Temporal Changes of Manure Chemical Compositions and Environmental Awareness in the Southern Great Plains

Hailin Zhang*, Fred Vocasek, Joao Antonangelo, and Christopher Gillespie

Abstract

Knowing the nutrient contents of animal manure is important in nutrient management plan development. Nutrient contents of manure may have been changed over time due to improvement of breeding, feeding, and manure handling. Therefore, the major characteristics of beef feedlot manure, dairy manure, poultry litter, and swine effluent were summarized using the data from two service laboratories in Kansas and Oklahoma. In general, dry matter contents, pH, and macro- and micronutrient contents of the manures had little changes over time in the last 5 to 20 yr. Only a trend of phosphorus decrease over time in swine effluent was observed. The nutrient contents of various manures largely depend on the dry matter contents. The nitrogen (N), phosphorus (P) and potassium (K) contents are in the following order: broiler litter > beef feedlot manure > dairy manure > swine effluent. Various environmental regulations related to animal manure management have been established and implemented in most parts of the world. The awareness of sustainable manure application to cropland has greatly improved in the last twenty years. More efforts need to be made to further improve nutrient use efficiency of animal manure, protect soil health, and environmental quality.

Animal production is a large segment of the U.S. economy and of many other countries in the world (Zhang and Schroder, 2014). Confined animal feeding operations (CAFOs) produce large quantities of manure that demand proper management; cattle are the greatest of manure producer, followed by pigs, poultry, sheep, and goats worldwide (Sommer and Christensen, 2013). The United States Department of Agriculture (USDA) estimated that in 2007 there were over 2.2 billion head of livestock and poultry in the U.S. (US-EPA, 2012), which produced over 1.1 billion tons of manure. Manure storage and disposal is a major expense and potential liability for animal operations.

Animal manures have been used by ancient and modern farmers to enhance crop production and to improve soil health (Bogaard et al., 2013; He, 2011; He, 2012). Besides providing valuable macro- and micronutrients to the soil, manure also supplies organic matter (OM) to improve soil tilth, enhance water infiltration, increase nutrient retention, reduce wind and water erosion, and promote growth of beneficial soil organisms. Manure application to croplands succeeds in both recycling nutrients and sustaining crop production (Fig. 1). Animal manure can be an asset rather than a liability for producers when effectively managed and properly used on field crops (Richards et al., 2011; Tang et al., 2007; Zhang et al., 1998).

Key Words: Animal manure, feedlot manure, dairy manure, poultry litter, swine effluent, nutrient content, nutrient loss, water quality, best management practices, manure regulations

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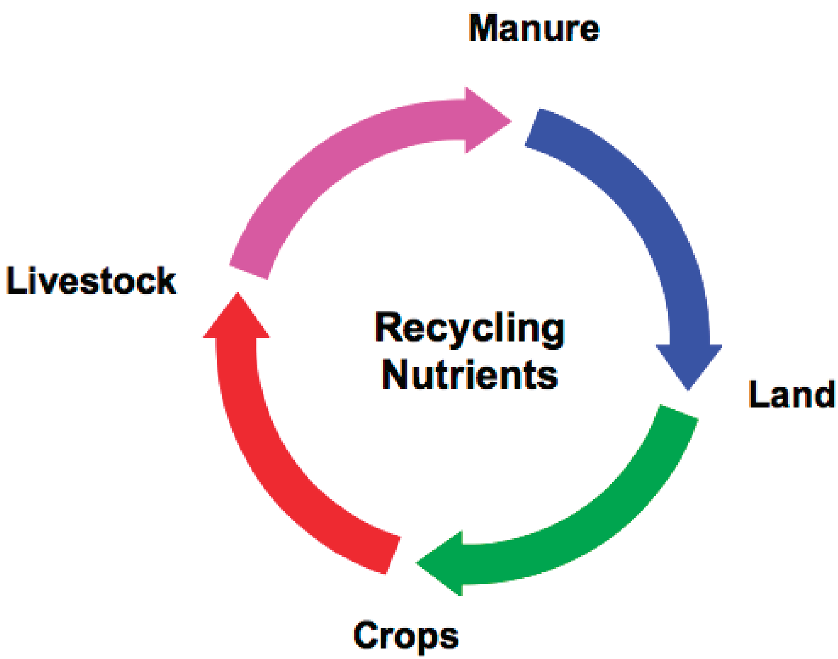

Fig. 1. Land application of animal manure recycles nutrients back to the land. It is the most economical and environmentally sound method to handle byproducts generated from meat and milk production if managed properly.

