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DATASETS

DATAMAN: A global database of nitrous oxide and ammonia emission factors for excreta deposited by livestock and land-applied manure

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Abstract

Nitrous oxide (N_2O), ammonia (NH_3), and methane (CH_4) emissions from the manure management chain of livestock production systems are important contributors to greenhouse gases (GHGs) and NH_3 emitted by human activities. Several studies have evaluated manure-related emissions and associated key variables at regional, national, or continental scales. However, there have been few studies focusing on the drivers of these emissions using a global dataset. An international project was created (DATAMAN) to develop a global database on GHG and NH_3 emissions from the manure management chain (housing, storage, and field) to identify key

Abbreviations: BD, bulk density; DM, dry matter; EF, emission factor; FW, fresh weight; GHG, greenhouse gas; IPCC, Intergovernmental Panel on Climate Change; TAN, total ammoniacal N; VWC, volumetric water content; WFPS, water-filled pore space.

variables influencing emissions and ultimately to refine emission factors (EFs) for future national GHG inventories and NH_3 emission reporting. This paper describes the "field" dat abase that focuses on N_2O and NH_3 EFs from land-applied manure and excreta deposited by grazing livestock. We collated relevant information (EFs, manure characteristics, soil properties, and climatic conditions) from published peer-reviewed research, conference papers, and existing databases. The database, containing 5,632 observations compiled from 184 studies, was relatively evenly split between N_2O and NH_3 (56 and 44% of the EF values, respectively). The N_2O data were derived from studies conducted in 21 countries on five continents, with New Zealand, the United Kingdom, Kenya, and Brazil representing 86% of the data. The NH_3 data originated from studies conducted in 17 countries on four continents, with the United Kingdom, Denmark, Canada, and The Netherlands representing 79% of the data. Wet temperate climates represented 90% of the total database. The DATAMAN field database is available at http://www.dataman.co.nz.

1 | INTRODUCTION

Livestock production systems are an important source of greenhouse gases (GHGs), contributing between 7 and 18% of global anthropogenic GHG emissions (Grossi, Goglio, Vitali, & Williams, 2018; Hristov et al., 2013). These systems are also a major source of ammonia (NH_3), representing 60% of global emissions (Uwizeye et al., 2020). The production and supply of animal-based food is projected to grow by about 1.2% per year (Grossi et al., 2018), so there is a need to identify more efficient farming systems where food production can meet local requirements while minimizing emissions of GHG and NH_3 from livestock systems (Grossi et al., 2018; Uwizeye et al., 2020).

The most important gases emitted from livestock production systems are methane (CH_4), nitrous oxide (N_2O), and NH_3 (Chadwick et al., 2011; Webb et al., 2005). Both CH_4 and N_2O contribute directly to global warming; N_2O also contributes to ozone depletion. Globally, CH_4 represents 44% of total GHG emissions from livestock production, mainly associated with enteric fermentation and manure storage, while N_2O represents 32%, which is associated with animal manure in storage, manure applied to land, and deposition of excreta (dung and urine) during grazing (Gerber et al., 2013; Uwizeye et al., 2020). Ammonia emissions have a range of impacts, including loss of nitrogen (N) from agricultural systems, secondary particulate formation, and ecosystem degradation, and are also an indirect source for N_2O emissions (Behera, Sharma, Aneja, & Balasubramanian, 2013; Hafner et al., 2018; Sigurdarson, Svane, & Karring, 2018). In livestock systems, NH_3 emissions are largely derived from manure storage and handling (Webb et al., 2005). Therefore, the manure management chain is an important source of direct and indirect GHG emissions as a consequence of its substantial concentration of N, carbon (C), and water (Chadwick et al., 2011). Although N leaching is also an indirect source of N_2O (IPCC, 2006), we have not included this loss pathway within the existing database due to limited resources. In the future, we hope to be able to expand t he database to include this source.

Several studies have focused on understanding the variables influencing N_2O and NH_3 emissions from manure management and identifying possible mitigation strategies (Broucek, 2018; Hafner et al., 2018; Montes et al., 2013; Sajeev, P., Winiwarter, & Amon, 2018). However, few studies focus on the effect of different manure management and livestock systems on emission factors (EFs), which represent the fraction of N applied as manure that is emitted as either N_2O and NH_3 (IPCC, 2006; Vigan et al., 2019). Emission factors are used in conjunction with activity data (e.g., total amount of manure-N applied to agricultural soils) to calculate gaseous emissions from a specific source, such as land-applied manure. Examples of the use of EFs include (a) constructing national GHG inventories, based on the Intergovernmental Panel on Climate Change (IPCC) inventory methodology guidelines (IPCC, 2006); (b) reporting by parties to the United Nations Convention on Long-range Transboundary Air Pollution, based on the European Monitoring and Evaluation Program/European Environment Agency Guidebook inventory methodology guidelines (European Environment Agency, 2019); and (c) for life cycle assessments, based on guidelines for assessing nutrient flows and emissions (FAO, 2018). Each of these guidelines provides standard methodologies for a specific application to ensure that inventories and life cycle assessments are reported using the latest science, thereby providing relevant information for policy development and climate action.

For national GHG inventory reporting based on the IPCC methodology, most countries currently adopt default Tier 1 EFs for calculating GHG emissions from livestock manure.

Recently, the default IPCC EFs were refined and, where appropriate, disaggregated by climate and N source by including data from more recent studies (IPCC, 2019). Although this refinement is welcome, there is a need to improve our understanding of the key drivers of these GHG EFs to aid the development of effective mitigation strategies (López-Aizpún et al., 2020). Over the last decade, a large body of data has been generated that quantifies emissions arising from each step of the manure management chain. However, there has been no consolidation of t hese data into one single database. Recently, the DATAMAN project was created to build a publicly available global database of CH_4, N_2O, and NH_3 emissions (plus relevant activity and ancillary data) relating to livestock housing, storage, and field application of manure (including excreta deposited during grazing) (GRA, 2020a). The overall aim of the DATAMAN project is to provide researchers and policy makers alike with the most up-to-date knowledge on methods for managing GHG and NH_3 emissions from manure.

The DATAMAN database, disaggregated into (a) housing, (b) storage, and (c) field-based emissions, provides an opportunity to identify possible variables influencing gaseous emissions from the manure management system. Because fluxes from grassland and cropland soils are relatively small compared with N_2O emissions (IPCC, 2006), these emissions were not included in the field database. The objective of the current study was to describe the field-based component of the DATAMAN database (http://www.dataman.co.nz), which focuses on N_2O and NH_3 EFs for land-applied manure and excreta collated from a wide range of countries.

