Animal Manure Production and Utilization: Impact of Modern Concentrated Animal Feeding Operations

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Abstract

The total number of livestock and poultry animals being raised in the United States has shown some fluctuation over time. From 2012 to 2018, however, there was a consistent increase of approximately 96 million head annually. This trend was fueled by strong growth in global demand over the past decade and net exports of meat are forecast to continue to grow rapidly. Swine and poultry tend to be raised in confinement, while beef cattle tend to be raised on pastures, but then are finished in confinement, while dairy cattle are often fed and milked in confinement but are allowed on pasture periodically. The number of small animal farms have continually decreased since 1982, while the number of confined animal feeding operations (CAFOs) have increased. In the United States, as much as 1.4 billion tons of manure is produced by the 9.8 billion heads of livestock and poultry produced yearly. These manures produced are primarily used as a nutrient source for crop production. However, because of the shift toward CAFOs producing most of the meat consumed, the mismatch of manure produced to area manure is applied is leading to negative environmental impacts.

By the traditional definition, animal manure is animal excreta (urine and feces) and bedding materials, usually applied to soils as a fertilizer for agricultural production (He, 2012). In fact, before the extensive application of synthetic fertilizer, the majority of outsourced crop nutrient inputs were from animal manure. Indeed, since the beginning of human agricultural activities, animal manure has been an integral part of sustainable crop production. For example, stable isotope analysis of charred cereals and pulses from 13 Neolithic sites across Europe (dating approximately 5900–2400 B.C.) has shown that early farmers used livestock manure and water management to enhance crop yields (Bogaard et al., 2013). However, the development of concentrated animal feeding operations (CAFOs) has produced a large amount of animal manure that far exceeds the needs of regional soils and crops. This practice toward fewer but larger operations of animal production has created environmental concerns in recycling and disposing of surplus animal manure (He, 2011; He et al., 2016). This introductory chapter first compares and discusses several terms used in animal manure management and research communities, then highlights the modern CAFO practices and their impacts on animal manure production and its utilization in the United States.

Abbreviations: AFO, animal feeding operation; AU, animal units; CAFO, concentrated animal feeding operation.

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Field Operation Terms Used Alternatively and/or Inappropriately

Animal Versus Livestock

In the scientific literature, there are publications that misuse terms "livestock" and "animal" by assuming poultry production to be a livestock operation. Per the U.S. Code of Federal Regulations (2019a, 2019b), the term "livestock" includes the following animals, among others: cattle (both dairy and beef cattle), sheep, swine, horses, mules, donkeys, and goats. However, turkeys or domesticated fowl are considered poultry and not livestock within this definition. The USDA and EPA statistics and literature listed livestock and poultry as two separate categories (e. g. USDA, 2015; USEPA, 2013). Based on these definitions, livestock manure is not equivalent to animal manure as the former does not include poultry manure. Thus, extra effort should be encouraged to apply these terms correctly.

Animal Head Versus Animal Unit

There are multiple ways of discussing how many animals are raised in the U.S. farms. Often times we see either animal head counts or "animal units". Animal head counts are intuitive as they represent the number of animal bodies being produced. On the other hand, an animal unit (AU) is 1000 pounds of live animal weight and is often the term used by agricultural engineers, as well as regulatory or conservation agencies in the United States (National Research Council, 2003). This allows for a common measurement between livestock and poultry species, which is particularly important when considering manure production. For example 1000 broiler chickens produce significantly less manure than 1000 dairy cows, but 1000 AU of broiler chickens (about 125,000 head of chickens) produce about the same amount of manure as 1000 AU of dairy cows (about 700 head of dairy cows). The average number of animals per AU, the amount of manure, and the amount of nutrients typically excreted by various livestock and poultry types can be found in Table 1. It should be noted that when converting animal head counts to AU, there are certain assumptions made that may differ across the United States (Gollehon et al., 2016) and thus the values shown in Table 1 are only estimates.