Mismanaged manure applications can cause both surface water and ground water pollution (He, 2011). Surface runoff from manured land usually contains plant nutrients and organic materials. Excess nutrients and organic materials that reach surface water often cause algal blooms that increase the turbidity and biochemical oxygen demand (BOD). The polluted water may generate disagreeable odors and the pollutants can cause fish kills if the dissolved oxygen falls below critical thresholds. Excess manure that remains on the application field may also cause nitrate–nitrogen (NO_3–N) and phosphorus (P) to accumulate in the treated soil. The excess NO_3–N can also reach surface water via drainage pathways or can leach into underlying ground water (He and Zhang, 2014).

To minimize the impact of animal manure land application on air and water quality, new regulations on manure management have been established and implemented in many countries and in most states of the United States due to pollution potential from improper manure applications (Sommer et al., 2013). The key to successful manure management is to develop and follow a nutrient management plan by applying the right amount at the right time. This requires one to know the nutrient needs of the intended crop through soil testing and the nutrient contents of the manure by manure analysis. When manure test is not available to some farmers, book values of nutrient contents of manure have been used. However, manure nutrient contents can change with time due to changes in animal feeding practices, manure management systems, nutrient use efficiency by animal due to breeding efforts, and other factors. It is essential to know the manure nutrient content to use it properly as a nutrient source and a soil amendment.

Average nutrient contents of manure are available in many publications and manuals (Midwest Plan Service, 1993; Christensen and Sommer, 2013; Hatfield and Stewart, 1998), but few highlighted the changes with time. This chapter presents a summary of inorganic characteristics of feedlot manure, poultry litter, dairy manure and swine effluent analyzed within the last two decades by two service laboratories in the Southern Great Plains and highlights environmental awareness by evaluating certain policies related to manure management.

Manure Chemical Composition

Animal manure contains valuable nutrients that can support crop production and can enhance soil chemical, physical, and biological properties. Manure can thus be an asset to a livestock production operation if the nutrient value is maximized. The nutrient composition of livestock manure varies widely between operations even for the same animal species. Some have raised concerns about whether manure nutrients or other constituents have changed over time due to genetic improvement of animals or due to updated management practices. Analysis results of four major manure types were obtained from Oklahoma State University (OSU) Soil, Water and Forage Analytical Laboratory- SWFAL (http://www.soiltesting.okstate.edu) and Servi-Tech Laboratories (https://servitechlabs.com) to identify possible temporal variability of the manure properties. Both laboratories use standardized methods for manure analyses (Peters, 2003). The analysis values listed in the Tables are averaged from actual samples submitted by the respective laboratory clients over a long period of time. These averages are valuable data, but represent wide ranges in the sample population. Manure should always be analyzed before application to determine the actual nutrient values and characteristics.

Poultry Litter

"Poultry litter" is a general term for chicken and turkey manure mixed with spilled feed and poultry house bedding materials. Litter may include wood shavings, saw dust, rice hulls and peanut hulls (Harsch, 1995). Moisture and nutrient contents can vary widely, depending on the type and age of the poultry. However,

Table 1. Characteristics of poultry litter tested by the Oklahoma State University Soil, Water and Forage Analytical Laboratory (results are expressed in "fresh weight"). §

Sample Period		Solids	pH	TDS†	TN	NO_3-N	NH_4-N	OC	P_2O_5	Ca	K_2O	Mg	Na	S	Fe	Zn	Cu
		%		ppm	%	—ppm—		—%—							—ppm—		
2001-04	Average	74.0	8.4	7114	3.12	605	4396	NA	3.13	2.92	2.70	0.53	0.66	0.68	394	452	574
(1250)‡	Median	75.8	8.3	7110	3.14	211	4398	NA	3.18	2.46	2.81	0.55	0.70	0.69	270	434	548
2005-09	Average	73.4	8.2	7673	3.19	580	3714	27.1	3.02	2.39	2.84	0.52	0.74	0.70	300	404	338
(1694)‡	Median	74.4	8.3	7845	3.27	755	2920	27.9	2.98	2.19	2.65	0.52	0.75	0.67	242	398	338
2010-13	Average	74.7	8.2	6826	3.23	71	2784	28.5	2.72	2.43	2.90	0.48	0.64	0.74	460	359	213
(1401)‡	Median	75.6	8.2	6726	3.29	19	2423	29.2	2.68	2.03	2.93	0.48	0.62	0.73	355	344	197
2014-18	Average	74.9	8.3	8019	3.16	NA	NA	29.4	3.00	2.63	2.52	0.52	0.71	0.86	554	468	217
(1294)‡	Median	75.7	8.3	8314	3.23	NA	NA	29.8	2.96	2.37	2.53	0.52	0.69	0.86	461	431	200

† TDS; total dissolved solids.

