MANUREDB: AGGREGATION OF U.S. MANURE NUTRIENT DATA

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HIGHLIGHTS

- A database housing U.S. manure and organic amendment data was developed and is publicly available.
- A template standardized the data coming in from multiple laboratory sources.
- The ManureDB website allows for simple summaries, data visualizations, and data downloads.

ABSTRACT. *Manure nutrients serve a valuable role in crop production. Due to the variable nature of manure relative to animal type, storage type, animal husbandry practices, climate, etc., manure sampling and analysis for composition are recommended. However, when specific manure samples are not obtainable, published averages from the past ("book values") are referenced. Temporal, spatial, and animal-specific book values are difficult to update and maintain for use in nutrient management planning and environmental modeling. The vision for a manure nutrient database (ManureDB) was to collect past, present, and future manure sample analysis data from multiple commercial and university laboratories that conduct manure analyses in the United States (U.S.) and dynamically aggregate this data in space and time while meeting FAIR data principles (Findable, Accessible, Interoperable, and Reusable) (Wilkinson et al., 2016). This paper details ManureDB development, database schema, sample template, data-sharing agreement, data upload process, and website to support the database. The prototype database was developed as a Python web app using an sqlite3 database, and a Linux VM deployed the web application. The database schema outlined the organization, labeling, and layout of the database. Laboratories shared manure data without customer names and limited geographical data to protect customer privacy. Data that met minimum requirements were uploaded into the database. The public-facing website showed aggregate summary data for a region, animal type, or time span. As of March 2025, ManureDB included over 481,000 samples from 49 states, 15 laboratories, over 65 animal type characterizations, and 12 organic amendments (e.g., biosolids, feed waste, and swine mortality). With changing animal genetics, feed sources, manure handling and storage systems, climatic conditions, and improved laboratory testing, having more current manure nutrient test values will improve nutrient management planning, manure storage design, prioritization of conservation programs, and agricultural modeling for farmers, agronomists, researchers, and policy makers.*

Keywords. *Agricultural waste, Data standardization, Database, Laboratory, Manure, Nitrogen, Nutrients, Organic amendments, Phosphorus, Potassium.*

When land-applied, livestock manure provides nutrients for growing crops. However, these nutrients are variable depending on animal species, age, diet, management, housing, climate, and manure storage and handling. Knowing what nutrients are contained in a certain manure can aid farmers to better match manure application to field and crop needs and reduce the risk of nutrient loss to the environment. The U.S. Department of Agriculture's Natural Resource Conservation Service (USDA-NRCS) conducts periodic assessments of the conservation practices on U.S. working lands through the Conservation Effects Assessment Project (CEAP). The CEAP II survey conducted in 2013–2016 reported manure was used as an organic fertilizer source on approximately

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13 million ha, equating to 10% of U.S. cultivated land (USDA-NRCS, 2022). The CEAP II survey also observed that 48% of the U.S. land receiving manure utilized manure testing. The remainder of those acres depended on estimated manure nutrient values.

When actual manure samples are not available for planning new animal feeding operations, regulatory targets, treatment functions, utilization estimates, and agricultural and environmental modeling efforts, book values are used to estimate manure nutrient content. Book values are the approximate manure nutrient concentrations of a group of manure samples, usually focused on the major nutrients of nitrogen (N), phosphorus (P), and potassium (K). Several commonly cited published sources of manure nutrient book values include Midwest Plan Service's (MWPS) Manure Characteristics (Lorimor et al., 2004); ASAE D384(R2019) Manure Production and Characteristics standard (ASABE Standards, 2019) that was last updated in 2005 and reaffirmed in 2019; and USDA NRCS's Ag Waste Management Field Handbook (USDA-NRCS, 2008). Most of these book values are based upon a narrow selection of samples from the late 1990s and early 2000s. With the livestock and poultry industries' continued evolution, many farmers, consultants, and researchers noticed a departure from the published book values compared to modern manure nutrient test values (Wilson et al., 2020). There is a clear need for more realistic numbers for current livestock and poultry production. With database management technology readily available, developing a dynamic manure nutrient test database would assist with continual data gathering in large quantities.