Animal Manure Versus Animal Waste

Animal manure was traditionally a valuable resource for agricultural production, and is still an essential fertilizer for organic farming today (He, 2019). On the other hand, the impact of manure generation and disposal by CAFOs is far greater than the role of organic fertilizers. Thus, in the last three decades or so, the objectives of animal manure management research have been focused on the basic knowledge of manure's impacts on the environment and relevant technologies for the best management of animal manure (He, 2011; He et al., 2016), leading to increased usage of the term "animal waste" (Food Print, 2019). While "animal waste" could be more than "animal manure", the two terms are equivalent in many cases. For example, under WAC 16–250–010 (WAC, 2003), Washington State Legislature defines "animal wastes" as a material composed of excreta, with or without bedding materials and/or animal drugs, collected from poultry, ruminants, or other animals except humans. Thus, the two terms are sometimes used alternatively, such as in the book title "Animal Waste Utilization: Effective Use of Manure as a Soil Resource" (Hatfield and Stewart, 1998). It is apparent that the term "animal waste" is negative, but "animal manure" is neutral if not positive. Thus, while both terms are acceptable for management, the neutral term "animal manure" seems more appropriate for use in research-relevant work and publications (He, 2012; He and Zhang, 2014; Sommer et al., 2013).

As-Excreted Versus As-Stored Manure

The amount of manure produced and nutrients present in raw manure as it comes out of the animal is often preceded by the term "as-excreted". These values can be found in the literature (ASABE, 2014; Lorimor et al., 2004) and are for planning purposes when designing manure storage facilities. The actual values can vary by up to 30% due to individual farm management as well as genetics and animal performance (Lorimor et al., 2004). It is important to distinguish between the characteristics of "as-excreted" manure from manure that has been stored (sometimes referred to "as-stored" manure) because housing, handling, and storage can significantly impact manure characteristics (ASABE, 2014; Lorimor et al., 2004). For example, approximately 25%, 10%, 26%, and 53% of nitrogen can be lost as ammonia before manure is land applied in dairy, beef, poultry, and swine operations, respectively (USEPA, 2004). In some cases, researchers do not identify what characteristics they are using in the literature (as-excreted versus as-stored) and caution must be taken to use the appropriate terminology in future.

Composition of Manure: Liquid Versus Slurry, Semi-Solid, and Solid

The composition of manure varies with the amount of solids that it contains. Liquid manures have less than 4% solids, slurries have between 4 and 10% solids, semi-solids have between 10 and 20% solids and may or may not be stackable, while manures with greater than 20% solids are stackable and considered to be solid manures (Lorimor et al., 2004). The amount of solids in the manure dictates how it can be handled, stored, and land applied. For instance, stackability, or the ability to pile manure, is determined by whether manure can be piled in

Table 1. Average number of animals in one animal unit (AU), plus the manure produced and nitrogen and phosphorus excreted per animal unit by livestock and poultry in the United States. (Source: Kellogg et al., 2014; USDA-NRCS, 1992; Wheeler and Zajaczkowski, 2009; Pagliari and Laboski, 2012, 2013).

Livestock Type	Number of animals in one Animal Unit	Manure produced	Nitrogen produced	Phosphorus produced
	(AU)		——— lb d^{-1} AU^{-1}———	
Beef Cattle	1.0	59.1	0.31	0.11
Dairy	0.7	80.0	0.45	0.07
Swine	2.5	63.1	0.42	0.16
Chicken (layer)	82.0	60.5	0.83	0.31
Chicken (broiler)	125.0	80.0	1.10	0.34
Turkey	56.0	43.6	0.74	0.28
Horse	0.9	51.0	0.28	0.20