‡ Number of samples included in this group.

§ Na; not analyzed.

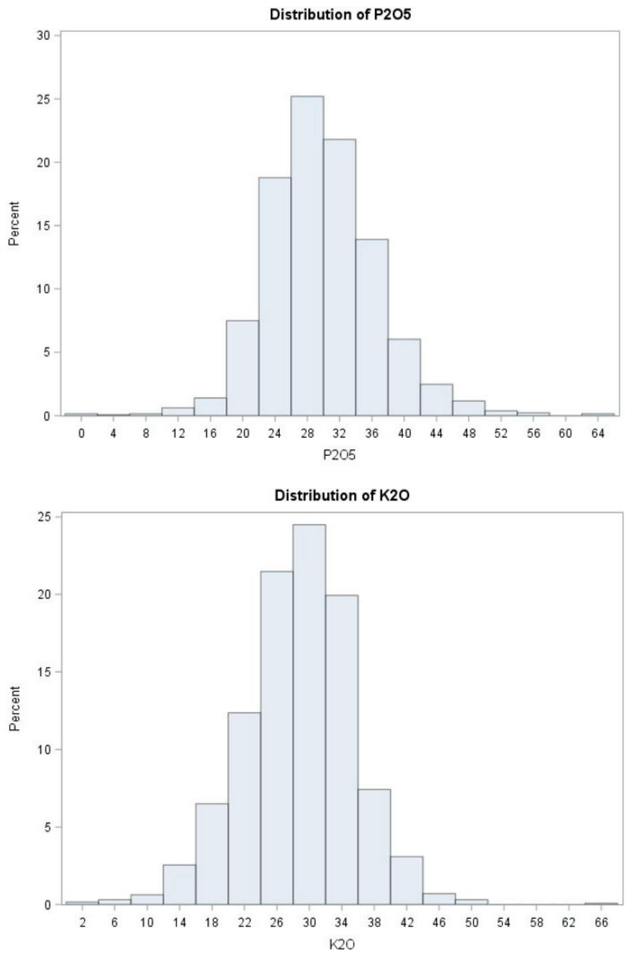

Fig. 2. Distribution of P_2O_5 (top) and K_2O (bottom) (kg Mg^{-1}) in poultry litter from 2014 to 2018 (*n* = 1294).

most poultry litter samples that are submitted for analysis are submitted by broiler operations and are managed like "dry manure" due to their low moisture content. The characteristics of poultry litter tested by OSU-SWFAL from 2001 to 2018 are presented in Table 1. The results were grouped into 4 to 5 year segments to show any temporal changes in nutrient content. The results are shown on an "as is" or "wet" basis (not corrected for moisture).

Poultry litter is alkaline with an average median pH of 8.3. This may be beneficial for maintaining soil pH or to help neutralize soil acidity when it is applied in acid soils. The pH values of poultry litter samples were not changed since 2001, indicating no or little feeding changes. The average solids content was 74% with no significant changes with time. Poultry litter contains significant amounts of both macronutrients and micronutrients, as well as some salts (as shown by "TDS" total dissolved solids). There were no significant temporal changes in the nutrients analyzed, except for copper (Cu), which showed a gradual decreasing trend over time, but the cause for this decline is unknown. Because those were actual farmer samples instead of replicated sampling, no statistical analyses were applied. The averages are very close to the median of all analytes, which suggests they were normally distributed. This is confirmed by the P and K distributions of the 2014 to 2018 data (Fig. 2).

