U.S. MIDWEST MANURE SECONDARY MACRONUTRIENT AND MICRONUTRIENT OBSERVATIONS 2021-2025

N.L. Bohl Bormann, M.L Wilson, E.L. Cortus, K.A.T. Silverstein, and L.M. Gunderson
University of Minnesota-Twin Cities, Saint Paul, MN
nlbb@umn.edu

ABSTRACT

Livestock and poultry manures provide multiple nutrients essential for plant growth and for some farms, manure is the major source of applied crop nutrients. While nutrient management planning and manure testing focus on the primary macronutrient content (N-P-K), manures also provide varying amounts of secondary macronutrients and micronutrients. With the thousands of samples archived in ManureDB, this manure nutrient database offers an opportunity to analyze Midwest region samples that had secondary macronutrient and micronutrient analyses done in addition to the primary macronutrients. Especially with sulfur applications recommended more often for certain crops and soils, knowing the approximate content in common Midwest manure sources can aid in management decisions. For this analysis, we chose solid and liquid dairy, solid and liquid beef, solid and liquid swine, and solid poultry manures from 2021-2025 to analyze for their secondary macronutrient (S, Mg) and micronutrient content (B, Cu, Mn, Zn). In general, the liquid and solid dairy manures had lower secondary macronutrient and micronutrient concentrations, and solid poultry manures had higher concentrations of those nutrients compared to the other manures. Depending on the type and application rate, manure can be an adequate source of secondary macronutrients and micronutrients for Midwest agronomic crops. As interest and research into crop response to these nutrients grows, ManureDB can be a resource and benchmark for these analytes.

INTRODUCTION

Crops need nutrients to grow, and manure contains varying amounts of macronutrients and micronutrients. ManureDB, a public US manure nutrient database, came online in 2023 and by October 2026 contained over 580,000 manure and organic amendment samples (Bohl Bormann, et al., 2026a). For details on sample collection, validation measures, and aggregation for ManureDB, see Bohl Bormann et al. (2025). Approximately 98% of ManureDB samples have major macronutrient (N, P, K) analysis. Often secondary macronutrients, micronutrients, and elements are analyzed and displayed in Table 1. These elements can be beneficial for crops or may be detrimental if overapplied in certain cases (e.g., copper toxicity).

Table 1. ManureDB macronutrient, micronutrient, and select beneficial element percentage for all years as of October 22, 2026, from 583,333 total samples.

Analyte	% of samples with analysis
Phosphorus (P)	98.1%

Potassium (K)	98.1%
Total Nitrogen (TN)	97.5%
Sulfur (S)	67.0%
Calcium (Ca)	60.6%
Manganese (Mn)	58.0%
Magnesium (Mg)	57.9%
Copper (Cu)	57.9%
Zinc (Zn)	57.7%
Sodium (Na)	57.1%
Iron (Fe)	52.9%
Boron (B)	40.0%
Ammonium-N (NH_4-N)	34.7%
Aluminum (Al)	29.6%
Nickel (Ni)	2.6%
Molybdenum (Mo)	1.7%
Chloride (Cl)	0.6%

ManureDB data has been reviewed and published for N-P-K content in common animal types, but not for secondary macronutrients or micronutrients (Bohl Bormann et al., 2026; Chatterjee & Bohl Bormann, 2026). This paper focuses on those secondary macronutrients (S, Mg) and micronutrients (B, Cu, Mn, Zn) that may be of interest to Minnesota (MN) and other Midwest farmers (Kaiser et al., 2023, 2024b, 2024a; Kaiser & Rosen, 2023, 2024; Kaiser & Vetsch, 2024; University of Minnesota Extension, 2026). Sulfur especially is of interest lately with some crops having economical responses to sulfur applications and less sulfur deposition from the atmosphere than in the recent past (EPA, 2023). Table 2 lists the MN recommended amounts of those selected nutrients to apply when warranted by soil or plant analysis.

Table 2. Minnesota S, Mg, B, Cu, Mn, and Zn recommended amounts to apply for mineral soils when applicable for agronomic crops (University of Minnesota Extension, 2026)

Secondary macronutrient or micronutrient	Application rate lbs./ac
S	10-25
Mg	10-100
B	2-4
Cu	0
Mn	0
Zn	1-2

MATERIALS AND METHODS

The October 22, 2026 ManureDB wet (as-received) basis dataset (Bohl Bormann et al., 2026) was sorted using the following parameters:

- Years: 2021-2025

- Animal manure types: liquid beef, liquid dairy, liquid swine, solid beef, solid dairy, solid swine, solid poultry, solid layer, solid broiler, solid turkey
    - Liquid manure <20% total solids (TS)
    - Solid manure >20% TS
- Analytes: S, Mg, B, Cu, Mn, Zn
- Midwest region states: IA, IL, IN, MI, MN, MO, OH, WI

We selected the recent five-year time span to capture modern livestock and poultry production and manure management practices. These manure types comprise most of the manure applied in the Midwest. We included a generic "poultry" label along with the poultry subtypes of broiler, layer, and turkey when available. The 20% TS threshold was used to divide the pumpable (liquid) manure from the stackable (solid) manure. However, the solid-liquid differentiation can vary based on species, bedding usage, housing, and manure management.