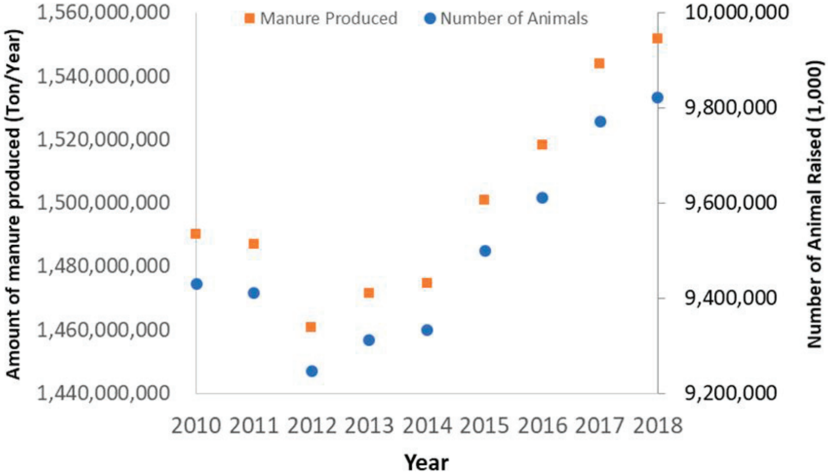

Fig. 1. Total number of animals produced and manure produced from 2010 to 2018. (Source: USDA-APHIS: www.aphis.usda.gov)

a 1:3 vertical to horizontal ratio or greater (USDA-NRCS, 2017). Waste from animal barns with bedding is typically treated as semi-solid or solid manure, while more intensive livestock rearing systems collect the manure as a liquid or slurry because concrete or slats are used to minimize the need for bedding (He et al., 2012; Janni and Cortus, 2019). Another term that is used in the literature outside of the United States includes "farmyard manure," which typically refers to semi-solid or solid manure from beef or dairy operations, but may also include manure from other species in operations that have diverse livestock and poultry.

Poultry Manure Versus Poultry Litter

Both terms of poultry manure (Dail et al., 2007; Waldrip-Dail et al., 2009) and poultry litter (Tewolde et al., 2018; Waldrip et al., 2015) can be found in literature. However, there are some differences in their compositions. In the poultry industry, poultry manure commonly refers to the bird excreta (feces and urine) collected from egg-laying and breeder facilities and can be treated as a solid, slurry, or liquid manure, depending on the storage and handling of the farm (USDA-NRCS, 2009). Poultry litter comes from chicken broiler and turkey grow-out facilities that produce meat and refers to the mixture of bird excreta and bedding materials removed from poultry houses (USDA-NRCS, 2009). Both manure and litter may include wasted feed and feathers as well. Of the poultry waste generated in 1990, approximately 68% was poultry litter and greater than 90% of both litter and manure was land applied (Moore et al., 1995). Despite the distinct differences between poultry manure and litter, it should be noted that the terms are occasionally interchanged in the literature (Bitzer and Sims, 1988; Billen et al., 2015) which can be confusing for those working in the industry and for researchers.

Unit Conversions

English units are used throughout the chapter as it is relevant to the livestock industry in the United States. Additionally, manure analyses often report various forms of nutrients which can be converted as needed (i.e., reports may show total phosphorus or total phosphorus as P_2O_5). Table 2 shows common conversions that can be used throughout this book.

Livestock and Poultry Production

The total number of livestock and poultry animals being raised in the United States has fluctuated over time. There was a decrease from 2010 to 2012 from around 9.4 billion head to 9.2 billion head, respectively (Fig. 1). From 2012 to 2018, however, there was a consistent increase in every year by approximately 96 million head annually, primarily for beef, chicken, and swine (Fig. 1). This trend was fueled by strong growth in global demand over the past decade and net exports of meat are forecast to continue to grow rapidly (Jones et al., 2018).

Swine and poultry tend to be raised in confinement while beef cattle tend to be raised on pastures, but then are often finished in confinement (Gillespie, 2019). Dairy cattle are often fed and milked in confinement but are allowed on pasture periodically (Gillespie, 2019). These systems are known as animal feeding operations (AFOs) and are defined by the USEPA as agricultural enterprises in which livestock (cattle, swine, and so forth) and poultry are kept and raised in confined conditions until they are transported to processing plants for slaughter, for a minimum of 45 d in a 12-mo period (USEPA, 2019). In these operations, food is typically harvested from the surrounding land and brought to the confinement area, as opposed to having animals directly graze forages. In some cases, feed can originate from areas further away and even other countries, depending on price.