2 | MATERIALS AND METHODS

2.1 | Process of dat a collection

Data collection was carried out from September 2018 to March 2020. Dur i ng this time, information on N_2O and NH_3 emissions from excreta (dung and urine) and land-applied manure was sourced from published peer-reviewed research, theses (undergraduate and postgraduate), and conference papers. Searches were performed using different Web-based platforms such as Web of Science, ScienceDirect, Scielo, and Google Scholar. Keywords included three search terms: (a) manure type (solid manure, farmyard manure, slurry, solid, broiler litter, urine, dung), (b) animal (dairy cattle, beef cattle, sheep, goat, pig, broiler), and (c) gas (N_2O, NH_3, CH_4). Searches included research in English, Spanish, and Portuguese to increase the number of studies included in the database. The database included information extracted from existing datasets that had been collated for developing either country-specific EFs (e.g., Chadwick et al., 2018; Krol et al., 2016; Thorman et al., 2020; van der Weerden et al., 2016,2020) or continental/global EFs (e.g., ALFAM2 (Hafner et al., 2018), ELFE (Vigan et al., 2019), and the 2019 refinement of the 2006 IPCC guidelines (IPCC, 2019). The U.K. studies (Chadwick et al., 2018; Thorman et al., 2020) can be found in the archived data sources of the United Kingdom's Agr i cultural and Environmental Data Archive (AEDA, 2019), where all relevant N_2O and NH_3 studies on excreta and manure (27 studies in total) were included in DATAMAN. Figure 1 presents a summary of the process for collating data.

> Core Ideas
>
> Livestock manure management systems are important sources of greenhouse gas and NH_3 emissions.
> The DATAMAN project aims to relate key variables with emissions and to refine emission factors.
> We built a database on N_2O and NH_3 emissions from land-applied manure and livestock excreta.
> This field database contains 5,632 observations compiled from 184 studies and 25 countries.
> The DATAMAN field database is available at http://www.dataman.co.nz.

All studies were checked for their suitability for inclusion in the database. The selection criteria for N_2O studies were: (a) the studies were field-based (i.e., excluded laboratory, greenhouse, and modeling studies), (b) the measurements were made using static or dynamic chamber-based methods, (c) the total study duration was 14 d or more, (d) cumulative N_2O emissions or EF values were reported, (e) the trials included a nonamended control, (f) the trials continued until the N_2O emissions and soil mineral N concentration from the N treatment had returned to background levels (i.e., there was no significant difference between the N treatment and the nonamended control), (g) the N treatments were limited to one N source to avoid additive or multiplicative effects (e.g., manure + fertilizer treatments were excluded), and (h) the activity data on the N load were available or could be calculated from information provided. These criteria ensured that data were representative of emissions from manure and excreta under field conditions. We acknowledge the criteria for duration of experiments is smaller than that used for recent meta-analyses of N_2O field experiments (30 d or more) (IPCC, 2019; López-Aizpún et al., 2020); the influence of experiment duration on N_2O EF will be analyzed in a subsequent study. Inclusion of relatively short-term experiments broadens the potential use of the database beyond revised EFs and identifying key drivers. For example, a future application of the database may include identifying proxies of EF values based on short-term experiments.

Selection criteria for NH_3 emission studies were: (a) the studies were field based; (b) the NH_3 emissions were measured using micrometeorological methods, aspirated

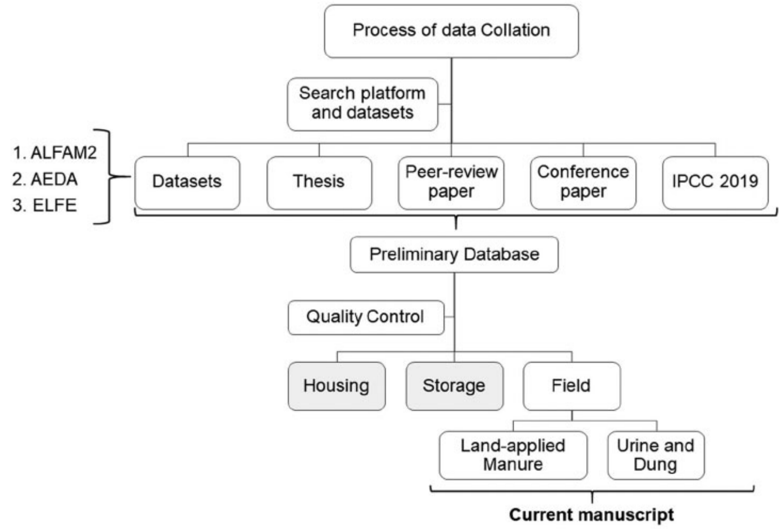

FIGURE 1 Summary of process for collating data of DATAMAN database and the focus of the current paper. AEDA, Agricultural and Environmental Data Archive (AEDA, 2020); ALFAM2, Ammonia Loss from Field-Applied Manure (Hafner et al., 2018); ELFE, ELevage et Facteurs d'Emission (Vigan et al., 2019)

chambers, wind tunnels, or passive sampling techniques; (c) the measurements were conducted for at least 1 d for all manures (except for poultry) and for 7 d or more for poultry manure experiments (due to the slow rate of urea hydrolysis of uric acid present in poultry manure); (d) cumulative NH_3 emissions or EF values were reported; (e) the N treatments were limited to one N source; and (f) activity data on N load were available or could be calculated from information provided. As for N_2O, a subsequent study will determine the influence of experiment duration on revised NH_3 EF values.

When the EF was not reported in the study, it was calculated using the following equation:

$$\text{EF}\ \ (\%) = \frac{\text{CE manure or excreta} - \text{CE control}}{\text{N load}} \times 100 \quad (1)$$

where CE is the cumulative emission of either N_2O or NH_3 (kg N ha^{-1}), and N load relates to total N applied as manure or excreta (kg N ha^{-1}).

2.2 | Description of variables included in the database

Field data were collated using a purpose-designed template developed in Microsoft Excel. The field template (accessible at https://www.dataman.co.nz/Home/About) included 96 variables, which were grouped into six categor ies: "General," "Gas measurement," "Animal," "Manure," "Land," and "Climate."