Utilizing the base R package (R Core Team, 2025), we calculated wet basis medians, median absolute deviations (MAD), and counts for each of the six analytes and animal and manure type combinations. We selected medians to report as they are less prone to outlier influence than means. Similarly, MADs were calculated as a standard deviation alternative to show data variability due to less impact from outliers. MAD is calculated by subtracting the median from every datapoint and finding the median of that group of calculations. These results were compared to the 2005 as-removed manure production characteristics from ASAE D384.2 (ASABE, 2019) when available.

RESULTS AND DISCUSSION

The select animal and manure type medians, MADs, and counts for the Midwest ManureDB data across 2021-2025 are shown in Table 3. The MADs displayed a wide array of nutrient concentrations for most of the different animal manure types. For liquid manures, dairy had the lowest sulfur concentrations (2.2 lbs. S/1000 gal) and beef had the highest (5.8 lbs. S/1000 gal). For solid manures, dairy had the lowest (1.4 lbs. S/ton), and the broiler manure had the highest (15.2 lbs. S/ton) S concentrations. Many broiler farms use S containing litter amendments such as sodium bisulfate or aluminum sulfate to control barn ammonia levels, which likely impact the resulting manure S levels (Marsh Johnson & Murphy, 2008; Moore, 2023). Most of the selected animal manure types contain adequate S concentrations for corn production depending on application rate. This S value, subject to current S prices and manure S concentration, may be worth incorporating into manure value calculations along with NPK if S is warranted for a particular crop and field scenario. Compared to ASAE D384.2 manure characteristics, the ManureDB data had less S in solid beef and liquid slurry dairy manures. The ManureDB data for liquid swine manure had more S than the five liquid swine types listed for ASAE D384.2. There were no S values for any of the poultry manures, solid dairy, solid swine, or liquid beef manure in ASAE D384.2.

Table 3. Select analyte (S, Mg, B, Cu, Mn, Zn) ManureDB medians for ten Midwest manure types 2021-2025. Sample counts are in parentheses.

Manure Types	S	Mg	B	Cu	Mn	Zn
			Median±MAD (count)			
Liquid			lbs./1000 gallons			
Beef	**5.8**±3.7 (1524)	**5.9**±2.9 (1083)	**0.02**±0.01 (127)	**0.06**±0.03 (1081)	**0.1**±0.09 (1084)	**0.3**±0.2 (1135)
Dairy	**2.2**±1 (27000)	**5.2**±2.3 (13697)	**0.02**±0.01 (8122)	**0.08**±0.09 (14641)	**0.1**±0.07 (14729)	**0.1**±0.07 (14815)
Swine	**4.2**±2.5 (15261)	**5.6**±4.5 (8290)	**0.02**±0.02 (579)	**0.3**±0.3 (8248)	**0.2**±0.1 (8278)	**0.7**±0.5 (9448)
Solid			lbs./ton			
Beef	**2.9**±1.6 (1530)	**4.7**±2.9 (1190)	**0.01**±0.01 (173)	**0.04**±0.03 (1202)	**0.2**±0.1 (1203)	**0.1**±0.1 (1313)
Dairy	**1.4**±0.9 (5550)	**4.3**±3.2 (2920)	**0.01**±0.01 (2069)	**0.03**±0.03 (3182)	**0.1**±0.08 (3183)	**0.1**±0.04 (3190)
Swine	**4.4**±2.6 (275)	**8.9**±8.1 (222)	**0.02**±0.02 (28)	**0.1**±0.2 (222)	**0.4**±0.4 (222)	**0.5**±0.4 (224)
Poultry	**7.4**±3 (4213)	**8.6**±3.2 (3809)	**0.04**±0.02 (492)	**0.2**±0.3 (3825)	**0.6**±0.2 (3824)	**0.6**±0.2 (3843)
Layer	**7.2**±3.4 (271)	**7.8**±3.9 (187)	**0.03**±0.01 (40)	**0.1**±0.07 (187)	**0.5**±0.3 (187)	**0.6**±0.3 (187)
Broiler	**15.2**±7.8 (96)	**9**±3.4 (87)	**0.2**±0.07 (12)	**0.7**±0.3 (87)	**0.7**±0.2 (87)	**0.6**±0.2 (87)
Turkey	**6.6**±2.3 (1127)	**7**±2.3 (721)	**0.06**±0.02 (32)	**0.6**±0.3 (721)	**0.6**±0.2 (721)	**0.5**±0.2 (721)