Swine Lagoon Effluent

Swine manure is typically treated in two-stage, anaerobic digestion lagoon systems, common in the Central and Southern regions of the United States. Manure produced in the swine housing unit is initially directed into the primary lagoon. The manure solids settle to the bottom of this lagoon and slowly undergo decomposition by acid-forming and methane-forming microorganisms. Liquids from the primary lagoon flow into the secondary lagoon, where further settling and decomposition may occur. Manure liquids from the surface of the secondary lagoon are removed by pumping. Liquids from the upper two feet or so are then applied to nearby fields as a nutrient and water source. The samples sent for lab analysis typically represent the liquids used for irrigation. The effluent sample results are found in Table 2. Results of other swine manure types were not included.

The solid contents from Table 2 results are less than 0.50%, because they represent effluent samples from the irrigation lagoon surface. The low solid contents resulted in low concentrations of all nutrients analyzed. However, significant amounts of soluble solids (i.e., "soluble salts") were present in the effluent. Irrigators should use caution when using effluent on salt sensitive crops. The phosphorus (P) concentration in the effluent is much lower than nitrogen (N) or potassium (K) because most of the phosphorus is found in the settled sludge solids on the lagoon bottoms. Nitrogen and potassium are more soluble, so tend to remain in the liquid fractions.

There were no obvious temporal trends among analytes, except for phosphorus. Phosphorus concentrations gradually decreased from 141 ppm P to 90 ppm P over the past 14 yr (Fig. 3). The declining phosphorus content could be attributed to improved feeding management and to supplementing swine feeds with phytase (Dr. Scott Carter, Oklahoma State University Animal Nutritionist, personal communication). Monogastric animals such as swine are unable to utilize the phytate phosphorus in the feed. It is therefore necessary to supplement some swine feeds with inorganic phosphorus. Adding phytase to a swine ration will

Table 2. Characteristics of swine effluent tested by Oklahoma State University Soil, Water and Forage Analytical Laboratory (results are expressed in "fresh weight").

Sample Period		Solids	pH	TDS†	TN	NO_3-N	NH_4-N	OC	P_2O_5	Ca	K_2O	Mg	Na	S	Fe	Zn	Cu
		%		ppm													
2005-09	Average	0.43	7.9	5398	626	0.20	426	1572	324	72.2	989	45.4	350	47.4	6.64	1.80	0.48
(115)‡	Median	0.36	7.9	5244	516	0.14	238	1270	246	49	968	15.7	320	40.2	2.52	2.52	0.18
2010-13	Average	0.48	7.8	4404	666	1.38	420	2000	288	128	626	60.4	240	61.4	7.46	4.88	0.80
(192)‡	Median	0.45	7.9	3996	588	0.84	334	1784	222	97.6	674	45.0	210	42.4	5.04	3.32	0.62
2014-18	Average	0.48	8.0	4766	606	5.18	114	1610	146	72.2	884	36.8	392	57.4	4.66	1.88	0.46
(161)‡	Median	0.40	8.0	2490	608	1.74	104	1484	145	58.4	874	21.2	324	37.6	2.44	1.06	0.18

† TDS; total dissolved solids.

‡ Number of samples included in this group.

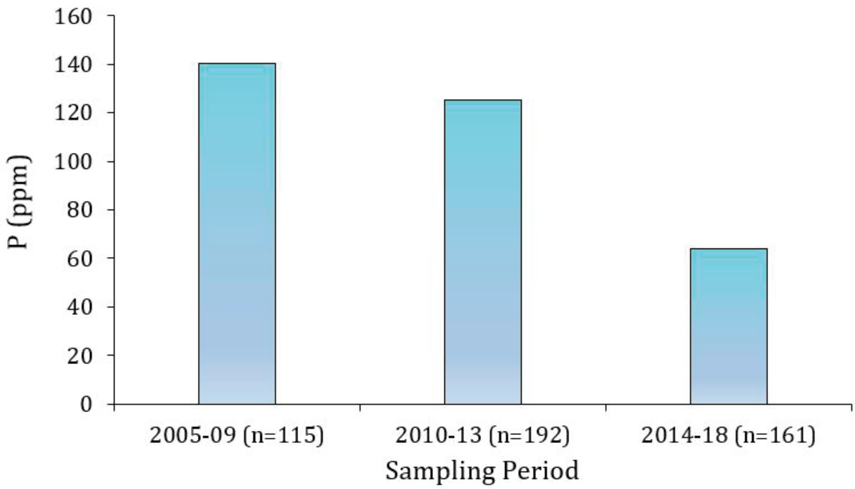

Fig. 3. Phosphorus (P) in swine effluent has been declining gradually over the last 14 yr as observed from samples analyzed by Oklahoma State University Soil, Water and Forage Analytical Laboratory.

increase phosphorus use efficiency and reduce the required amount of inorganic phosphorus supplement. Reducing the phosphorus in the manure will result in less phosphorus enrichment in soil receiving swine effluent and thus less potential phosphorus loss to surface waters.