The "General" category contained 23 variables, including trial description, country, research institute that conducted the study, replicate number, latitude, longitude, dat abase identification, online link to published research paper, reference of research paper, degree of variation in reported EF means, statistical method used for determining EF means, comments, and experiment identification.

The "Gas measurement" category contained 13 variables, including gas measured, emission measurement technique, application start date, start and end of gas measurements, number of measurements, number of chambers per plot, chamber area, number of gas samples per chamber, cumulative emissions, and EF.

The "Animal" category contained 22 variables, including animal category and subcategory, animal breed, and 19 variables associated with animal feeding. Animal categories included cattle, dairy cattle, beef cattle, swine, poultry, sheep, and goat. "Cattle" included both beef cattle and dairy cattle for a small number of studies where it was not possible to disaggregate this animal category further.

The "Manure" category contained 24 variables, including manure type, manure treatment (e.g., none, acidification, anaerobic digestion, covered, compacted, separation, use of inhibitors), chemical composition of manure (e.g., dry matter [DM] content, total N concentration, total ammoniacal N [TAN] concentration, uric acid content [for poultry manures], organic C concentration, C/N ratio, pH), manure application rate, manure total N application rate, manure TAN application rate, manure application method, manure soil incorporation, time of manure incorporation, and type of bedding materi al. We consulted the Ramiran glossary (Pain & Menzi, 2011) for guidance on manure type definitions.

The "Land" category contained 21 variables, including chemical properties of the soil, such as ammonium-N concentration, nitrate-N concentration, total N concentration, organic C concentration, pH, soil bulk density, soil clay, soil texture (all measured at the beginning of the application/excret a deposition), soil water content (either as water-filled pore space [WFPS] or volumetric water content [VWC], both averaged over 30 d following manure application/excreta deposition and also averaged across the entire experiment), crop type, total crop yield, and total N exported in the crop yield.

The "Climate" category contained 11 variables, including climate zone, air temperature (average temperature on first day following manure application, average over first 30 d following manure application, and average across the entire experiment), rainfall and/or irri gation (total mm at first day, average over the first 30 d, and average across the entire experiment), temperature, and windspeed. Climate zone was divided into four categories: temperate wet and dr y and tropical wet and dry. The division between wet and dry in the tropics was based on 1,000 mm of precipitation (>1,000 mm equating with wet/moist climate), and the division in the temperate region was based on mean annual precipit ation/potential evapotranspiration ratio of 1 (>1 equating with a wet/moist climate) (IPCC, 2019). We used GIS data on the IPCC climate zones to categorize zones for each study. In most cases, this was a simple process (e.g., country or coordinates obtained from the research publication). However, in several instances where the study location was close to the boundary of two climate zones and coordinates were not available, it was necessary to conduct a visual comparison of the climate zone GIS layer with towns noted in the research publication.

These variables were selected based on the variables included in the ALFAM2 database (building on earlier informal discussions between members of the Global Research Alliance Manure Management Network [GRA, 2020b; Hafner et al., 2018] and expert judgment of DATAMAN researchers). No one study had the full suite of variables available; however, studies were accepted if either cumulative losses and/or emission factors were included. Several studies had limited information relating to soil and manure characteristics and climate. In those cases, the first or corresponding authors of these studies were contacted for additional information. A similar process was carried out when EF values were not reported or could not be calculated from the information supplied in the publication.

2.3 | Quality control

The database was subjected to a quality control check to identify and correct errors during the data entry phase, thereby increasing the accuracy and confidence of data analysis. The quality control process involved two people: one person sourced the data from publications, conference papers, or theses and entered this into the database. Thereafter, a second person independently checked each data entry by comparing the value against the original source.

This quality control process was limited to the entry of data sourced from individual publications, conference papers, or theses. The data obtained from existing databases (i.e., ALFAM2, ELFE, and AEDA) had already undergone a quality control process when they were collated (Hafner et al., 2018; Vigan et al., 2019; R. Thorman, personal communication, 2020). However, data within the final field database were also visually inspected to identify potential errors in data entry. Data were also checked for duplication, which could occur due to the incorporation of existing datasets and collation of data from individual studies.

3 | MAJOR CHARACTERISTICS OF THE DAT ASET

3.1 | Summary of database per country, continent, and climate zone

Table 1 and Figure 2 present a summary of the database, which is comprised of 5,632 observations that were compiled from 184 studies (existing datasets, theses, conference papers, and peer-reviewed papers) conducted by 91 different institutes. Nitrous oxide emissions represented 56% of the total database, supplying 3,167 observations, and NH_3 represented 44% of the total data. A small number of studies reported both N_2O and NH_3 emission factors, representing 0.2% of the total dataset.

Nitrous oxide EF data were collated from five continents (Africa, the Americas, Asia, Europe, and Oceania) and 21 countries, with New Zealand, United Kingdom, Kenya, and Brazil representing, respectively, 56, 18, 6, and 6% of the total N_2O dataset (Table 1). The Americas represented 11% of the dataset (344 observations), of which Brazil represented 51% of the American dat a, followed by the United States, Canada, Colombia, Argentina, Chile, and Nicaragua. Europe represented 24% of the dataset, where the United Kingdom was the main source of data (73% of the European dataset), followed by Ireland, The Netherlands, Sweden, Germany, Austria, France, and Belgium. Oceania represented 57% of the total N_2O dataset, with 99% of these data sourced from New Zealand studies and the remaining data sourced from

TABLE 1 Summary of the database for NH_3 and N_2O emission factors following land-applied manure or direct deposition of urine and dung of livestock animals

		Number of observations	
Continent	Country	N_2O emission factors	NH_3 emission factors
Europe	Austria	5	7
	Belgium	3	–
	Denmark	–	213
	France	–	43
	Germany	11	125
	Ireland	153	68
	Italy	–	82
	Netherlands	18	183
	Norwa y	–	9
	Sweden	15	49
	Switzerland	–	46
	United Kingdom	557	1,339
	Total	761	2,164
The Americas	Argentina	6	–
	Brazil	177	59
	Canada	54	207
	Chile	2	10
	Colombia	10	–
	Nicaragua	2	–
	United States	93	16
	Total	344	292
Oceania	Australia	26	–
	New Zealand	1,788	8
	Total	1,814	8
Africa	Kenya	201	–
	Zimbabwe	13	–
	Total	214	–
Asia	China	17	–
	Japan	16	1
	Total	33	1
Grand total		3,167	2,465

Australian studies. Africa represented 7% of the total dataset, where information was collated from Kenya and Zimbabwe (94 and 6% of data from Africa, respectively). Asia represented 1% of the total dataset, with data collated from China and Japan.