For ManureDB magnesium data, all the liquid manures ranged between 5-6 lbs. Mg/1000 gal, while for solid dairy again had the lowest concentration (4.3 lbs. Mg/ton) and broiler manure had the highest (9 lbs. Mg/ton). The ManureDB data had lower Mg for solid beef manure and higher Mg for solid layer and liquid swine manure compared to the ASAE D384.2. There were no ASAE D384.2 Mg values for liquid beef, solid turkey, or solid swine manure. Depending on the situation and manure application rate, manure may be a good source of Mg to fulfill crop needs.

The ManureDB boron levels had the lowest concentrations of the six selected analytes in this study. The liquid manures all had similar B concentrations of 0.02 lbs. B/1000 gal. The solid manures ranged from beef and dairy with the lowest concentrations (0.01 lbs. B/ton) to the broiler with the highest concentration (0.18 lbs. B/ton). Broiler manure is the only manure type likely to make much impact on soil B levels for agronomic crops. ASAE D384.2 did not include B concentrations.

For the ManureDB copper data, the liquid beef had the lowest concentration (0.06 lbs. Cu/1000 gal), and the liquid swine had the highest (0.3 lbs. Cu/1000 gal). The ManureDB solid dairy and beef data had the lowest Cu concentrations of 0.03 and 0.04 lbs. Cu/ton, respectively. The solid turkey and broiler manure had the highest Cu

concentrations of 0.6 and 0.7 lbs. Cu/ton, respectively. Compared to ASAE D384.2, there was more Cu in the ManureDB data for solid dairy manure, though still at low concentrations. There were no ASABE Cu values for liquid beef, any of the solid poultry manures, or solid swine manure. No copper applications are currently recommended for agronomic crops in MN and in certain situations, farmers need to be cautious of high copper accumulations in plants and soil (Kaiser & Rosen, 2023). When utilizing manure nutrients, monitor the Cu level of your manure, soil, and potentially plant tissue to avoid Cu toxicity.

The ManureDB manganese levels were similar for the liquid manures with concentrations ranging from 0.1-0.2 lbs. Mn/1000 gal. Solid dairy manure had the lowest Mn concentration (0.1 lbs. Mn/ton) and three solid poultry manures had the highest Mn concentrations (0.5-0.7 lbs. Mn/ton). The ManureDB solid beef manure had less Mn, and the solid dairy manure had more Mn than ASAE D384.2. There were no ASABE Mn values for liquid beef, any of the solid poultry manures, or solid swine manure. According to Table 2, Mn applications are unlikely to be warranted in most agronomic crop cases. Again, monitoring manure and soil tests can assist in management decisions.

For liquid ManureDB zinc data, the dairy manure had the lowest (0.1 lbs. Zn/1000 gal), and the swine manure had the highest (0.7 lbs. Zn/1000 gal) concentrations. For the solid ManureDB Zn data, the beef and dairy manure had the lowest concentration (0.1 lbs. Zn/ton), and the swine and poultry manure had the highest (0.5-0.6 lbs. Zn/ton). Agronomic recommendations suggest applying 1-2 lbs. Zn/acre when necessary and manure likely can fulfill Zn needs for crops. The ManureDB solid beef manure had less Zn, and solid dairy manure had more Zn than ASAE D384.2. There were no ASABE Zn values for liquid beef or solid poultry or swine manures.

ManureDB contains samples from wider geographic areas and in larger quantities than available before and can offer nutrient approximations when manure analyses are not available. ManureDB offers other more specific scenarios with whole dataset downloads available at https://manuredb.umn.edu/data-explorer. The ManureDB sample descriptions may not have many details, and the MADs demonstrated great analyte variability, thus using your own manure analysis is recommended for nutrient management planning. While manure application rates will still be calculated off N or P-based rates instead of secondary macronutrient or micronutrient-based rates, manure applications will likely fulfill crop needs for most secondary macronutrients and micronutrients. Soil and/or plant tissue testing can identify whether these nutrients are necessary or excessive for crops. Manure testing can provide more confidence in all the macronutrients and micronutrients being applied to your farm.