Almost all the treated effluent generated by U.S. swine producers is land applied using high-volume sprinklers or center-pivot irrigation systems. Potential concerns for sprinkler systems include application timing, water losses, odors, and ammonia emissions. These become more of a problem under hot and dry conditions (Stone et al., 2008).

Application problems mentioned above can be minimized with subsurface drip irrigation (SDI) systems (Stone et al., 2008). Subsurface drip irrigation has been used to increase water and nutrient use efficiency, reduce nutrient losses from runoff, and to mitigate odor. In general, SDI systems conserve water and achieve higher crop or forage yields when compared with sprinkler or center-pivot irrigation systems (Stone et al., 2008).

Beef Feedlot Manure

Feedlot manure samples were submitted by farmers or consultants to Sevi-Tech Lab; only data from those two periods were available. The samples were typically collected directly from cattle feedlot pens or from manure storage piles. The test results of feedlot manure samples from two time periods are shown in Table 3. The average median solid content was about 73%, and total N, P_2O_5 and K_2O were 1.23%, 1.04%, and 1.32%, respectively. There were few differences found for all analytes between the two sampling periods. Therefore, we conclude that the characteristics of beef feedlot manure have not changed significantly in the last two decades.

Dairy Manure

The characteristics of dairy manure tested by Servi-Tech Laboratories from the middle of the last decade and the middle of this decade showed few changes (Table 4) for all analytes. Dairy manure had higher moisture contents than poultry litter or beef feedlot manure and accordingly had comparatively lower nutrient contents. We also conclude that the characteristics of dairy manure have not changed significantly in the last two decades.

Manure Nutrient Content

Manure nutrient contents are typically expressed on test reports as "pounds per ton" of solid manure or as "pounds per 1000 gallons" of liquid manure in the United States. Phosphorus and potassium are expressed with the fertilizer industry conventions of "phosphate, P_2O_5" and "potash, K_2O". This makes it easier for farmers to calculate the equivalent amount of fertilizer nutrients and to develop nutrient management plans.

The most recent average nutrient contents of the four types of manure presented above are shown in Table 5. All manures contain significant amounts of N, P, and K making them valuable resources for crop production. Poultry litter had the highest wet weight based nutrient content followed by feedlot, dairy manure, and swine effluent. The difference may reflect the respective moisture contents and the amount and types of bedding materials in different manures. Both the nutrient content and manure weight or volume must be used to calculate the final nutrient application rate. Although the nutrient contents of swine effluent are very low, nutrient credits can be quite high if a large amount is applied. For example, swine effluent can contribute 137 lb (62 kg) N, 46 lb (21 kg) P_2O_5, and 200 lb (91 kg) K_2O for each acre-inch of effluent (27,000 gallons) that is applied as irrigation.

Table 3. Characteristics of Beef Feedlot Manure Tested by Servi-Tech Laboratories (results are expressed in "fresh weight").

Sample Period		Solids	OC	Total N	NH_4-N	NO_3-N	P_2O_5	K_2O	Ca	Mg	S	Na	Zn	Fe	Mn	Cu	B
		%											ppm				
2006-08	Average	70.8	15.7	1.28	0.17	0.01	1.05	1.38	1.98	0.50	0.30	0.23	191	4420	181	36	13
(157)†	Median	72.7	14.3	1.24	0.150	0.002	0.97	1.29	1.48	0.47	0.28	0.21	163	3227	167	35	10
2014-17	Average	70.1	14.2	1.22	0.15	0.01	1.22	1.40	2.08	0.47	0.31	0.23	188	4907	211	35	14
(1336)†	Median	71.3	13.7	1.21	0.130	0.001	1.10	1.34	1.77	0.44	0.28	0.21	168	4601	187	32	12

† Number of samples included in this group.

Table 4. Characteristics of Dairy Manure Tested by Servi-Tech Laboratories (results are expressed in "fresh weight").