Ammonia EF data were collated from 17 countries spread across three continents, where the United Kingdom contributed most of the NH_3 dataset (54%) and Denmark, Canada, and The Netherlands combined supplied 25% of the dataset (Table 1). Europe represented 88% of the observations, with the United Kingdom and Denmark supplying 63% of European data. America represented 12% of t he NH_3 dataset, with Canada and Brazil representing 91% of t he American data. Oceania and Asia represented <1% of the dataset. We were unable to source NH_3 EF data from African countries.

Results indicate that Oceania, Asia, and Africa have generally focused on evaluating N_2O emissions from manure and direct deposition of urine and dung, whereas Europe and America have conducted studies on both N_2O and NH_3 emissions from livestock manure and excreta. In addition, more than 70% of data collated from each continent was supplied by only two countries (Figure 2). For example, 100, 78, and 73% of data in Oceania, America, and Europe, respectively, were collated f rom two countries per continent. Although this observation is influenced by the number and size of countries per continent, the importance of agriculture on the

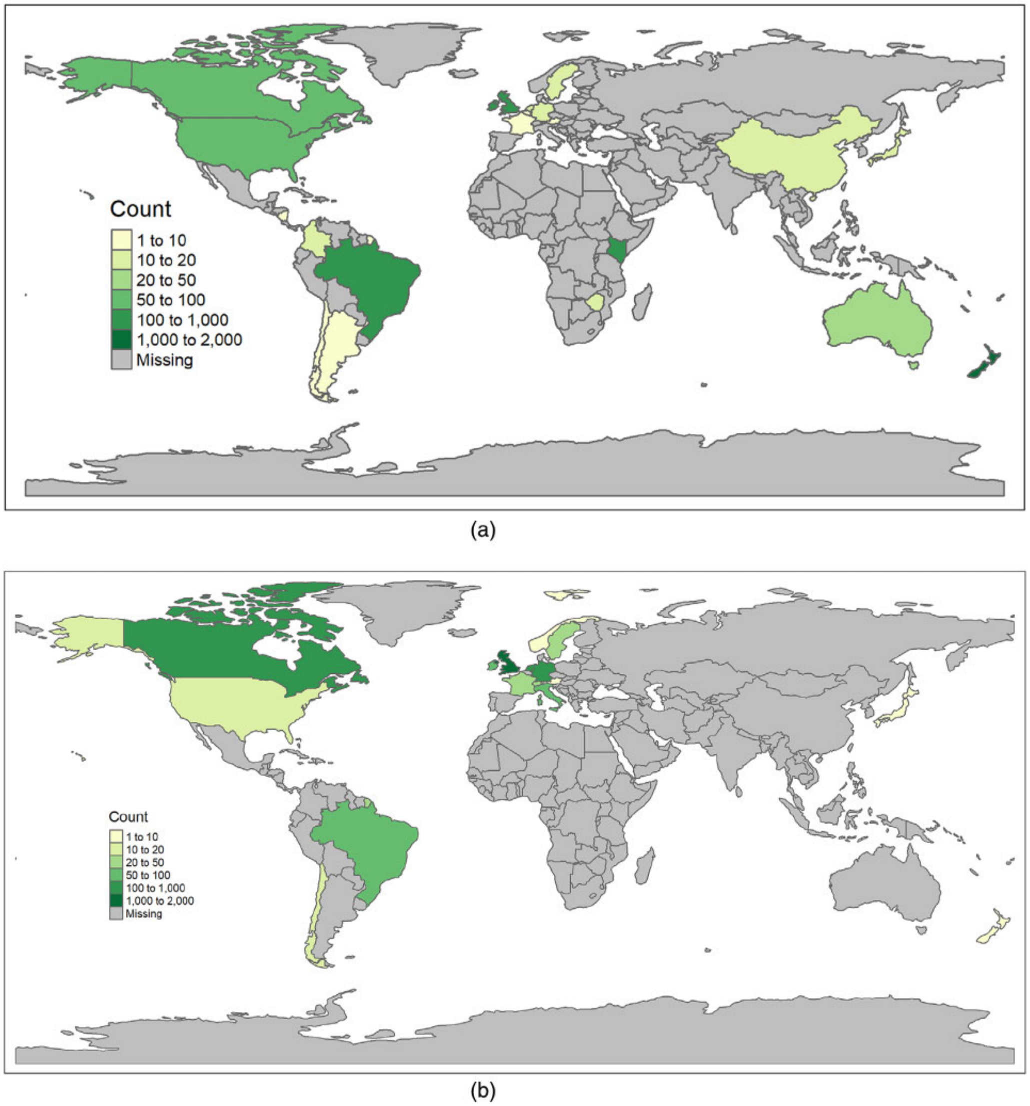

FIGURE 2 Distribution per country for (a) N_2O emission factors and (b) NH_3 emission factors associated with land-applied manure and direct deposition of urine and dung

overall national economy is also influential (e.g., Brazil and New Zealand).

Temperate climates dominated the N_2O and NH_3 studies, representing, respectively, 83 and 98% of the data (Tables 2 and 3). The default N_2O EF for land-applied manure and direct deposition of urine and dung currently used within national GHG inventories is not modified according to climate zone (IPCC, 2006). However, the 2019 refinement of the 2006 IPCC guidelines (IPCC, 2019) includes two climate zones ("wet" and "dry") for N_2O emissions from land-applied manure (EF_1) and from urine and dung deposited by cattle, pigs, and poultry ($EF_{3PRP,\ CCP}$). Our data suggest a large imbalance in the dat aset for both N_2O and NH_3 emissions. Although the current dominance of data from wet temperate climates is partly influenced by the countries participating in the DATAMAN project, a large effort was made to identify and include studies from tropical (dry and wet) and temperate dry climates. Given the importance of

TABLE 2 Summary of data collated for N_2O emission factors for land-applied manure and deposited excreta according to climate zone, animal type, manure type, manure treatment, type of soil and type of crop