Agricultural data aggregation and curation are becoming increasingly widespread to have better knowledge of current conditions and to improve decision-making. From plant and animal genomics and genetics to soil organic matter and nutrient levels, agricultural database projects are increasingly collaborative and expanding (Harper et al., 2018; Lawrence et al., 2020; Lyons et al., 2020; Wieder et al., 2021). Brouder et al. (2019) stated the importance of advancing agriculture from short data life cycles and minimal sharing to an attitude of cultivating open data and data reusability. Data standardization collaborations across the U.S. and the world result in more uniform, understandable, accessible, and science-based data references. Future machine-actionable data depends on good data management based on FAIR Principles (Wilkinson et al., 2016). Having available, rich metadata in a searchable source with a data usage license (Creative Commons, 2025) enables broader database accessibility and application.

A research team of manure management and testing experts sought to investigate, collect, and aggregate manure sample data from across the U.S. through a collaborative effort between universities, laboratories, and related interest groups and transform the information into a dynamic database. A development team at the Minnesota Supercomputing Institute helped scaffold the database architecture. Named ManureDB, the manure database project can be found at z.umn.edu/manuredb, where options to view summary statistics and download data are available to the public (Bohl Bormann et al., 2024a). At the time of publication, the database and related activities are ongoing. The objective of this paper is to describe the development and construction of ManureDB.

Stakeholder Involvement

Building the project included the creation of a stakeholder committee. The stakeholder committee steered the direction of database construction and potential use cases and provided feedback and ideas. The stakeholder committee consisted of public and private laboratory managers, researchers, a biogas representative, livestock companies, and lab proficiency program administrators from across the U.S.

Database Architecture

Minnesota Supercomputing Institute team members developed the prototype database as a Python web app using an sqlite3 database. The database eventually migrated to a Linux VM to deploy the web application. The website utilized a CSS Bootstrap framework.

Database Schema

The schema, shown as an entity relational diagram (ERD) in figure 1, contained five main categories: Lab, AnimalType, Sample, LabResult, and Assay. Each laboratory (Lab) or other data curation participant in the project was assigned a lab_id that was associated with corresponding samples that include name, shortcode, and default_region attributes. The name was the laboratory name, and the shortcode was a lab name abbreviation. Each laboratory was also categorized by one of the seven default U.S. regions based on the laboratory location with the default_region label. Seven regions (Midwest, Northeast, Northern Plains, Pacific Northwest, Southeast, Southern Plains, and Southwest) were delineated to separate areas of the U.S. similar to the USDA Climate Hub regions, except that ManureDB included California in the Southwest region and excluded the Northern Forests and Caribbean regions (USDA, 2020).

The AnimalType category included the animal_type_id, the animal or other amendment type selected for a sample, and the name, category, and combined_category. For example, for the name "Chicken – Breeder," the category would be "Chicken," and the combined_category would be "Poultry." An animal type combined category (combined_category) was created to group together some of the like animal or other amendment types (animal_type_id); all samples were assigned an animal_type_id of beef, swine, dairy, poultry, other animal, or other amendment. The Sample category included the laboratory's sample ID (sample_id) and a unique ManureDB Sample ID (manuredb_sample_public_identifier) given to each sample along with the lab_id, animal_type_id as described previously. Other metadata about the sample were also contained in this category, including year analyzed (year_analyzed), state (state), region (region), manure type (manure_type), manure treatment (manure_treatment), agitation status (agitated), bedding type (bedding_type), storage type (storage_type), length of storage (length_of_storage), application method