Sample Period		Solids	OC	Total N	NH_4-N	NO_3-N	P_2O_5	K_2O	Ca	Mg	S	Na	Zn	Fe	Mn	Cu	B
		%											ppm				
2006-08	Average	53.7	13.4	0.94	0.09	0.01	0.58	1.09	0.82	0.38	0.23	0.23	77	2251	92	39	12
(202)†	Median	54.7	12.5	0.86	0.069	0.001	0.51	0.97	0.52	0.33	0.25	0.15	61	1504	77	15	10
2014-17	Average	55.5	12.0	0.84	0.06	0.01	0.59	1.02	1.38	0.36	0.19	0.21	101	3432	122	38	14
(560)†	Median	60.4	10.7	0.76	0.044	0.001	0.52	0.83	1.18	0.31	0.16	0.14	76	3030	114	19	11

† Number of samples included in this group.

Table 5. Range and average of nutrient contents in "fresh weight" of major manure types analyzed in the last 4 to 5 years.

Manure Type	Dry Matter	Total N	P_2O_5†	K_2O†	Total N	P_2O_5	K_2O
	%	lb ton^{-1}			kg Mg^{-1}		
Broiler Litter	42-92 ‡	5.2-153	0-128	0-135	2.6-77	0-64	0-68
	75±7.3 §	63±27.1	59±13.8	57±14	31.5±14	30±7	29±6.8
Feedlot Manure	41-90	0.59-60	0.39-302.8	1.38-63.9	21-45	0.3-30	0.20-151.4
	70±11.4	24±9.2	24±14.4	28±11.8	35±5.7	12±4.6	12±7.2
Dairy Manure	41-90	2.4-50.2	0.79-47.6	0.59-76.3	1.2-25.1	0.40-23.8	0.30-38.2
	56±22.3	17±8.9	12±7.7	20±15.3	28±11.2	6±3.9	10±7.7
	lb 1000 gal^{-1}				kg m^{-3}		
Swine Effluent	0.05-1.4	0.1-12.8	0.03-15.2	0.72-14.6	0.01-1.54	0.00-1.83	0.09-1.8
	0.48±0.26	5.1±2.6	1.2±1.9	7.4±2.6	0.6±0.3	0.14±0.23	0.89±0.31

† P_2O_5 and K_2O are commonly used expressions for fertilizer ingredients instead of P and K. Laboratories may report in elemental P and K content. To convert, use the following equations: $K = K_2O \times 0.83$ or $P = P_2O_5 \times 0.44$

‡ Range from minimum to maximum value observed

§ Average values ± Standard deviation

The average N, P, and K contents in the four types of manure summarized in Table 5 are similar to averages published in extension fact sheets (Mitchell, 2008; Zhang, 2002). Although the average values can serve as a reference for planning purposes, it is important to have individual manure tested before land application because the ranges of nutrient content are very large (Table 5), for example, the P_2O_5 of dairy manure ranged from 0.4 to 24 kg Mg^{-1}.

Environmental Awareness and Regulations Related to Manure Management

Environmental Concerns

There are numerous benefits resulting from manure land application, including: building organic matter content, supplying nutrients, buffering soil pH, enhancing biological activities, and improving soil physical properties (Zhang and Schroder, 2014). There are also many concerns involving manure application impacts on environmental quality (Moore, 1998; Sharpley et al., 1998). The top concerns include soil phosphorus accumulations leading to increased offsite loss potential to water bodies, elevated soil concentrations of certain metals (Moore, 1998; Richards et al., 2011; Sweeten, 1998; Sharpley et al., 1998), and potential pathogens.

Manure application rates were historically based on the agronomic nitrogen requirement. The soil phosphorus content or the crop phosphorus requirement was typically not considered in the past. The typical N/P ratio of manure is usually lower than that required by plants (Pote et al., 1996; Gotcher et al., 2014). Fertilizing crops with manure based on the agronomic nitrogen needs alone will result in over applying phosphorus. This practice has resulted in significant accumulations of soil phosphorus where manure has been repeatedly applied (Moore, 1998). Over time, failure to consider the manure phosphorus contribution may saturate the soil's phosphorus sorption capacity near the soil surface and also in deeper layers, which often increases the dissolved phosphorus in runoff (Moore, 1998; Sharpley et al., 1994; Sharpley et al., 1998; Wang et al., 2011).

Significant quantities of micronutrients such as copper (Cu), iron, (Fe), manganese (Mn), or zinc (Zn) can also accumulate in the soil if large amounts of manure are applied (Penha et al., 2015). Long-term applications could cause some of these elements to reach toxic levels within or near the application zone.