	Number of observations for N_2O emission factors	
Variables	Count	Percentage [a]
Climate zone		
Temperate wet	2,641	83
Tropical dry	225	7
Temperate dry	121	4
Tropical wet	180	6
Animal		
Dairy cattle	2,014	64
Beef cattle	569	18
Sheep	405	13
Swine	101	3
Poultry	51	2
Cattle[b]	27	1
Manure type		
Urine—real	1,426	45
Dung	808	26
Slurry	372	12
Urine—synthetic	194	6
Dirty water	180	6
Solid manure	85	3
Farmyard manure	37	1
Broiler litter	30	1
Layer manure	18	1
Composted manure	15	0
Manure treatment		
None	2,612	82
Nitrification inhibitor	454	14
Composted	18	1
Digestion	8	0
Covered	6	0
Solid separation	5	0
Urease inhibitors	5	0
Compacted	4	0
Drying	2	0
Other	37	1
Unsure	16	1
Soil texture		
Silt loam	1,874	59.2
Clay loam	302	9.5
Sandy loam	300	9.5
Clay	216	6.8
Sandy clay loam	95	3.0
Sand	83	2.6
Silty clay loam	28	0.9
Loamy sand	21	0.7
Loam	20	0.6
Sandy clay	8	0.3
Not determined	216	6.8
Crop type		
Grass	2,835	89.6
Cereal	150	4.7
Residue/stubble	100	3.2
Other	50	1.6
None	9	0.3
Not determined	19	0.6

(Continues)

TABLE 2 (Continued)

[a] Totals may not equal 100% due to rounding errors.
[b] "Cattle" includes both beef cattle and dairy cattle because these data were not able to be disaggregated.

tropical regions such as South, East, and Southeast Asia; Latin America; and the Caribbean as hotspots of N_2O and NH_3 emissions from livestock systems (Uwizeye et al., 2020), we encourage researchers to conduct and publish more field studies from these climates to improve our understanding of emissions from land application of livestock manure and excreta. This knowledge will help to further improve default EFs according to climate zone and to increase our understanding of drivers influencing emissions in these regions.

3.2 | Type of animal and manure

The numbers of N_2O and NH_3 EF observations are summarized based on animal and manure types in Tables 2 and 3. Dairy cattle represented 64% of the N_2O dataset, followed by beef cattle (18%) and sheep (13%). Other animal categories represented <7% of the N_2O data. Regarding manure type, urine (real and synthetic) was the most common N source (51% of the dataset);the next most common N sources were dung (26%) and slurry (12%). The remaining 11% was represented by dirty water, solid manure, farmyard manure, broiler litter, layer manure, and composted manure. Given that urine represents 29% of total N_2O emissions from livestock production (Gerber et al., 2013), it was not surprising to see a large proportion of studies focused on this N source.

For NH_3, cattle, swine, and dairy cattle were the most important animal categories, roughly equally contributing to a total of 96% of the dataset. As noted earlier, "cattle" represents the studies where we were unable to disaggregate into dairy or beef cattle. Slurry was the main manure type, representing

TABLE 3 Summary of data collated for NH_3 emission factors for land-applied manure and deposited excreta according to climate zone, animal type, manure type and manure treatment

Variables	Number of observations for NH_3 emission factors	
	Count	Percentage [a]
Climate zone		
Temperate wet	2,406	98
Tropical wet	59	2
Animal		
Cattle[b]	946	38
Swine	748	30
Dairy cattle	681	28
Poultry	52	2
Beef cattle	23	1
Sheep	15	1
Manure type		
Slurry	2,262	92
Urine—real	55	2
Solid manure	40	2
Farmyard manure	35	1
Broiler litter	31	1
Layer manure	17	1
Dung	14	1
Dirty water	4	0
Urine—synthetic	4	0
Deep litter	3	0
Manure treatment		
None	2,001	81
Solid separation	101	4
Digestion	88	4
Nitrification inhibitor	69	3
Acidification	26	1
Covered	4	0
Digestion and solid separation	3	0
Compacted	2	0
Other	156	6
Unsure	15	1

[a]Totals may not equal 100% due to rounding errors.
[b]"Cattle" includes both beef cattle and dairy cattle because these data could not be disaggregated.

92% of the NH_3 dataset. The large number of studies evaluating NH_3 emissions from cattle and pig slurry i s likely to be associated with the significant NH_3 emissions from those sources (Aita et al., 2019; Amon, Kryvoruchko, Amon, & Zechmeister-Boltenstern, 2006; Bourdin, Sakrabani, Kibblewhite, & Lanigan, 2014; Webb, Pain, Bittman, & Morgan, 2010) and the extensive use of slurry as an N source for grassland (Salazar, Martínez-Lagos, Alfaro, & Misselbrook, 2014) and crop production (Velthof & Mosquera, 2011).

3.3 | Manure treatment

The majority of NH_3 and N_2O studies (82%) have determined emissions from untreated manures (Tables 2 and 3). The effectiveness of nitrification inhibitors as a mitigation treatment was examined in 14% of N_2O studies, whereas other manure treatments were either not or very occasionally included (1% of data). For NH_3, a small number of studies focused on storage-based solid separation (4%) or digestion (4%); field-based inclusion of nitrification inhibitors (3%) were also assessed. It was found that only 9.4% of total data (5.1 and 4.3% for the N_2O and NH_3 datasets, respectively) included information on the duration of manure storage, which ranged between 1 and 7 mo.

3.4 | Soil texture and crop type

A summary of soil texture and crop type data is presented in Tables 2 and 3. For the N_2O dataset, silt loam was the most common soil texture, representing 59% of dataset, followed by clay loam (9.5%), sandy loam (9.5%), and clay (6.8%). The remaining 15% was either represented by other soil textural classes (8%) or not determined (7%). Regarding crop type, 90% of the N_2O data was obtained from studies conducted on grass, followed by cereal (4.7%), residue/stubble (3.2%), "other" crop, and "no" crop.

For the NH_3 dataset, clay was the most dominant soil texture (25% of observations), followed by sandy loam (13.5%); loam (12%); and then sand, loamy sand, and clay loam, each representing 11% of the observations. The remaining 17% was represented by other soil textural classes. The majority (56%) of NH_3 data did not include information on crop type. The remaining 44% of studies were carried out on grass (25%), cereal (9%), residue/stubble (8%), and other (1%) types of crop.

3.5 | Manure application method

A summary of data collated on the method of manure application to land is provided in Table 4. This analysis was limited to mechanically applied manures and excludes urine and dung, which are directly deposited by grazing livestock.