ACKNOWLEDGEMENTS

This material is based upon work supported by the U.S. Department of Agriculture, under agreement number [grant no. NR253A750008C001]; the Agriculture and Food Research Initiative Foundational and Applied Science Program [grant no. 2020-67021-32465] from the USDA National Institute of Food and Agriculture; the University of Minnesota College of Food, Agricultural and Natural Resource Sciences; and the Minnesota Supercomputing Institute. We appreciate all the ManureDB data

collaborators who make this resource possible and Carl Rosen, Jeff Vetsch, and Stephen Gregg for their review of this paper.

REFERENCES

ASABE, 2019. *ASABE Standard: Manure Production and Characteristics* (Version ASAE D384.2 MAR2005 (R2019)). American Society of Agricultural and Biological Engineers, St Joseph, MI.

Bohl Bormann, N. L., Cortus, E. L., Wilson, M. L., Silverstein, K. A. T., Janni, K. A., & Gunderson, L. M., 2025. ManureDB: Aggregation of U.S. Manure Nutrient Data. *Journal of the ASABE*, *68*(5), 829–835. https://doi.org/10.13031/ja.16396

Bohl Bormann, N. L., Wilson, M. L., Cortus, E. L., Silverstein, K. A. T., Janni, K. A., & Gunderson, L. M., 2026a. *ManureDB*. http://manuredb.umn.edu/

Bohl Bormann, N. L., Wilson, M. L., Cortus, E. L., Silverstein, K. A. T., Janni, K. A., Gunderson, L. M., Cates, A. M., & Pagliari, P. H., 2026b. Nutrient data from US manure systems from 2012 to 2022: Spatial and temporal trends. *Journal of Environmental Quality*, *55*(5), e70268. https://doi.org/10.1002/jeq2.70268

Chatterjee, A., & Bohl Bormann, N. L., 2026. Moving beyond book values: Using machine learning to improve the accuracy of manure nutrient concentration predictions. *Journal of Environmental Quality*, *55*(3), e70203. https://doi.org/10.1002/jeq2.70203

EPA, 2023. *Power Sector Programs: Progress Reports*. https://www3.epa.gov/airmarkets/progress/reports/acid_deposition_figures.html

Kaiser, D., & Rosen, C., 2023. *Copper for crop production* [University of Minnesota Extension]. https://extension.umn.edu/agriculture/crop-production/nutrient-management-for-minnesota-crops/copper-for-crop-production

Kaiser, D., & Rosen, C., 2024. *Magnesium for crop production* [University of Minnesota Extension]. https://extension.umn.edu/agriculture/crop-production/nutrient-management-for-minnesota-crops/magnesium-for-crop-production

Kaiser, D., Rosen, C., & Sutradhar, A., 2023. *Manganese in Minnesota soils* [University of Minnesota Extension]. https://extension.umn.edu/agriculture/crop-production/nutrient-management-for-minnesota-crops/manganese-in-minnesota-soils

Kaiser, D., Rosen, C., & Sutradhar, A., 2024a. *Boron for Minnesota soils* [University of Minnesota Extension]. https://extension.umn.edu/agriculture/crop-production/nutrient-management-for-minnesota-crops/boron-for-minnesota-soils

Kaiser, D., Rosen, C., & Sutradhar, A., 2024b. *Zinc for crop production* [University of Minnesota Extension]. https://extension.umn.edu/agriculture/crop-production/nutrient-management-for-minnesota-crops/zinc-for-crop-production

Kaiser, D., & Vetsch, J., 2024. *Sulfur for Minnesota soils* [University of Minnesota Extension]. https://extension.umn.edu/agriculture/crop-production/nutrient-management-for-minnesota-crops/sulfur-for-minnesota-soils

Marsh Johnson, T., & Murphy, B., 2008. *Use of Sodium Bisulfate to Reduce Ammonia Emissions from Poultry and Livestock Housing* [Proceedings]. Mitigating Air Emissions From Animal Feeding Operations, Iowa State University, Ames, IA. https://lpelc.org/use-of-sodium-bisulfate-to-reduce-ammonia-emissions-from-poultry-and-livestock-housing/

Moore, P. A., 2023. Treating Poultry Litter with Aluminum Sulfate (Alum). *SERA17 Phosphorus Conservation Practices Fact Sheets*. https://sera17.wordpress.ncsu.edu/treating-poultry-litter-with-aluminum-sulfate/

R Core Team, 2025. *R: A language and environment for statistical computing* [Computer software]. R Foundation for Statistical Computing. https://www.R-project.org/

University of Minnesota Extension, 2026. *Nutrient management*. https://extension.umn.edu/agriculture/crop-production/nutrient-management-for-minnesota-crops