The number of AFOs in the United States has been reported to be around 450,000 (USEPA, 2004). The number of farms considered small confined operations (with less than 300 animals) decreased from 435,000 in 1982 to 213,000 in 1997 (Ribaudo et al., 2003). In 2010, the number of operations with more than 200

Table 2. Conversion table.

To convert from	To	Multiply by
Pound	Kilogram	0.454
Ton (short)	Ton (metric)	0.907
Acre	Hectare	0.405
Gallons	Liters	3.79
%	Milligrams per liter	1.0
K	K_2O	1.2
P	P_2O_5	2.3
Pounds per acre	Kilograms per hectare	1.12
Pounds per acre	Megagrams per hectare	0.00112
Pounds per 1000 gal	Milligrams per liter	119.8
Pounds per ton	Milligrams per kilogram	500
Gallons per acre	Liters per hectare	9.354
Tons (short) per acre	Metric tons per hectare	2.24

Confined Animal Feeding Operations and Human Health: Case Studies

Wing and Wolf (2000) surveyed residents of three rural communities in North Carolina totaling 155 respondents. The communities could be distributed as one with residents living in the vicinity of a 6,000-hog operation, one in the vicinity of beef cattle operations, and the last one in an area with no livestock operation nearby. The results of the survey showed that communities living in close proximity to hog farms have increased respiratory related problems, gastrointestinal problems, and mucous membrane irritation, in addition to lower quality of life compared with the other two communities.

Hooiveld et al., (2016) surveyed a community to understand the prevalence of respiratory and gastrointestinal conditions of people (119,036 participants) living in close proximity (about 10 km) to swine, poultry, cattle and goat CAFOs. In this report the authors found that poultry and cattle had no effect on health conditions, but swine and goat CAFOs significantly increased the odds of unspecified infectious disease and pneumonia.

Radon et al. (2006) surveyed and performed medical tests in approximately 7,000 residents from four rural towns in northwest Germany between 2002 and 2004. Survey participants ranged from 18 to 44 years of age. The results showed that high density of CAFOs near residential areas significantly affected respiratory health. Among all potential environmental concerns, manure management will be the focus of this chapter.

Fig. 2. Case-studies of the human health impacts of confined animal feeding operations (CAFOs) on local communities.

heads of milking cows in the United States constituted 69% and those with 199 or less were 31%; in comparison, for swine, the number of operations with 2000 of more heads constituted 85% and those with 1999 or less made up 15% (USDA-APHIS, 2011). In contrast, 87% of all beef cattle were being raised in small-scale operations (USDA-APHIS, 2011). The USDA-APHIS considers small-scale operations the farms which report annual gross sales of agricultural goods ranging from $10,000 to $499,999, and in 2011 there were approximately 350,000 small farms in the United States (USDA-APHIS, 2011). Horses and other equids are the second largest group of animals to be raised by small-scale farms with 38% of total animals grown in small farms in the United States. In contrast, dairy cattle, swine, and poultry grown in small-scale farms represent 8.5%, 5.1%, and 16.9%, respectively, of total animals grown in the United States (USDA-APHIS, 2011).

Concentrated animal feeding operations, or CAFOs, are AFOs with more than 1000 animal units (AU). The use of CAFOs to raise livestock and poultry have been shown to improve farm income, increase animal density, and lower the amount of land required to raise large amounts of animals. On the other hand, many environmental concerns have been brought forward since the inception of CAFOs, such as large amounts of waste produced in a relatively small area, lagoon management, odor, pathogens, presence of significant amounts of pharmaceuticals in the waste, and nutrient management (Cole et al., 2000; Wing and Wolf, 2000). Confined animal feeding operations also pose significant risks to human health (Ribaudo et al., 2003; Hooiveld et al., 2016). See Fig. 2 for some cases studies exploring the risks. Due to the potential environmental and human health concerns, manure management will be the focus of this chapter.