For the N_2O dataset, surface broadcast ("broadcast") was the most common manure application method (72%). Many of these N_2O studies have assessed potential co-benefits or pollution swapping associated with reduced NH_3 emissions from low-trajectory techniques such as trailing shoes and hoses and application methods such as shallow injection (e.g., Chadwick et al., 2011; Dell, Meisinger, & Beegle, 2011; Thomsen, Pedersen, Nyord, & Petersen, 2010; Webb et al., 2010). Briefly, trailing hoses apply liquid manure to the vegetation close to the ground in parallel bands; manure

TABLE 4 Summary of data collated for NH_3 and N_2O emission factors for land-applied manure according to method of application

	Number of observations	
Method application	N_2O emission factors	NH_3 emission factors
Broadcast	381	893
Trailing hose	70	546
Trailing shoe	60	229
Shallow injection	19	226
Band spread on slots	–	12
Closed slot	–	28
Closed slot, winged tine	–	3
Pressurized injection	–	3
Unsure	–	6
Other	–	8

Note. Urine and dung data were excluded.

is not deposited between the bands. Trailing shoes part the crop or grass leaves and stems to apply the manure on the soil surface in parallel bands. Shallow injection of manure involves cutting a slot into the soil and injecting the slurry, commonly to a soil depth of 50 mm (Pain & Menzi, 2011).

For the NH_3 studies, the method of manure application has been a particular focus of a large number of these studies. Broadcast application represented 48% of the NH_3 dataset, followed by trailing hose and trailing shoe (27 and 11%, respectively). Other manure application methods represented 15% of the total data. A similar result was reported in the ALFAM2 database (Hafner et al., 2018), which is not surprising, given the ALFAM2 dataset represents 54% of the NH_3 data in the current DATAMAN field dataset. When urine and dung are excluded, more than 90% of NH_3 data relate to slurry application.

The interest in manure application methods primarily stems from the need to more accurately quantify the effectiveness of low-trajectory and injection techniques for reducing NH_3 emissions compared with traditional broadcast methods in Europe, given current restrictions on NH_3 emissions (European Union, 2016). Although the focus has been on reducing NH_3 (and odor) emissions, studies have also investigated whether these novel application methods have a synergistic or antagonistic effect on direct N_2O emissions (Webb et al., 2010).

3.6 | Variables collated in the N_2O and NH_3 dataset

Variables collated in the N_2O and NH_3 dataset are presented in Table 5. Here, we limit the database observations to those including an EF value (i.e., excluding "control" or nil N treatments) and classify the availability of each variable using arbitrary categories of (a) >85% representation and (b) between 50 and 85% representation. For the N_2O dataset, only three variables (manure DM, manure N load, and soil texture) were available in conjunction with the EF values for m ore than 85% of the land-applied manure data. For urine and dung deposition by grazing livestock, this degree of representation was limited to only two variables (manure N load and soil texture). For 50–85% representation, data for 12 variables (manure N concentration, manure organic C concentration, manure pH, manure TAN, soil N, soil organic C, soil pH soil bulk density [BD], soil clay, soil texture, air temperature, and total rainfall) were available for land-applied manure EF values, whereas urine and dung had nine variables (soil N, soil organic C, soil pH, soil BD, soil clay, air temperature, total rain, VWC, and WFPS) available. The information described above suggests that studies evaluating the effect of direct deposition of urine and dung on N_2O emissions generally report more information on soil variables rather than excreta composition variables, whereas studies evaluating N_2O emissions from land-applied manure reported a broader range of variables relating to soil and manure characteristics.

For the NH_3 dataset, variables with >85% representation in association with land-applied manure EF values included manure DM, manure pH, manure total N and TAN load, and soil texture. For urine and dung, the same degree of representation (>85%) was met by only three variables: manure N load, soil clay, and soil texture. For 50–85% representation, six variables (manure total N and TAN concentration, soil pH, soil BD, soil clay, and windspeed) included data in association with land-applied manure EF values, whereas dung and urine deposition had six variables, all associated with soil properties (NO_3, NH_4, total N, organic C concentration, pH, and BD). Studies examining NH_3 emissions from manure application have focused on reporting manure variables that are key in driving the magnitude of NH_3 loss.

3.7 | Frequency and distribution of variables

For the N_2O dataset, EF values were typically between 0 and 2% (Figure 3), although negative EF values (3% of all data) and values >5% (26 observations, or 0.8% of all data) were also present. There were 26 observations where EF values ranged between 5 and 11% for a range of N sources, including urine (EF, 5–9%, 18 observations), slurry (EF, 5–8%, four observations), solid manure (EF, 6–11%, two observations), and dung (EF, 6%, two observations). Most of these observations (21 of 26) were replicate-level data supplied directly by the researcher; such data will have a greater variance compared with mean-level data typically reported in research publications. Where mean-level data are provided, we have included the degree of variance of the mean values when provided in the research publication. Manure N load (kg N

TABLE 5 Percentage of observations for a selection of variables relative to the total number of N_2O and NH_3 emission factors

Variable	N_2O		NH_3	
	Urine and dung (n = 2,424)	Land-applied manure (n = 739)	Urine and dung (n = 73)	Land-applied manure (n = 2,392)
	%			
Manure DM, %	22	93[1]	5	99
Manure total N, kg N t^{-1} FW	43	53	26	62
Manure TAN, kg TAN t^{-1} FW	10	41	0	62
Manure RAN, kg RAN t^{-1} FW	0	2	0	0
Manure organic C, kg C t^{-1} FW	15	67	5	11
Manure C/N ratio	12	22	5	1
Manure pH	9	79	12	96
Manure N load, kg N ha^{-1}	100	94	100	97
Manure TAN load, kg N ha^{-1}	8	52	49	95
Soil NO_3, mg N kg^{-1} dry soil	15	34	60	13
Soil NH_4, mg N kg^{-1} dry soil	15	34	60	13
Soil total N, %	51	51	55	8
Soil organic C, %	76	62	60	47
Soil pH	80	75	79	66
Soil BD, Mg m^{-3}	87	62	71	57
Soil clay, %	59	73	100	69
Soil texture	95	88	89	98
VWC (%, first 30 d)	68	50	0	<1
WFPS (%, first 30 d)	68	50	0	<1
Air temperature ,˚C (first 30 d)	51	57	11	<1
Total rain, mm (first 30 d)	76	79	11	0
Windspeed, m s^{-1} (first 12 h)	0	0	0	56