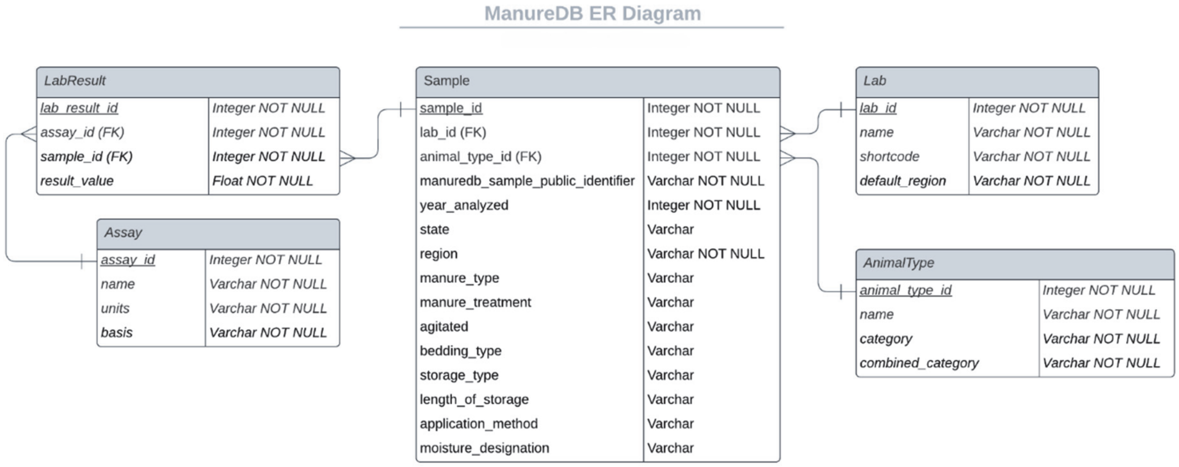

Figure 1. ManureDB entity relational (ER) diagram as of February 2024. ["NOT NULL" indicates the entity is required for inclusion in the database; variable character (varchar); foreign key (FK).]

(application_method), and moisture designation (moisture_designation). These attributes are further described in the following sections.

The Assay category included assay_id, with associated name, units, and basis. The assay_id was the analyte name (e.g., N, P, K, S, etc.), name was the analytical method used for that analyte, units showed what units the result_value was reported in, and basis showed if the sample was reported on a wet (as-received) or dry basis. The analytical method options were derived from the Recommended Methods of Manure Analysis (Wilson et al., 2022), the AgGateway Modus Agricultural Lab Test Data Standard (AgGateway, 2023), and interviews with laboratories. In the LabResult category, each lab_result_id had a sample_id, assay_id, and result_value associated with it. The sample_id was the same as described in the Sample category above. The assay_id was the same as described in the Assay category above. The result_value was the numerical result of an analysis. A Lab may have used a specific Assay to analyze many Samples to obtain a LabResult for each one. At a minimum, each sample must include laboratory name (lab_id), animal or other amendment type (animal_type_id), and year analyzed (year_analyzed).

Data Privacy

This project protected data privacy through data sharing agreements and established rules. A participating laboratory or data partner and the University of Minnesota both signed a data use agreement prior to data transfer. Laboratories shared manure sample analysis data (Sample) with no customer names or addresses attributed to manure samples. Only the state and/or first three digits of a ZIP Code were uploaded into the database. The public-facing website did not include ZIP Codes, laboratory identities (lab_id), analytical methods (assay_id), account information (sample_id), or sample notes. A minimum of five annual samples for a specific animal or other amendment type from a state, region, or the U.S. was necessary for inclusion in public summaries, a requirement verified by the second data validation step. By incorporating these rules, the public dataset is available for downloading to all users.

Creation of the Data Template

A standardized survey data template with versioning was created and iteratively refined to capture the information coming from laboratories while placing that data into a standard format prior to uploading it into the database. The template contents are displayed in table 1. The category names are (or represent) the schema names. For inclusion in the database, the only requirements were the year the sample was analyzed (year_analyzed), the laboratory where analyzed (lab_id), and the animal type or other organic amendment category (animal_type_id) for inclusion in the database. The variety of date options came from interviews with laboratory managers and their data reporting procedures.

The sample notes column included any notes the customer wrote on the sample submittal form and were included with the data submitted to the ManureDB project. During the data cleaning process, prior to database upload, a ManureDB team member searched the sample notes column with keywords to see if other labels for a sample could be added. The data template incorporated the broad range of manure types, storage, treatment, bedding, and handling information collected on data submittal forms for the various laboratories (table 1). Table 1 shows that the template provided a diverse analyte selection, including macronutrients, micronutrients, metals, characteristics, and calculations. For each analyte, users chose the analytical method (assay_id), units (unit), and basis (basis) from controlled options.