Animal Manure Produced

The amount of manure produced on a daily basis by different livestock and poultry, as well as the daily amount of nitrogen (N) and phosphorus (P) excreted, can be found in Table 1. These values are estimates based on literature data and reflect the amount of nutrients in the manure without bedding. The amount of manure produced per animal species varies substantially, even when adjusted to an animal unit (AU) as observed in Table 1. Chicken broiler and dairy are the biggest producers generating about 80 lb manure d^{-1} AU^{-1}; while turkey produces the least amount, 43.6 lb manure d^{-1} AU^{-1} (Table 1). Similarly, the amount of N and P in the manures varies and is highest in poultry and turkey (range 0.74 to 1.10 lb N and 0.28 to 0.34 lb P d^{-1} AU^{-1}) than in the other animal species considered (range 0.28 to 0.45 lb N and 0.07 to 0.20 lb P d^{-1} AU^{-1}) (Table 1).

It is estimated that in 2017, about 1.4 billion tons of manure was produced from over 9.8 billion heads of livestock including beef cattle, dairy cows, swine, poultry, goat, sheep, horse, and others (USDA-APHIS, 2017). Table 3 presents the number of animals raised in 2017, potential amount of manure produced by each animal species, and the amount of N and P in the animal manures. Figure 1 shows the total amount of manure produced from 2010 to 2018 (2018 being estimated based on limited information available at the time the report was generated). The amount of manure produced decreased from 2010 to 2012 following the decrease in the number of total head produced during that same time, and then showed a consistent increase of 15 million tons of manure yr^{-1} from 2012 to 2018 (Fig. 1). Beef cattle (1.2 billion ton yr^{-1}) generated about 78% of the total amount of manure produced in 2017, followed by dairy and horse (296 and 46 million ton yr^{-1}), while turkey and chicken layers produced the least amount of manure among all species considered, at 35,000 and 49,000 ton yr^{-1}, respectively (Table 3). It is nearly impossible to estimate the amount of bedding that is used by livestock and poultry operations, which end up being mixed in with the manure. In most published reports, manure is regarded as the feces, urine,

Table 3. Number of poultry and livestock animals (source: USDA-APHIS, 2017) in 2017 in the United States, along with the estimated amount of manure produced and nitrogen and phosphorus excreted that year.

Livestock Type	Number of animals	Manure produced‡	Nitrogen produced‡	Phosphorus produced‡
	— 1000 head—		ton yr^{-1}	
Beef Cattle	108,405	1200,000,000	6294,416	2233,503
Dairy	14,181	145,000,000	1663,735	258,803
Swine	129,388	596,000	3967	1511
Chicken (layer)	375,845	49,000	672	251
Chicken (broiler)	8913,000	1050,000	14,438	4463
Turkey	242,500	35,000	594	225
Horse	3914†	36,000,000	197,647	141,176
Total	9,822,460	1,382,730,000	8,175,469	2,639,932

† Data available is from 2012 only.

‡ Data estimated using values reported in Table 1.

and bedding all combined, but in some cases, the term feces or feces and urine is used to specify that bedding is not included. In this chapter, manure is referred to feces and urine and manure plus bedding will be regarded as litter.

In 2017, 8.1 million tons of manure N and 2.6 million tons of manure P were excreted by livestock and poultry (Table 3). More than 75% of the total manure N and P was excreted by beef cattle, with dairy, horse, and broilers following behind (Table 3). The lowest amount of manure N and P was found in manure from turkeys and layers (Table 3). In comparison, the amount of N and P excreted in 1997 was 1.23 million and 0.66 million tons, respectively (Gollehon et al., 2001). When bedding is added, the amount of nutrients in the manure may change, or it may stay the same. For example, Long et al. (2018) reported that dairy manure mixed with bedding had a composition of 5.8 lb P_2O_5 ton^{-1} and 8.0 lb N ton^{-1}, while as-excreted book values for the region would be 4.4 lb P_2O_5 ton^{-1} and 9.9 lb N ton^{-1}. For swine manure the values for manure plus bedding and as-excreted book values for the region were 19.3 lb P_2O_5 and 43.1 lb N 1000 gal^{-1} and 37.9 lb P_2O_5 and 45.5 lb N 1000 gal^{-1}, respectively.

