak, V. V., Tyagi, V. V., Yadav, B. C. & Singh, D. P. (2020) Assessment of Indian bioenergy policy for sustainable environment and its impact for rural India: Strategic implementation and challenges. Environmental technology & innovation, 20, 101078

Kulling, D. R., Menzi, H., Kröber, T. F., Neftel, A., Sutter, F., Lischer, P., & Kreuzer, M. (2001) Emissions of ammonia, nitrous oxide and methane from different types of dairy manure during storage as affected by dietary protein content. Journal of Agricultural Science, 137 (02), pp. 235-250.

Kumar, D. (2015) Neem coated urea: uses and benefits. Employment News. 15, p. 63.

Kumar, A., Shinoj, P., & Jee, S. (2013). Do dairy co-operatives enhance milk production, productivity and quality? Evidences from the Indo-Gangetic Plain of India. Indian Journal of Agricultural Economics, 68(902-2016-66835), 457-468.

Kumar, A., Mishra, A. K., Saroj, S., Sonkar, V. K., Thapa, G., & Joshi, P. K. (2020). Food

Accepted Manuscript

Downloaded from https://www.cambridge.org/core, IP address: 143.234.194.201, on subject to the Cambridge Core terms of use, available at https://www.cambridge.org/core/terms. https://doi.org/10.1017/S0021859622000120

safety measures and food security of smallholder dairy farmers: empirical evidence from Bihar, India. Agribusiness, 36(3), 363-384.

Kumar, N., & Kapoor, S. (2014). Study of consumers' behavior for non-vegetarian products in emerging market of India. Journal of Agribusiness in Developing and Emerging Economies.

Ladha, J. K., Jat, M. L., Stirling, C. M., Chakraborty, D., Pradhan, P., Krupnik, T. J., Sapkota, T. B., Pathak, H., Rana, D. S., Tesfaye, K. & Gerard, B. (2020). Achieving the sustainable development goals in agriculture: The crucial role of nitrogen in cereal-based systems. Advances in Agronomy, 163, 39-116.

Lassey, K., & Harvey, M. (2007). Nitrous oxide: the serious side of laughing gas. Water Atmos, 15(2), 10-11.

Lassey, K. R. (2008). Livestock methane emission and its perspective in the global methane cycle. Australian Journal of Experimental Agriculture, 48(2), 114-118.

Lindahl, J. F., Chauhan, A., Gill, J. P. S., Hazarika, R. A., Fairoze, N. M., Grace, D., Gaurav, A., Satpathy, S. K. & Kakkar, M. (2020). The extent and structure of peri-urban smallholder dairy farming in five cities in India. Frontiers in Veterinary Science, 7, 359.

Luo, J. C. A. M., De Klein, C. A. M., Ledgard, S. F., & Saggar, S. (2010) Management options to reduce nitrous oxide emissions from intensively grazed pastures: a review. Agriculture, Ecosystems & Environment, 136 (3), pp. 282-291

Malla, G., Bhatia, A., Pathak, H., Prasad, S., Jain, N., & Singh, J. (2005). Mitigating nitrous oxide and methane emissions from soil in rice–wheat system of the Indo-Gangetic plain with nitrification and urease inhibitors. Chemosphere, 58(2), 141-147.

Manohar, D. S., Goswami, S. C., & Bais, B. (2014). Study on feeding management practices of buffaloes in relationship with selected traits of respondents in Jaipur district of Rajasthan, India. Indian Journal of Animal Research, 48(2), 150-154.

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Downloaded from https://www.cambridge.org/core, IP address: 143.234.194.201, on subject to the Cambridge Core terms of use, available at https://www.cambridge.org/core/terms. https://doi.org/10.1017/S0021859622000120

Manoj, P. K. (2015). Cattle feed industry in India: a macro perspective. International Journal of Business, Management & Social Sciences (IJBMSS)(ISSN-P: 2249-7463), 96-101.

MoEFCC. (2021). India: Third Biennial Update Report to the United Nations Framework Convention on Climate Change. Ministry of Environment, Forest and Climate Change, Government of India

Mohan, C. (2019). Cattle Farming Merely a Status or an Alternate Way of Earning ? Animal Husbandary. Retrieved on 14 November, 2021 from https://krishijagran.com/animal-husbandry/cattle-farming-merely-a-status-or-an-alternate-way-of-earning/

Mohini, M., Mondal, G., Thakur, S. S., & Gupta, S. (2016) Trends in methane emission from Indian livestock. In: Proceedings of XVI Biennial Animal Nutrition Conference on "Innovative Approaches for Animal Feeding and Nutritional Research, Held at NDRI, Karnal.