Initially, the animal or other amendment type field primarily contained common livestock species. However, as data collection progressed, the nomenclature expanded to accommodate more details and naming conventions. This involved incorporating specific sex and life stages, as well as a wider range of species. Some laboratories utilized general terms like "poultry," where others specified "chicken-layer" or "turkey." Similarly, "cattle" lacked differentiation between beef and dairy. Further complexity grew with the addition of gender or life stage information, such as "swine-

Table 1. Data template for ManureDB as of 2/21/2025. Entity relational diagram (ERD) names are shown in italics and relate to figure 1. Required items denoted with an *.

Template Categories	Sample Metadata Fillable and Selection Options
Date	*Year analyzed (*year_analyzed)*, date sampled, date received, date reported
Lab sample designations	*Lab name (*lab_id*), sample ID (*sample_id*), account #, sample notes
Location	State (*state*), ZIP code (first three digits only)
Manure type (*manure_type*)	Liquid, Slurry, Semi-solid, Solid, Separated Liquid, Separated Solid, Digestate, Digested Solid, Runoff, Sludge, As-excreted (urine), As-excreted (feces), Litter, Compost, Unknown
Manure treatment (*manure_treatment*)	Dried, Aerobic, Alum, KLASP, Phytase, PLT, Poultry Guard, Other Treatment, Unknown, No Treatment
Agitation (*agitated*)	Yes, No, Unknown
*Animal or Other Amendment Type *(animal_type_id)*	Alpaca, Bat, Beef, Beef – Breeding, Beef – Calf, Beef - Replacement Heifers, Beef – Finisher, Beef – Stocker, Biosolids, Bison, Cattle, Chicken, Chicken – Breeder, Chicken – Broiler, Chicken – Layer, Chicken – Pullet, Cricket, Dairy, Dairy – Calf, Dairy - Calf and Heifer, Dairy – Heifers, Dairy - Lactating Cow, Dairy - Dry Cow, Dairy – Steer, Deer, Dog, Donkey, Duck, Egret, Elephant, Elk, Emu, Ferret, Fish, Geese, Goat, Guinea Pig, Horse, Llama, Mink, Mouse, Partridge, Pigeon, Poultry, Poultry – Mortality, Rabbit, Rat, Quail, Sheep, Swine - Farrow to Wean, Swine - Farrow to Feeder, Swine - Farrow to Finish, Swine - Feeder to Finish, Swine – Finisher, Swine – Gestation, Swine - Wean to Finish, Swine – Nursery, Swine - Boar Stud, Swine – Mortality, Swine, Turkey, Turkey – Meat, Turkey – Hen, Veal, Worm, Other - Brewery Waste, Other – Biochar, Other - Cardboard Waste, Other - Egg Shells, Other - Egg Wash Water, Other - Fish Pond Sludge, Other - Feed Leachate, Other - Food Waste, Other - Grape Pomace, Other - Milkhouse Rinse Water, Other – Mushroom, Other - Paper Waste, Other – Paunch, Other - Sewage Sludge, Other - Spoiled Feed, Other – Whey, Other - Truck Wash, Other - Yard Waste, Mixed, Unknown
Bedding type (*bedding_type*)	Hardwood Sawdust, Hardwood Shavings, Paper, Peanut Hulls, Pine Sawdust, Pine Shavings, Rice Hulls, Sand, Straw, Other/Unspecified Bedding, Not Included, Unknown
Storage type (*storage_type*)	Lagoon, Uncovered Pit or Tank, Covered Pit or Tank, Earthen Basin, Runoff Holding Pond, Solid, Underfloor Solid Storage, Stockpiled Under Cover, Stockpiled Outdoors, Cage-free Poultry, Unknown
Length of storage (length_of_storage)	Daily haul, 0 to <3 months, 3 to <6 months, 6 to <12 months, 12+ months, Unknown
Application method (*application_method*)	Irrigation, Broadcast, Broadcast - Incorporated within 24 hours, Broadcast - Incorporated after 24 hours, Injection, Unknown
Analyte information (*assay_id*)	Analytical method (*name*), reported units (*units*), basis (*basis*) Targeted analytes: Total Solids, Moisture, Total Nitrogen, Phosphorus, Water Extractable Phosphorus, Potassium, Soluble Potassium, Zinc, Sulfur, Sulfate-S, Total Carbon, Total Organic Carbon, pH, Volatile Solids, Total Suspended Solids, Total Dissolved Solids, Nitrate-N, Chloride, Ash, Electrical Conductivity, Organic Matter, Carbon:Nitrogen Ratio, Ammonium-N, Boron, Calcium, Copper, Iron, Magnesium, Manganese, Molybdenum, Sodium, Arsenic, Cadmium, Cobalt, Chromium, Mercury, Nickel, Lead, Selenium, Aluminum, Barium, Silicon, Strontium, Calcium Carbonate Equivalent (CCE), Sodium Absorption Ratio (SAR), Cation Ratio of Soil Structural Stability (CROSS), Fecal Starch