Environmental Awareness and Regulations

New regulations on manure management have been established and implemented in most states due to pollution potential from improper manure applications. The U.S. Environmental Protection Agency (US-EPA) considers eutrophication through organic enrichment the most widespread water quality impairment in the United States (US-EPA, 2017). The greatest potential for eutrophication of surface waters usually occurs in watersheds with intensive animal production (CAST, 1996; He et al., 2016).

In 1998, the USDA and EPA announced a joint strategy to implement "comprehensive nutrient management plans (CNMPs)" for animal feeding operations (AFOs) by 2008. A CNMP is a conservation farm plan that is specific to AFOs. The CNMP incorporates practices to utilize animal manure and organic by-products as beneficial resources. It documents the management strategies adopted by the AFO to address natural resource concerns related to soil erosion, animal manure management, and disposal of organic by-products. Nutrient management plans emphasize a balance between nutrient supply and crop utilization and may include nutrient removal.

The CNMP normally contains six different elements: (i) manure and wastewater handling and storage, (ii) land treatment practices, (iii) the nutrient management plan, (iv) record keeping, (v) feed management considerations, and (vi) other waste utilization options.

The NRCS 590 planning standard that deals with nutrient management has been revised several times to include a phosphorus-based planning standard as a consequence of the USDA/EPA joint strategy (Sharpley et al., 2003; USDA-NRCS, 2013). The strategy made three phosphorus-based choices available for states to use in developing nutrient management planning policies. These approaches were to use: (i) agronomic soil test phosphorus recommendations, (ii) environmental soil test phosphorus thresholds, or (iii) a phosphorus loss index (P-index) that ranked fields according to their vulnerability for potential phosphorus loss (Sharpley et al., 2003).

By the year 2003, 48 states had adopted the phosphorus index approach (Sharpley et al., 2003). Overall, 23 states have adopted the original P-index format or have modified the index for local conditions. There are 25 states that use the P-index and/or an environmental phosphorus threshold. Two states use agronomic soil test phosphorus recommendations (Sharpley et al., 2003). The P-index policy is thus an integral part of most CNMPs and is widely used to determine manure application rates.

The original P-index was developed by Lemunyon and Gilbert (1993) to identify the vulnerability of agricultural fields to phosphorus loss. The P-index accounts for and ranks certain "source" factors (soil test P, fertilizer and manure rates, application methods, etc.) and certain "transport" factors" (erosion, runoff or leaching potential, landscape and soil characteristics, connectivity to surface water, etc.) that could control offsite phosphorus loss potential. These individual site characteristics were weighted differently. It was assumed that different site characteristics have different effects on phosphorus loss. Each site characteristic was assigned a phosphorus loss rating value: negligible (0), low (1), medium (2), high (4), and very high (8). The phosphorus loss rating value was multiplied by the weighting coefficient to obtain a P-index value for the individual source or transport factor. The individual P-index values were then added together to obtain the final P-index value.

Most states use the P-index approach, but many of them have modified the original P-index format. The changes included: multiplication instead of addition of source and transport factors; consideration of distance to water; and quantification of erosion, soil test P, and phosphorus application rate. Other states have derived predictive loading models that calculate edge-of-the-field phosphorus loss in kg P ha^{-1} yr^{-1} (Osmond et al., 2006). Additional states have moved to more quantitative predictions since then (Osmond et al., 2017). Those P-indices have played a major rule in reducing phosphorus loss and protecting water quality. However, agronomic phosphorus recommendations still differ widely between states (Osmond et al., 2006, 2012, and 2017). The Europe Union and other regions of the world have also established and implemented various environmental regulations related to animal manure management (Sommer et al., 2013)`

Conclusion

The major characteristics of beef feedlot manure, dairy manure, poultry litter, and swine effluent were summarized using the data from two service laboratories in Kansas and Oklahoma. In general, dry matter contents, pH, and macro- and micronutrient contents of the manure had little changes over time in the last 5 to 20 yr. Only a trend of phosphorus decrease over time in swine was observed. Various environmental regulations related to animal manure management have been established and implemented in most parts of the world. The awareness of sustainable manure application to cropland has greatly improved in the last twenty years. More efforts need to be made to further improve nutrient use efficiency, soil health, and environmental quality.

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