Most of the estimates reported in Table 3 refer to the amount of manure and nutrients excreted, but the amount that is land applied may be different. For example, the USDA-NRCS has reported that under the best circumstances only 90% to 95% of the total manure produced can be recovered and reutilized (USDA-NRCS, 1992). This indicates that as much as 0.15 billion tons of manure is lost or remains in storage every year. Additionally, manure nutrients can be lost through handling and storage. For example, N is constantly being volatilized (Cole et al., 2005; Selbie et al., 2015) and N and P, in addition to all other nutrients found in manure, can runoff from litter piles any time there is a rain event and water runs through the litter pile (Pagliari 2014). These losses make manure nutrient availability unpredictable unless a sample is collected and sent to a lab immediately prior to land application.

Land Application of Manure

Land application is the most economical way to reuse animal manure, although other possibilities are currently being investigated for manure reuse, including the use of manure for biochar and energy production (Pagliari et al., 2010; Lundgren and Pettersson, 2009; Ro, 2012). Unfortunately, many livestock and poultry producers are not using best management practices for manure management, which is exceedingly problematic (Jackson et al., 2000; Ribaudo et al., 2003; Long et al., 2018). For example, the repeated application of manure to meet the N needs of the crop will bring soil test P (STP) to levels that are excessive (Lehmann et al., 2005; Waldrip et al., 2015). Excessive nutrients in the soil will increase the potential for nonpoint-source pollution to reach ground and surface waters by leaching and runoff. However, the potential for environmental problems depends on many factors, such as the amount of nutrient applied in excess, nutrient management practices, soil type, cropping systems used, and others.

On the other hand, many producers see manure as a useful soil amendment and utilize nutrient management plans to help them apply the manure properly (Dagna and Mallarino, 2014). When used as recommended, manure can result in similar or higher crop yields when compared with inorganic fertilizer, thereby minimizing reliance on synthetic chemical inputs for food production (Carter et al., 2010; Ayinla et al., 2018). Manure can be applied to fields in a few different methods: as a liquid using sprinkler irrigation; liquids and slurries can be injected underneath the soil surface; and liquids, slurries, semi-solids, or solids can be broadcasted and either incorporated or not incorporated after application. Incorporation of manure soon after application is vital to assure N is kept in the field and does not volatilize contributing to nonpoint source–pollution. Jackson et al. (2000) reported that sprinkler irrigation of liquid swine manure resulted in 88% of manure N being transferred to the atmosphere which was much higher than when manure was injected into the soil (34% of total N lost to the atmosphere). Nitrogen losses from liquid dairy manure are also much higher when manure was broadcast (60% of total ammonium N) than when manure was injected (40% of total ammonium N) into a poorly drained clay soil (Pfluke et al., 2011). In general, ammonia emission reduction can vary from 0 to 100% when manure is injected using open slot injection and from 58 to 100% when using closed slot injection (Dell et al., 2011).

Regardless of whether farmers are utilizing their manure as a waste or as a resource, overapplications may still occur due to the significant variability in nutrient content which could lead to erroneous calculations. Nutrient values presented as reference values (also known as "book" values) are usually a generalization of many samples collected over a wide area and different practices. It is well known that nutrient content changes based on feed, animal age, health status, and climatic conditions. For example, collecting manure samples for chemical analyses after rain periods when manure is stored outdoors could dilute manure nutrients due to the addition of water. Similarly, collecting manure after a prolonged dry season could increase the amount of nutrients in manure due to the loss of moisture. This reiterates the need to test manure for nutrient availability as close to field application as possible.