Móring, A., Hooda, S., Raghuram, N., Adhya, T. K., Ahmad, A., Bandyopadhyay, S. K. & Sutton, M. A. (2021) Nitrogen Challenges and Opportunities for Agricultural and Environmental Science in India. Frontiers in Sustainable Food Systems, 5.

Nautiyal, S., Goswami, M., Manasi, S., Bez, P., Bhaskar, K., & Khan, Y. I. (2015) Potential of manure based biogas to replace conventional and non-conventional fuels in India: Environmental assessment for emission reduction. Management of environmental quality. [Online] 26 (1), 3–20.

Ndegwa, P.M., Hristov, A.N., Arogo, J. & Sheffield, R.E. (2008) A review of ammonia emission mitigation techniques for concentrated animal feeding operations. Biosystems Engineering, 100 (4), pp. 453-469.

Oenema, O. (2006) Nitrogen budgets and losses in livestock systems. International Congress Series, 1293, pp. 262-271.

Oita, A., Malik, A., Kanemoto, K., Geschke, A., Nishijima, S., & Lenzen, M. (2016).

Accepted Manuscript

Downloaded from https://www.cambridge.org/core, IP address: 143.234.194.201, on subject to the Cambridge Core terms of use, available at https://www.cambridge.org/core/terms. https://doi.org/10.1017/S0021859622000120

Substantial nitrogen pollution embedded in international trade. Nature Geoscience, 9(2), 111-115.

O'Mara, F. P. (2011). The significance of livestock as a contributor to global greenhouse gas emissions today and in the near future. Animal Feed Science and Technology, 166, 7-15.

Omara, P., Aula, L., Oyebiyi, F., & Raun, W. R. (2019). World cereal nitrogen use efficiency trends: review and current knowledge. Agrosystems, Geosciences & Environment, 2(1), 1-8.

Panda, S. (2015) Farmer education and household agricultural income in rural India. International journal of social economics. [Online] 42 (6), 514–529.

Parihar, S. S., Saini, K. P. S., Lakhani, G. P., Jain, A., Roy, B., Ghosh, S., & Aharwal, B. (2019). Livestock waste management: A review. J. Entomol. Zool. Stud, 7, 384-393.

Pathak, H., Jain, N., Bhatia, A., Mohanty, S., & Gupta, N. (2009). Global warming mitigation potential of biogas plants in India. Environmental monitoring and assessment, 157(1), 407-418.

Pathak, H., Jain, N., Bhatia, A., Patel, J., & Aggarwal, P. K. (2010). Carbon footprints of Indian food items. Agriculture, ecosystems & environment, 139(1-2), 66-73.

Paul, D., & Chandel, B. S. (2010). Improving Milk Yield Performance of Crossbred Cattle in North-Eastern States of India § . Agricultural Economics Research Review, 23(1), 69-75.

Phillips, C. J. (2021). Are There Lessons from India about the Management of Cattle? A Review of 'Cow Care in Hindu Animal Ethics' by Kenneth R. Valpey. Animals, 11(8), 2175.

Pierre, G. & Harald, M. (2006) Greenhouse gases and animal agriculture: an updated nitrogen losses from intensive livestock farming systems in Southeast Asia: a review of current trends and mitigation options. In: Proceedings of the 2nd International Conference on Greenhouse Gases and Animal Agriculture, Held in Zurich, Switzerland, International

Accepted Manuscript

Downloaded from https://www.cambridge.org/core, IP address: 143.234.194.201, on subject to the Cambridge Core terms of use, available at https://www.cambridge.org/core/terms. https://doi.org/10.1017/S0021859622000120

Congress Series, 1293, pp. 253-261.

Prasad, C. S., Anandan, S., Gowda, N. K., Schlecht, E., & Buerkert, A. (2019). Managing nutrient flows in Indian urban and peri-urban livestock systems. Nutrient Cycling in Agroecosystems, 115(2), 159-172.

Prasad, S., Kumar, S., Sheetal, K. R., & Venkatramanan, V. (2020). Global climate change and biofuels policy: Indian perspectives. In Global climate change and environmental policy (pp. 207-226). Springer, Singapore.

Rao, T. K. S., Chaurasia, S., Singh, A., & Gamit, V. V. (2016). Management of Stray Cattle in Urban Area. Indian Farmer, 455.

Reay, D. S., Davidson, E. A., Smith, K. A., Smith, P., Melillo, J. M., Dentener, F., & Crutzen, P. J. (2012). Global agriculture and nitrous oxide emissions. Nature climate change, 2(6), 410-416.

Rajendran, K., & Mohanty, S. (2004). Dairy co-operatives and milk marketing in India: Constraints and opportunities. Journal of Food Distribution Research, 35(856-2016-56967), 34-41.