nursery" or "swine-gestation." Making additional subtype options is straightforward and may have valid reasons for future data classifications. However, there is a cost-benefit consideration, as this requires a review, potential reclassification, and reincorporation of previously uploaded data. Laboratories also analyzed organic amendments for nutrient analysis, so the team decided to include types of organic amendments used for agricultural purposes that had multiple samples analyzed.

DATA COLLECTION AND INCORPORATION

Recruitment to participate in this project came through prior relationships, articles, outreach through laboratory proficiency organizations, presentations at regional, national, and international conferences, conference proceedings, and word of mouth. Data curation partners included U.S.-based private laboratories, university laboratories, and university researchers who sent their samples to other laboratories. The Manure Analysis Proficiency (MAP) program is the only manure analysis proficiency program in North America (proficiency samples are sent to labs twice annually), and an estimated 95% of the samples in ManureDB came from MAP-participating laboratories (MDA, 2025). After a data use agreement was signed between the University of Minnesota and the data curation partner, the data curation partner emailed a spreadsheet of their data to a ManureDB team member. A ManureDB team member then saved and formatted the data file to fit the survey data template along with further classifying the data from the sample notes and/or extra laboratory information given using a ManureDB Data Standard Operating Procedure (SOP) developed iteratively throughout the data acquisition and cleaning process.

After the cleaned data file was saved in a comma-separated values (CSV) text file format, it was manually reviewed in the primary validation step to confirm that the required information was filled out for each sample (lab name, year analyzed, animal or other amendment type), proper date and ZIP code formatting was used, metadata was selected from a controlled vocabulary of options for analytes, and the data was restricted to numerical characters for analyte values. The CSV file was then uploaded into a private section of the ManureDB website that provided a programmatic review of the same items. After primary validation, the CSV file was uploaded into the database for the second validation step. The second validation step matched ZIP Codes with supplied U.S. state data, samples with blanks for all analyte data, values below minimum (0.0) or above maximum (100.0) for Total Solids or Moisture, and text that matched the options available for these columns: Manure Type, Animal or Other Amendment Type, Manure Treatment, Agitated, Bedding Type, Storage Type, Length of Storage, and Application Method. After passing the second validation step, the data was imported into the database and each sample was assigned a randomly generated Universally Unique

Identifier (UUID) with no relation to the lab, location, or any other attribute.

During the upload process to the database, several other data columns were added to the sample data in post-processing. The moisture_designation column in figure 1 was calculated from the moisture designation rule defined in table 2. A region label was added to a sample based on the rule also in table 2. We reviewed laboratories that had the state labeled on their samples and calculated what percentage of the samples were in that same region as the laboratory. After reviewing eight laboratories with known sample locations, an average of 92% of samples from those eight laboratories came from the same region as the laboratory location. Based on that information, we felt confident in those region assignments to samples with unknown locations.

For analytes with multiple analytical method options, a new combined method column was created for each analyte to assist with analyte comparisons regardless of analytical method. This combined method column was the analyte column shown in the public download, as the analytical method selections were available internally only. ManureDB incorporated conversion equations based on the Recommended Methods of Manure Analysis to store and display data in consistent units on the ManureDB database and website (Wilson et al., 2022).

