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Supplementary materials

Estimation of methane and nitrous oxide emissions from Indian livestock

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1. Enteric methane emission

Total methane production from enteric fermentation was estimated using the following equation

$$ME_{ef}\,(\text{Gg year}^{-1}) = \sum_{T,A} MEF_{ef(T,A)} \times N_{(T,A)} \times 10^{-6} \qquad \text{(Eq. S1)}$$

where, ME_{ef} is the aggregated annual methane emission from enteric fermentation, $MEF_{ef(T,A)}$ is the annual methane emission factor (MEF) from enteric fermentation by *A* category of *T* livestock species (kg methane animal^{-1} year^{-1}), $N_{(T,A)}$ is the number of *A* category of *T* livestock species.

$MEF_{ef(T,A)}$ was calculated using the following equation as proposed in the Tier 2 methodology of IPCC.[1]

$$MEF_{ef(T,A)} = \frac{GE_{(T,A)} \times \frac{Y_{m(T)}}{100} \times 365}{55.65} \qquad \text{(Eq. S2)}$$

Where, $MEF_{(T,A)}$ = emission factor for *A* category of *T* livestock species (kg methane animal^{-1} year^{-1}), $GE_{(T,A)}$ = gross energy intake (MJ animal^{-1} day^{-1}) by *A* category of *T* livestock species, $Y_{m(T)}$ = methane conversion factor for *T* livestock species, per cent of feed gross energy intake converted to enteric methane, and the factor 55.65 (MJ kg^{-1} methane) is the energy content of methane.

Gross energy intakes were calculated from nutrient requirement standards in Indian conditions for cattle, buffalo sheep and goat using the following equation:

$$GE_{(T,A)}\,(\text{MJ day}^{-1}) = \frac{TDN_{(T,A)} \times 18.45}{\frac{DE}{100}} \qquad \text{(Eq. S3)}$$

where, $TDN_{(T,A)}$ is the TDN requirements (kg day^{-1}) for *A* category of *T* livestock species. DE is the fraction of GE of feeds, which is digestible. The TDN requirements were estimated considering TDN requirements for maintenance, growth, milk production, pregnancy and work depending upon the categories of livestock species (for growing animals, $TDN_{(T,A)}$ = TDN for maintenance + growth; for lactating animals, $TDN_{(T,A)}$ = TDN for maintenance + lactation; for dry dairy animals, $TDN_{(T,A)}$ = TDN for maintenance; for working animals, $TDN_{(T,A)}$ = TDN for maintenance + work (h day^{-1}); $TDN_{(T,A)}$ = TDN for maintenance + pregnancy). As pregnant animals are supplied with extra nutrients in their third trimester of pregnancy, $TDN_{(T,A)}$ intakes for these animals were considered based on gestation periods.

2. Methane emission from manure management

Methane emission from manure management of cattle, buffalo, sheep, goat, yak and mithun were estimated using the Tier 2 approach of IPCC[1] guidelines.

$$ME_{mm}\ (\text{Gg year}^{-1}) = \sum_{T,A} (MEF_{mm(T,A)} \times N_{(T,A)}) \times 10^{-6} \qquad \text{(Eq. S4)}$$

where, ME_{mm} is the aggregated annual methane emission from manure management and $MEF_{mm(T,A)}$ is the annual methane emission factor from manure management of *A* category under *T* livestock species (kg methane $animal^{-1}$ $year^{-1}$). The $MEF_{mm(T,A)}$ was estimated using the following equation.[1]

$$MEF_{mm(T,A)} = (VS_{(T,A)} \times 365) \times \left[Bo_{(T)} \times 0.67 kg/m^3 \times \sum_{S,K} \frac{MCF_{(S,K)}}{100} \times MS_{(T,S,K)} \right]$$

(Eq. S5)

where, $VS_{(T,A)}$ = daily volatile solid excreted for *A* category of livestock species *T* (kg organic matter $animal^{-1}day^{-1}$), 365 = basis for calculating annual $VS_{(T,A)}$ production, days $year^{-1}$, $Bo_{(T)}$ = maximum methane producing capacity (m^3 methane kg^{-1} of VS excreted) for manure produced by livestock category *T*, 0.67 = conversion factor of m^3 methane to kg methane, $MCF_{(S,K)}$ = methane conversion factors in percent for each manure management system *S* by climate region *K*, $MS_{(T,S,K)}$ = fraction of livestock category *T*'s manure handled using manure management system *S* in climate region *k*, dimensionless.

The VS excretion was estimated using the following equation.

$$VS_{(T,A)} = \left[GE_{(T,A)} \times \left(1 - \frac{DE}{100} \right) + (GE \times UE) \right] \times \left(\frac{1 - Ash}{18.45} \right) \qquad \text{(Eq. S6)}$$

where, $GE_{(T,A)}$ = gross energy intake (MJ day^{-1}) by *A* category of *T* livestock species, DE = digestibility of feeds in percent, (UE × GE) = urinary energy expressed as fraction of GE intake. Ash = the ash content of manure, 18.45 = conversion factor for dietary GE per kg of dry matter (MJ kg^{-1}). This value is relatively constant across a wide range of forage and grain-based feeds commonly consumed by livestock. Urinary energy excretion was considered to be 0.04 fraction of GE.[11] The ash content was taken to be 0.17 of manure dry matter in Indian manure[2].

3. Nitrous oxide emission from animal waste management systems

Direct nitrous oxide emission from manure management was estimated using the Tier 2 approach of IPCC[1] employing the following equation.

$$NE_{mm}(Gg/year) = \sum_{T,A} \left[\left(N_{ex(T,A)} \times 365 \times \sum_{T} MS_{(T,S)} \times EF_{n(S)} \right) \times N_{(T,A)} \right] \times \frac{44}{28} \times 10^{-6} \qquad \text{(Eq. S7)}$$

where, NE_{mm} = direct nitrous oxide emission (Gg $year^{-1}$) from manure management in the country, $N_{ex(T,A)}$ = daily average nitrogen excretion (kg nitrogen $head^{-1}$ day^{-1}) of *A* category of *T* livestock species kg, $MS_{(T,S)}$ = fraction of total annual nitrogen excretion for each *T* livestock species that is managed in manure management system *S*, (dimensionless), $EF_{n(S)}$ = emission factor for direct nitrous oxide emission (kg nitrous oxide-N) from manure management system *S*, 44/28 = conversion of N_2O-N emission to N_2O emission.

The $N_{ex(T,A)}$ for different categories of livestock was derived from the following equation.

$$N_{ex(T,A)}(kg/day) = N_{i(T,A)} \times (1 - N_{r(TA)}) \qquad \text{(Eq. S8)}$$

where, $N_{ex(T)}$ = daily N excretion rates(kg N animal^{-1} day^{-1}), $N_{i(T,A)}$ = the daily N intake (kg day^{-1}) per head of *A* category of *T* livestock species, $N_{r(T,A)}$ = fraction of daily N intake that is retained by *A* category of *T* livestock species.

References

1 IPCC, 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Prepared by the National Greenhouse Gas Inventories Programme, Eggleston HS, Buendia L, Miwa K, Ngara T and Tanabe K (eds), IGES, Japan (2006).

2 Gaur AC, Neelakandan S and Dargan K S, Organic Manures, Revised edition, Indian Council of Agricultural Research, New Delhi (1984).