Common book values for the nutrient content of manure can be found through the MidWest Plan Service (MWPS) and American Society Agricultural and Biological Engineers (ASABE). Figure 3 reports data for beef and dairy manure book values (liquid and solid) as indicated by the MWPS and ASABE as well as data that were obtained from commercial laboratories around the upper Midwest United States for chemical tests. The commercial laboratory data represents real analyses from livestock and poultry operations in the region. For beef manure, the MWPS reports, in most cases, lower nutrient for Total N, P, and K than all other samples, while ammonia-N is usually higher in the MWPS, with exception for liquid beef manure (Fig. 3). For dairy manures, values are more similar between the MWPS and ASABE, and both are slightly higher than the values observed in the commercial laboratories (Fig. 3). It is also interesting to note how variable the samples are. Total N in liquid beef manure ranges from 0 to 45 lb 1000 gal^{-1}, while total K in liquid dairy manure ranges from 0 to near 70 lb 1000 gal^{-1} (Fig. 3). Most importantly, data from Fig. 3 demonstrate how nutrient concentration changes dramatically across farms and species, and thus regular manure sampling is the best strategy to apply correct amounts of nutrients to fields. Ribaudo et al. (2003) reported that in 1998 only 19% of animal feeding operations with less than 1000 AU were testing manure for total N and P; while the number of CAFOs testing manure for total N and P prior to application was 73%. However, the data reported by Ribaudo et al. (2003) are 20 yr old and new, more reliable information is warranted.

Special Considerations for CAFO Manure

While AFOs and CAFOs have increased in number, the amount of land for manure application has decreased, which is becoming problematic. In 1982, the available cropland managed by farmers with livestock and poultry operations available for manure

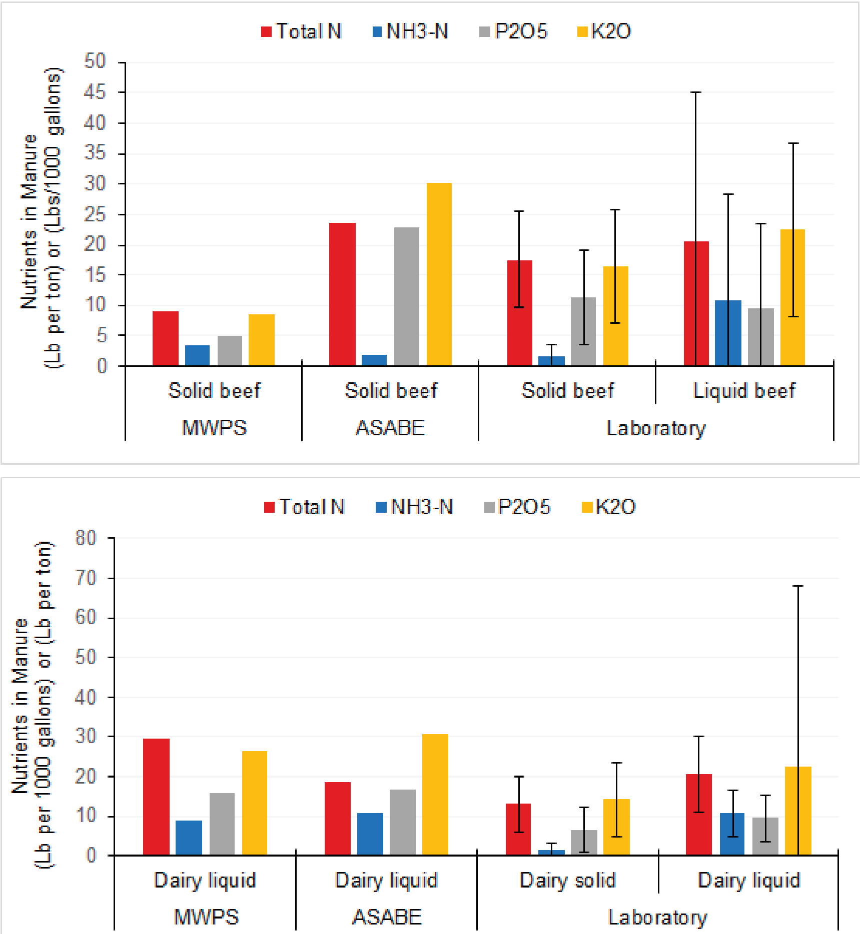

Fig. 3. Nutrient concentration as reported by MidWest Plan Service (MWPS) and American Society Agricultural and Biological Engineers (ASABE), and from samples submitted to various laboratories throughout the United States.