Rees R. M., Baddeley, J. A., Bhogal, A., Ball, B. C., Chadwick, D. R., Macleod, M. & Williams, J. R. (2013) Nitrous oxide mitigation in UK agriculture, Soil Science and Plant nutrition, 59(1), pp.3-15.

Reichenbach, M., Pinto, A., Malik, P. K., Bhatta, R., König, S., & Schlecht, E. (2021). Dairy feed efficiency and urbanization–A system approach in the rural-urban interface of Bengaluru, India. Livestock Science, 253, 104718.

Rotz, C. A. (2004). Management to reduce nitrogen losses in animal production. Journal of animal science, 82(suppl_13), E119-E137.

Sajeev, E. P. M., Amon, B., Ammon, C., Zollitsch, W., & Winiwarter, W. (2018). Evaluating the potential of dietary crude protein manipulation in reducing ammonia emissions from

Accepted Manuscript

Downloaded from https://www.cambridge.org/core, IP address: 143.234.194.201, on subject to the Cambridge Core terms of use, available at https://www.cambridge.org/core/terms.
https://doi.org/10.1017/S0021859622000120

cattle and pig manure: A meta-analysis. Nutrient cycling in agroecosystems, 110(1), 161-175.

Samer, M. (2015) GHG emission from livestock manure and its mitigation strategies. In: Sejian, *et al*. (Eds.), Climate Change Impact on Livestock: Adaptation and Mitigation. Springer, India, pp. 321-346, 978-981-322-2264-4.

Sfez, S., De Meester, S., & Dewulf, J. (2017). Co-digestion of rice straw and cow dung to supply cooking fuel and fertilizers in rural India: Impact on human health, resource flows and climate change. Science of the Total Environment, 609, 1600-1615.

Sharma, UC (2020) Methane and Nitrous Oxide Emission from Livestock in India: Impact of Land Use Change, Journal of Agriculture and Aquaculture, 2(1).

Shankar, V., & Gupta, J. N. (1992). Restoration of degraded rangelands. Restoration of Degraded Lands-Concepts and Strategies. Rastogi Publications, Meerut, India, 115-155.

Singh, B. & Singh, Y. (2008) Reactive nitrogen in Indian agriculture: inputs use efficiency and leakages. Current Science, 94, pp. 1382-1393.

Singh, P. R., Singh, M., & Jaiswal, R. S. (2004). Constraints and strategies in rural livestock farming in Almora district of hilly Uttaranchal. Indian Journal of Animal Research, 38(2), 91-96.

Singh, S., Sharma, A., & Kulshrestha, U. C. (2016). Relative contributions of NH3, NO2, NH4+ and NO3− to total nitrogen deposition at an agricultural site in the Indo-Gangetic Plain of India. In Proceedings of the 2016 International Nitrogen Initiative Conference, "Solutions to improve nitrogen use efficiency for the world (pp. 4-8).

Snijders, P. J. M., Davies, O., Wouters, A. P., Gachimbi, L., Zake, J., Ebanyat, P., Ergano, K., Abduke, M. & Van Keulen, H. (2009). Cattle manure management in East Africa: Review of manure quality and nutrient losses and scenarios for cattle and manure management. Report 258. Wageningen UR Livestock Research: Wageningen, Netherlands

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Sommer, S. G., Webb, J., & Hutchings, N. D. (2019). New emission factors for calculation of ammonia volatilization from European livestock manure management systems. Frontiers in Sustainable Food Systems, 101.

Stewart, G. J., Acton, W. J. F., Nelson, B. S., Vaughan, A. R., Hopkins, J. R., Arya, R., Mondal, A., Jangirh, R., Ahlawat, S., Yadav, L., Sharma, S. K., Dunmore, R. E., Yunus, S. S. M., Hewitt, C. N., Nemitz, E., Mullinger, N., Gadi, R., Sahu, L. K., Tripathi, N., Rickard, A. R., Lee1, J. D., Mandal, T. K. & Hamilton, J. F. (2021). Emissions of non-methane volatile organic compounds from combustion of domestic fuels in Delhi, India. Atmospheric Chemistry and Physics, 21(4), 2383-2406.

Thimnavukkarasu, D., Narmatha, N., Doraisamy, K. A., & Sakthivel, K. (2019) Future Prospects of Smallholder Dairy Production: Pragmatic Evidence from Crop-Livestock Farming Systems of an Economically Transforming State in India. Cuadernos de desarrollo rural. [Online] 16 (84).

Thomson, A. J., Giannopoulos, G., Pretty, J., Baggs, E. M., & Richardson, D. J. (2012). Biological sources and sinks of nitrous oxide and strategies to mitigate emissions. Philosophical Transactions of the Royal Society B: Biological Sciences, 367(1593), 1157-1168.