Note. Italic text shows variables with more than 50% of data. BD, bulk density; DM, dry matter; FW, fresh weight; TAN, total ammoniacal N; RAN, readily available N (uric acid, ammonium, and nitrate); VWC; volumetric water content; WFPS, water-filled pore space.

ha^{-1}) varied widely, with typical application rates of 100–1,200 kg N ha^{-1}. However, there were 12 observations (0.4% of all data) where the N load was between 2,000 and 3,900 kg N ha^{-1}. These data were derived from urine (11 observations) and dung (one observation) studies where either high urine and dung volumes and/or high urine N concentrations were used. Manure DM content was typically between 0.3 and 20%, with urine and dirty water having values of <1%; slurry typically ranging from 1 to 10%; and dung, farmyard manure, solid manure, broiler litter, and layer manure typically >10%. Manure total N content was generally between 0.5 and 8 kg N t^{-1} fresh weight (FW), with lower values associated with dirty water and urine and higher values associated with dung, farmyard manure, and broiler litter. Manure organic C content was typically between 5 and 90 kg C t^{-1} FW, whereas manure C/N ratio varied widely (from 2 to 35).

Regarding soil variables relating to the N_2O dataset, soil pH was typically between 5 and 7, whereas soil N and organic C content ranged between 0.07 and 0.55% and between 2 and 7%, respectively. Soil clay content and soil bulk density were generally between 5 and 35% and between 0.6 and 1.4 g cm^{-3}, respectively. The WFPS and VWC, each averaged over the first 30 d following manure application to land, was typically between 25 and 90% and between 20 and 60% v^{-1}, respectively. Climate variables showed a wide variation, with average air temperature over the first 30 d ranging between 6 and 30 ˚C and total rainfall in the first 30 d ranging from 0 to 150 mm.

For the NH_3 dataset, EF values were typically between 10 and 40% of the total N applied but had a positively skewed distribution with some very large EF values (Figure 4). We identified 10 observations where EF values ranged between 100 and 245%, which were reported in studies evaluating the soil application of swine and cattle slurry (eight and two observations, respectively). Seven of these observations relate to broadcast application of slurry, with the remaining derived from trailing hose (2) and closed slot (1) slurry application. These observations, also reported in the ALFAM2 database (Hafner et al., 2018), suggest that NH_3 was volatilized from other sources in addition to the applied slurry (e.g., soil) and/or large errors associated with the measurement technique, including manure characterization; eight of the

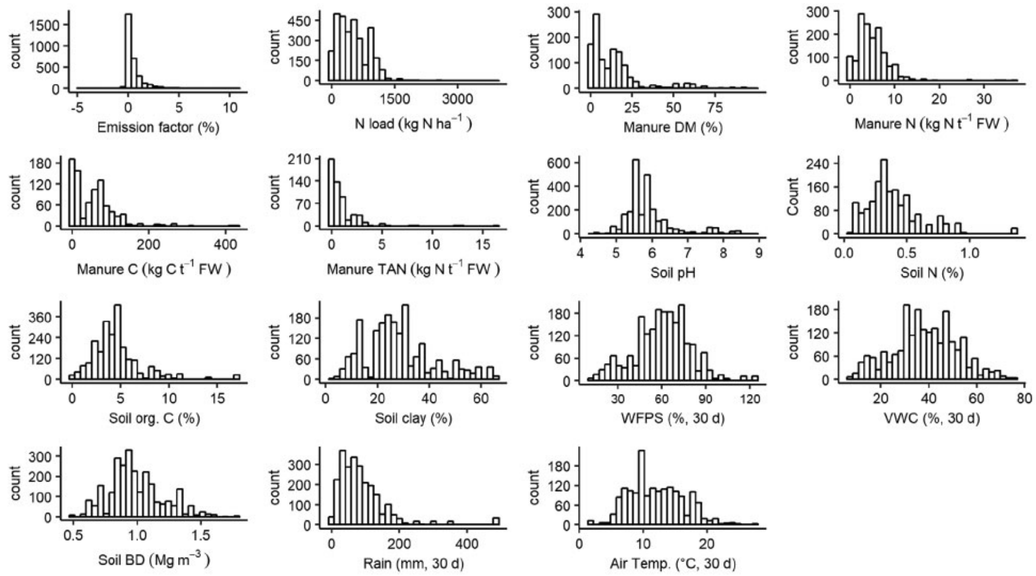

FIGURE 3 Histogram of manure, soil and climate variables for all manure type included in the N_2O database. The y axis shows frequency (count). . BD, bulk density; DM, dry matter; FW, fresh weight; Manure C, manure organic C; TAN, total ammoniacal N; RAN, readily available N (uric acid, ammonium, and nitrate); VWC (%, 30 d), volumetric water content over first 30 d following manure application; WFPS (%, 30 d), water-filled pore space over first 30 d following manure application

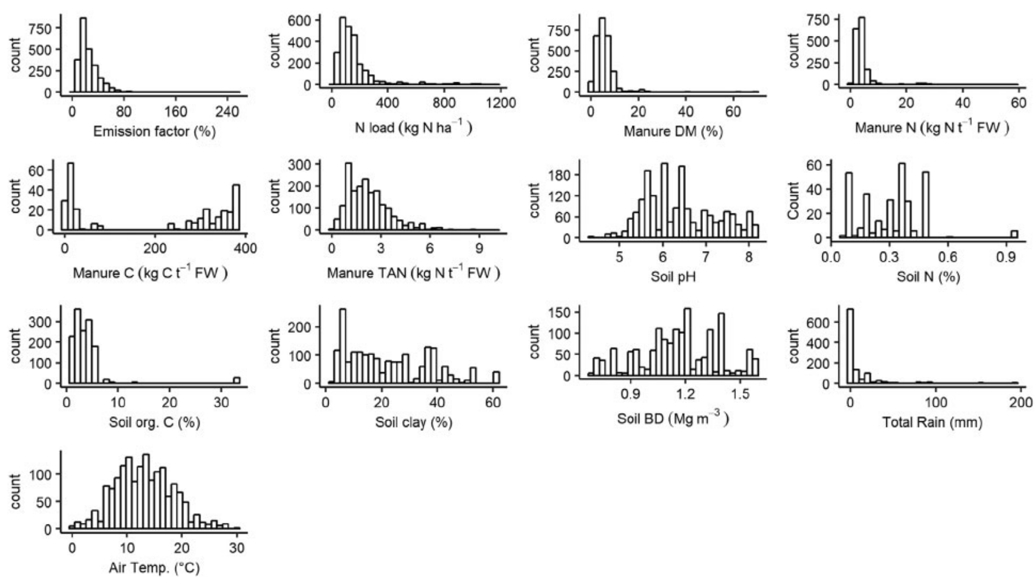

FIGURE 4 Histogram of manure, soil and climate variables for all manure type included in the NH_3 database. The y axis shows frequency (count). BD, bulk density; DM, dry matter; FW, fresh weight; Manure C, manure organic C; TAN, total ammoniacal N; RAN, readily available N (uric acid, ammonium, and nitrate); VWC (%, 30 d), volumetric water content over first 30 d following manure application; WFPS (%, 30 d), water-filled pore space over first 30 d following manure application