application was 3.6 acres per AU, which declined to 2.2 acres per AU by 1997 (Ribaudo et al., 2003). This is likely due to the decrease in the number of small farms with lower number of livestock (less than 1000 heads) and an increase in the number of livestock (1000 or more heads) in larger operations (USDA-APHIS, 2017). Nowadays, we are starting to see more livestock operations with no crop acreage. The percent of farms producing livestock with no harvested crop acres have increased from 21% to 36% from 1996 to 2015, respectively, with beef cattle and swine being the biggest contributors (MacDonald et al., 2018). This represents an increase of 71% in the number of farms with no land for manure application. The reduction in acreage per AU suggests that more manure will be applied on land that does not necessarily need manure.

Some reports have suggested that the amount of N and P in manure being produced by CAFOs is in excess of more than 50% of what would be safe to apply in land in a way that remains economically and environmentally viable (Jackson et al., 2000; Ribaudo et al., 2003). In fact, Long et al. (2018) assessed how manure and its associated nutrients produced by CAFOs in Michigan are handled on a farm-basis scenario. The authors reported that 42% of all manure application between 2013 and 2015 happened in soils which already had excessive amounts of soil available P (soil test $P > 50$ ppm). The excess nutrients applied to the field with excessive soil test P levels would be enough to supply almost 10,000 acres with manure P for a soybean crop (Long et al., 2018). Similarly, Jackson et al. (2000) estimated that if manure applications were based on supplying the P needs of the crop (not N), then the 10 CAFOs used in the study would need ten times more land to safely use manure than the land they were currently using for manure application, increasing from 2449 ac to 23,109 ac. In a different study, Ribaudo et al. (2003) used data from the 1998 Hog Agricultural Resource Management Survey to generate a detailed report on the acreage used by confined hog operations and whether more acreage is needed for proper manure disposal. The authors found that only 37% of operations with less 1000 AU had the sufficient amount of land needed to safely apply manure using N rate applications (Ribaudo et al., 2003). In contrast, the authors reported that only 3% of operations with more than 1000 AU had been applying manure on agronomic rates (Ribaudo et al., 2003). Fertilizer recommendations are usually based on yield goal, and farmers are responsible for setting their own yield goal based on soil type and yield potential for a given crop and soil. In many cases, CAFO operators and farmers will overestimate yield potential of a certain field to increase the amount of nutrients that are needed for such field (Jackson et al., 2000; Long et al., 2018). Other ways to maximize how much manure will be applied to a field is by basing the manure application on the N requirement of the crop without much consideration for the soil test P levels (Ribaudo et al., 2003). These practices force overapplication of manure on land that should not receive the manure, or perhaps, should not receive as much as what ends up being applied. Furthermore, in many cases farmers will add inorganic fertilizer, N and P, in addition to the manure already applied in excess (Long et al., 2018). In cases where manure nutrients are mishandled, farms tend to apply 100% more P than farms that do not use manure (91 lb of P_2O_5 acre^{-1} compared with 45 lb of P_2O_5 acre^{-1}) (Long et al., 2018).

Final Considerations

Production of livestock and poultry under CAFOs has proven to be an effective way to raise a very large number of animals in a small area. However, the practice is also proving to be detrimental to the environment. When manure is applied at agronomic rates, it can be considered a valuable nutrient source and a soil amendment that improves soil physical, chemical, and biological properties. However, many farmers are either not using management practices that are ideal or simply lack information to maximize the use of manure for food production because of the variability inherently found in manure nutrient content. When misused, manure can be a source of nonpoint-source pollution to aquatic ecosystems. Repeated application of high rates of manure to the same land is causing nutrients to build up to levels considered excessive. Future work should focus on better predicting nutrient availability across soil types and climates, as well as best alternative options for manure reuse in farms that no longer have land where manure can safely be applied. Education and outreach will be critical so that livestock and poultry farm operators have the best information for making site-specific manure management decisions. Future chapters outline how mitigation strategies are being developed for sustainable use of these important nutrient sources.

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