MANUREDB DATA AGGREGATION

The first datasets were uploaded into the database in November 2022, and the website interface became public in May 2023. Data was available for structured exploration, and a download option became available in January 2024. On the ManureDB website dashboard, one can select the animal type combined category of either beef, dairy, swine, poultry, sheep, or horse and customize the search by choosing year analyzed, display units, U.S. region, moisture designation, manure type, bedding type, and storage type. Graphics and tables display total N, P_2O_5, K_2O, sulfur, NH_4-N, and total solids medians and interquartile ranges, medians over time, and medians by state. These dashboard options allow for easy sharing; however, there are limits with the predefined selections. On the data explorer tab of the website, one can select animal type combined categories, animal type, moisture designation, U.S. region, state, year, and units and download that data selection as a CSV file.

As of March 2025, ManureDB included over 481,000 samples from 49 states, 15 laboratories, 65 animal types, and 12 organic amendments, spanning 1998–2023. Most samples were from animal sources and fewer than 2,400 were from other organic amendments, such as biosolids, swine mortality, or spoiled feed. Including various analytical methods and nutrient analyses brought ManureDB as of March 2025 to >5,100,000 total data points. Tables 3 and 4 demonstrate the distribution of metadata categories and analytes. Some data commonalities included 98% of samples reporting Total N, P, and K, 85% reporting manure type, 53% reporting total solids, and 50%–60% reporting for most micronutrients. Sample data included state in 74.2% of samples, followed by manure_type (66.6%), storage_type (45.2%), application_method (39.3%), bedding_type (7.3%), length_of_storage (4.2%), manure_treatment (3.1%), and agitated (0.2%). Metadata labels are subject to interpretation. For example, "lagoon" has different meanings across the country from a manure storage area with extra volume for treatment purposes to any unroofed earthen basin. Interpretation of labels is left to the discretion of the user.

DATA SOURCE COMPARISONS

Using previously published MWPS (Lorimor et al., 2004) and ASABE (ASABE Standards, 2019) as-stored manure characteristics, we compared the data sources of select similar animal types to ManureDB from 2012 to 2022. Often MWPS and ASABE had several values for a species to account for different life stages or manure storages. A strength of ManureDB was the large quantity of manure samples to draw from compared to either MWPS or ASABE. While MWPS did not specify the number of samples their nutrient averages were calculated from, ASABE did include the sample quantities for most manure types. For total N, P_2O_5, and K_2O, ManureDB had over 26,000 solid dairy manure samples compared to ASABE's 666 samples for their estimates. The

Table 3. Percent of ManureDB samples that have metadata descriptions, as of February 2024.

ManureDB Data Template Metadata Categories	%
Animal or Other Amendment Type	100
Animal Type Combined Category	100
Year Analyzed	100
Region	100
Moisture Designation	99.4
State	74.2
Manure Type	66.6
Storage Type	45.2
Application Method	39.3
Bedding Type	7.3
Length of Storage	4.2
Manure Treatment	3.1
Agitated or not	0.2

Table 2. Post-processing sample classifications for region and moisture designation.

Calculated Column	Classification Process
Region (*region*)	1. One of seven region labels (Midwest, Northeast, Northern Plains, Pacific Northwest, Southeast, Southern Plains, and Southwest) were added to a sample based on the sample's state during the import process. 2. If no ZIP Code or state were listed for a sample, the *default_region* was assigned automatically to the region where the laboratory was located during the data import process
Moisture Designation (*moisture_designation*)	1. If a sample had total solids measured, it had a moisture designation based on if total solids="liquid", >4%–10% total solids="slurry," >10%–20% total solids="semi-solid," or >20% total solids="solid" based on Midwest Plan Service (MWPS) definitions (Lorimor et al., 2004). 2. If a sample had no total solids or moisture level, we used the lab-designated manure type label of liquid, solid, slurry, or semi-solid. 3. If the manure type was labeled as litter, the sample was then labeled as solid. 4. If a sample had no total solids, moisture, or manure type, this category was left blank.

Table 4. Percent of ManureDB samples that have certain analyte measurements, as of February 2024.