observations were made using wind tunnels, whereas the remaining two were made using a micrometeorological method. Manure N load, manure DM, N content soil organic C, and soil clay also showed a positively skewed distribution but with a greater frequency of data, at approximately 100 kg N ha^{-1}, 5% DM, 5 kg N t^{-1} FW, 5% soil organic C concentration, and 5% clay concentration, respectively. Manure organic C concentration, manure C/N ratio, and soil N concentration showed a multimodal distribution, suggesting these variables were derived from g roups of studies with different features, possibly due to the wide range of countries, animals, and manure type included in the field database. Soil pH and soil BD showed a symmetric distribution of data, with mean values of approximately 6 and 1.2 Mg m^{-3}, respectively. Air temperature shows a normal distribution of data (0–30 ˚C), with a greater number of data between 7 and 20 ˚C. Total rainfall over the entire experiment, which averaged 25 d duration, was typically lower than 40 mm.

Although the database has undergone a data entry quality control process, there are still uncertainties in the measurements. Therefore, data should still be critically evaluated before use.

3.8 | Implications of the database

We have collated into a single database N_2O and NH_3 EFs and ancillary data from land-applied livestock manure and direct deposition of urine and dung, sourced from field studies conducted in 25 countries across the globe. Although every continent (except Antarctica) is represented, the database is imbalanced, with nearly 90% of the dat a derived from only eight countries (United Kingdom, New Zealand, Canada, Brazil, Ireland, Denmark, Kenya, and The Netherlands). Furthermore, t he purpose of most experiments has been to investigate specific scenarios, with no attempt to cover all scenarios in a balanced way. Composite EFs based on a meta-analysis of collated studies are therefore likely to be biased because of this imbalance, and care should be taken to investigate possible biases. To expand the diverse range of livestock production systems captured in the database, we encourage further studies in temperate dry and in tropical wet and dry regions, given the low representation from these regions in the database (2, 4, and 4% of the total database, respectively).

Although the database structure includes 94 variables, there are many gaps due to studies not reporting all these variables. This is not surprising, given each field study had different objectives and therefore had different data requirements. However, to ensure that results can be used in meta-analyses for refinement of EF values, model development, or assessing mitigation options, we encourage researchers to include the reporting of crucial manure as well as climate and soil variables (see Hafner et al. [2018] and de Klein et al. [2020], respectively, for suggested NH_3 and N_2O reporting criteria). Analysis of the current version of the field database will be reported in a subsequent study; this will also help to identify key variables for reporting in future studies.

This is the first iteration of the field database (Version 1.0); however, it is envisaged that this database will expand over time, initially as part of a follow-on project called "Mitigating greenhouse gas Emissions from Livestock Systems" or "MELS" (EraNet Joint Call, 2018). This follow-on project will increase the opportunities for improving our knowledge of key drivers, developing more detailed EF values for manure sources across different climatic zones and livestock systems, and evaluating mitigation strategies. Please contact the corresponding author if you wish to contribute data.

4 | CONCLUSION

The DATAMAN "field" database contains information on N_2O and NH_3 EFs for land-applied manure and direct deposition of urine and dung. The database is comprised of 5,632 observations, with N_2O representing 56% and NH_3 representing 44% of the data, and includes soil, manure, and climate data collated from studies conducted in a wide range of countries. The database could be used (a) to estimate EF values and identify key dr ivers, (b) for future refinement of EF values for the IPCC Emission Factor Database and for reporting national inventories, (c) for improving empirical and/or process-based models aimed at estimating N_2O and NH_3 EFs from different animal and manure types, and (d) for assessing potential GHG and NH_3 mitigation strategies for a wide range of manure application and grazing systems. Further studies on GHG and NH_3 emissions from livestock manure management systems across the world will be included over time, thereby increasing oppor tunities for refining and disaggregating EF values and improving our knowledge of key drivers along the manure management chain.

DATA AVAILABILITY STATEMENT

The DATAMAN field database is available at http://www.dataman.co.nz.

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AUTHOR CONTRIBUTIONS

Ignacio Beltran: Data curation; Formal analysis; Investigation; Methodology; Visualization; Writing-original draft; Writing-review & editing. Tony J. van der Weerden: Conceptualization; Data curation; Formal analysis; Funding acquisition; Investigation; Methodology; Project administration; Validation; Writing-original draft; Writing-review & editing; Marta A. Alfaro: Conceptualization; Funding acquisition. Barbara Amon: Conceptualization; Methodology; Validation; Writing-review & editing. Cecile A.M. de Klein: Conceptualization; Methodology; Validation; Writing-review & editing. Peter Grace: Investigation. Sasha Hafner: Investigation; Methodology; Validation. Mélynda Hassouna: Conceptualization; Investigation; Methodology; Validation; Writing-review & editing. Nicholas Hutchings: Conceptualization; Methodology; Validation; Writing-review & editing. Dominika J. Krol: Conceptualization; Investigation; Writing-review & editing; April B. Leytem: Investigation; Writing-review & editing. Alasdair Noble: Formal analysis; Investigation; Methodology; Validation; Writing-original draft; Writing-review & editing. Francisco Javier Salazar: Conceptualization; Methodology; Validation; Writing-original draft. Rachel E. Thorman: Conceptualization; Funding acquisition; Investigation; Methodology; Validation; Writing-review & editing. Gerard L. Velthof: Investigation; Writing-review & editing.

CONFLICT OF INTEREST

The authors declare no conflicts of interest.

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