Thornton, P. K. (2010). Livestock production: recent trends, future prospects. Philosophical Transactions of the Royal Society B: Biological Sciences, 365(1554), 2853-2867.

Vij, S., & Narain, V. (2016). Land, water & power: The demise of common property resources in periurban Gurgaon, India. Land Use Policy, 50, 59-66.

Webb, J., Sommer, S. G., Kupper, T., Groenestein, K., Hutchings, N. J., Eurich-Menden, B. & Amon, B. (2012) Emissions of ammonia, nitrous oxide and methane during the management of solid manures. Sustainable Agriculture Reviews, 8, pp. 67-107.

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Fig. 1. Manure mismanagement as a driver of nitrogen emissions from livestock production in India.

Fig. 2. Factors that affect N emission from cattle production in India.

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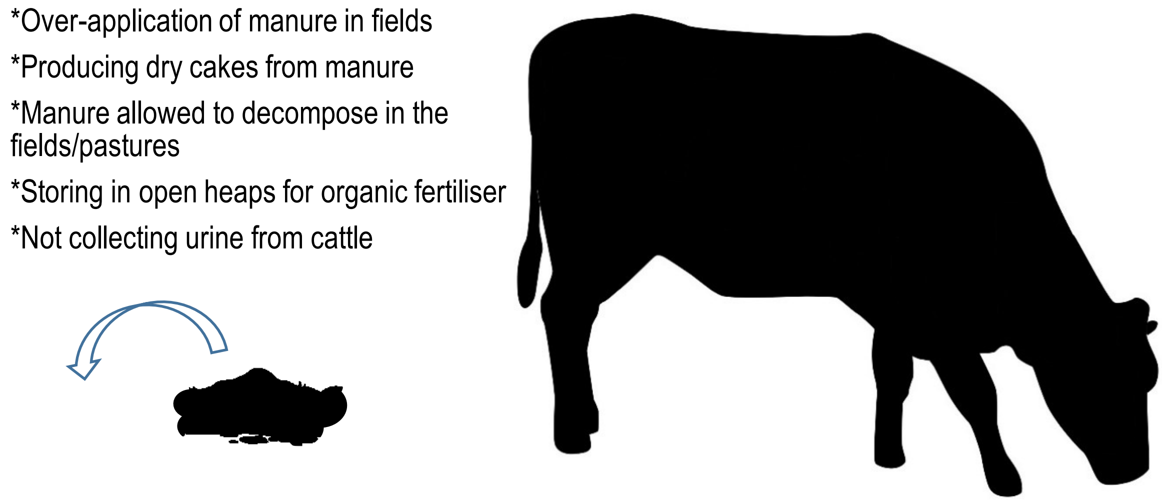

Fig. 1.

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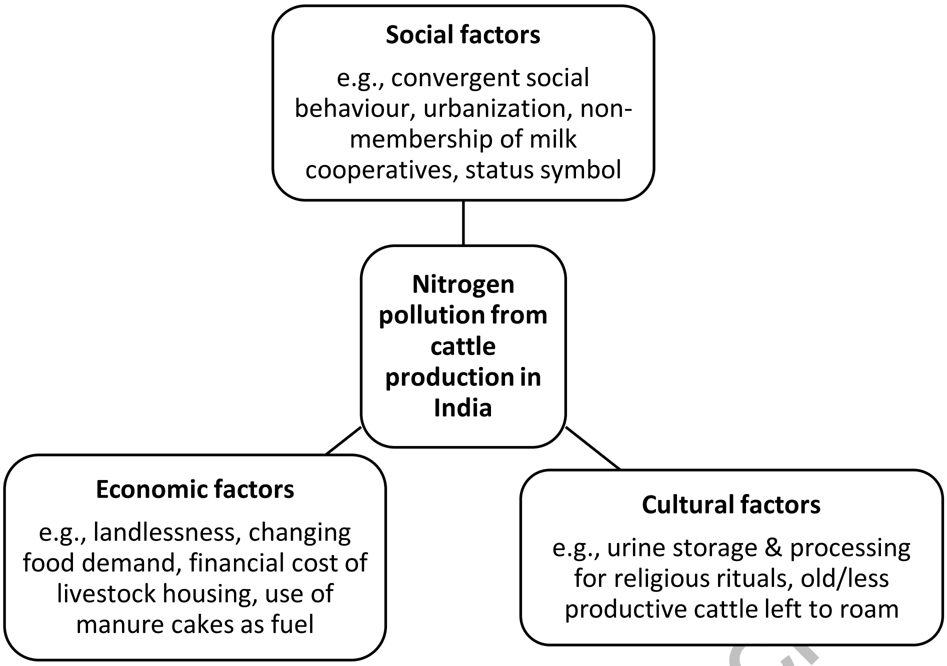

Fig. 2.

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