ManureDB Data Template Analyte Categories	%
Phosphorus	99.1
Potassium	99.1
Total N	98.6
Sulfur	67.2
Total Solids	58.4
Calcium	58.4
Magnesium	58.3
Sodium	58.2
Zinc	58.1
Manganese	58.0
Copper	57.7
Moisture	54.5
Iron	53.2
Boron	43.3
pH	36.5
Ammonium-N	34.2
Aluminum	33.0
Nitrate-N	3.1
Carbon:Nitrogen Ratio	3.0
Ash	3.0
Electrical Conductivity	2.3
Volatile Solids	1.2
Organic Matter	1.0
Nickel	0.8
Chromium	0.7
Chloride	0.5
Molybdenum	0.4
Total Dissolved Solids	0.4
Total Carbon	0.3
Calcium Carbonate Equivalent	0.2
Water Extractable Phosphorus	0.2
Cadmium	0.2
Lead	0.2
Cation Ratio of Soil Structural Stability	0.1
Sodium Absorption Ratio	0.1
Sulfate-S	0.1
Arsenic	0.1
Cobalt	0.1

ASABE broiler chicken nutrient values were derived from only 95 samples, while ManureDB had over 18,000 broiler manure samples. ManureDB's data originated from commercial and university laboratories across 13 states that analyzed samples across multiple other states. While the ASABE and MWPS values also drew from university and commercial laboratories, they had fewer locations compared to ManureDB. For example, the ASABE broiler chicken values were derived from only samples from Missouri and Oklahoma, and there were no details on the quantity or origination of the ASABE turkey samples.

ManureDB can store metadata details about manure samples, but these were not always available from laboratory records. For this reason, the MWPS and ASABE book values did offer a better insight for some scenarios. Determining whether ManureDB manure nutrient values have changed from the MWPS and ASABE book values will be difficult to discern. One cannot know whether there were shifts in manure nutrients or just differences resulting from a larger volume of samples drawn from more locations across the U.S. that were available in ManureDB. Improved ManureDB sample metadata, especially for manure storages, life stages, manure treatments, and bedding inclusion would enhance comparisons to previously published book values.

Discussion and Future Plans

Updated manure book values would better estimate how much land would be required for new or expanding animal feeding operations. Manure nutrient data similarly informs nutrient reduction strategies for water quality improvements (Iowa Department of Agriculture and Land Stewardship et al., 2012; Minnesota Pollution Control Agency, 2014). While this manure database resource will provide a broader dataset for manure nutrient estimates, the wide variation in any analyte should also encourage manure and organic amendment producers and users to analyze their manure and organic amendments more frequently, once a farm is established. Obtaining a representative manure sample through proper agitation/mixing and subsample collection (Aguirre-Villegas et al., 2018; Miller et al., 2019; Wilson et al., 2022) is important in getting nutrient analyses that reflect the manure produced and stored on a farm and the manure nutrients applied to fields. This database attempts to minimize the variation introduced through unequal sampling in space and time with the large sample numbers. Routine manure sampling is still recommended, and hopefully emphasized, by this database.

With more interest in agricultural and environmental modeling (Jones et al., 2017), having a larger database of many manure types can create a useful resource for manure reference numbers on a variety of analytes. This database can also show improved estimates of other less studied manure components such as chloride, which has become a water quality concern in some regions (Belanger, 2023). The significance of an open-access manure database is equitable access to realistic manure values for different scenarios across the country and the ability of it to stay current with annual data additions. This database could eventually expand to include other aspects of manure and organic amendments such as greenhouse gas emissions potential, biogas potential, wastewater, nutrition and diet information, and compost. The project could also expand the footprint to include other countries. The team archived the first dataset in the USDA National Agricultural Library Ag Data Commons in August 2024 and plans to continue archiving the ManureDB data on an annual basis (Bohl Bormann et al., 2024b; Re3data.Org, 2015). New data will continue to be reviewed before incorporation into the database.

Summary

With the work already completed and plans for continued growth and improvement, this manure database project assists with the goal of providing realistic nutrient test values from many sources, regions, and operations while utilizing FAIR principles. This information enhances the ability to benchmark a farm's manure nutrients against collective data; improve nutrient management planning and manure storage design; prioritize conservation programs; and support agricultural modeling for farmers, agronomists, researchers, and policy makers.

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