2020

Impacts of Beef Concentrated Animal Feeding Operations on Environmental Sustainability in the United States and Practices for Improvement

Laura Clark
Virginia Commonwealth University

Impacts of Beef Concentrated Animal Feeding Operations on Environmental Sustainability in the United States and Practices for Improvement

Final Research Paper

Laura Clark

Virginia Commonwealth University

Faye Prichard

13 December 2019

Abstract

The geographic concentration of beef concentrated animal feeding operations [CAFOs] has changed the landscape of environmental sustainability for agriculture in the United States. As land availability has decreased, operations have struggled to maintain feasible practices to minimize environmental detriment. The United States Environmental Protection Agency [EPA] imposed rules to be followed as a means of mitigation, but the fast-paced rate of change minimizes effectiveness. The overall environmental sustainability of beef CAFOs has shifted from historical rates, leading to a need for reassessment. Part of this reassessment will include stronger environmental practices to be considered for implementation. I explored the role of manure management practices in CAFOs to evaluate the ways in which these practices contribute to water pollution of nearby sources. Additionally, I investigated what transportation of manure to off-site locations and nutrient management plans [NMPs] can do in relation to rebuilding the health of soil and aquatic ecosystems. The three aforementioned topics are dominated by land availability, so I delved into the impact that the modern decrease of land space plays on overall manure management practice efficiency. Dietary manipulation was also studied because of its relationship with nutrient excess in manure and maintaining animal productivity. In addition to this, cattle-based emissions were considered as they heavily result from feed digestibility. I lastly researched the ways in which water quality is impaired by CAFO functions and how that translates to surrounding lands, aquatic ecosystems, and even human health. The primary impacts of beef CAFOs on environmental sustainability result from decreased land availability. This has led to nutrient overloading from manure and degraded water quality, causing the need for alternative practices. Changing animal diet to increase feed efficiency, transporting manure off-site, and using phosphorus-based nutrient management plans are practices with the greatest promise for increasing environmental sustainability.

Keywords: manure management, dietary manipulation, geographic concentration

Impacts of Beef Concentrated Animal Feeding Operations on Environmental Sustainability in the United States and Practices for Improvement

The late 1800s were a crucial time in farm-life for Americans. The Homestead Act of 1862 supported the dreams of young Americans and immigrants and increased the westward expansion of farms in the United States. Consider the experience of Charles and his wife Caroline, a fourth-generation farmer’s son and a seamstress’ daughter. After a long wagon journey, the young couple arrives at their plot and stops for a moment to take it all in. Charles’ vision for his new land seems like the perfect picture: a log house fit for a real family, a drinking-well within a short walk from the front door, a large garden sitting adjacent to be tended by his wife and eventual children, crop fields stretching to the horizon, a stable to house a horse, chickens, and goats - the cattle will range, and no neighbors within eyesight. For now, it’s all his. He has all he needs. His crops will feed the animals and his family, the animals will also provide food as well as stable income, and the manure from the animals will safely feed the crops. If you’re thinking “Little House on the Prairie,” you’re spot on. These small family farms dominated America’s economy and labor force in a relatively safe, secure way. They were generally environmentally friendly, animal waste was manageable, and productivity rates were successful.

Fast forward to 2010 and beyond. The view outside a young girl’s window is everything but picturesque. A massive operation with nearly a thousand head of cattle is what she wakes up to each morning. Fence line and concrete half-walls stretch across her vision, filling the landscape. Silos reach for the sky, and animal barns congregate as a mass in the back corner. Several feedlots are crowded with 1,000lb cattle pushing against one another for better food advantage. Deep loud bellows ring out through the air, overcoming the whir of cars and machinery. A faint buzz of heavy-duty equipment can be heard just beneath the noise of the cattle, occasionally interrupted by abrupt clangs. A pungent stench infiltrates her suburban neighborhood from the sheer amount of waste produced by the animals and fermenting feeds. A small creek that teemed with life prior to the operation's construction is now plagued by algal blooms. The most life it holds is that of green aquatic plants, as all other life is slowly suffocated or forced to relocate. On the operation, the constant struggle with too much manure and not enough space torments the owners. Animal waste has turned into a harrowing task rather than a resource and must now be managed for the reality of environmental detriment. Yet the creek still did not survive.

Introduction

The development of concentrated animal feeding operations proved pivotal in the structure of American labor—compare the 64% of farmers in the labor force in the 1850s to the 11% (Morrison, Melton, & Kassel, 2019) of today. The expanse of small family farms has been replaced by massive operations with hundreds to thousands of cattle. A majority of these giants are geographically concentrated within a thin belt running vertically through our nation's Midwest—concerningly close to the Mississippi river. The United States' Environmental Protection Agency declared a set of regulations to be followed by these colossal operations, yet the landscape of CAFOs has changed drastically to the point where concerns have been raised over the effectiveness of the EPA's CAFO Final Rule. Technological innovations have allowed

CAFOs to continue their expansion, but they have not been sufficient in keeping up with the increasing demand of proper management practices for operations of such magnitude.

Historically, the waste produced by animals could be used at agronomically consistent levels as there was less output. Today, the intensiveness of industrial farming exceeds the levels which would be considered sustainable due to decreased land availability for application. Manure has become an emphasis in conservation efforts, and concerns over its utilization and disposal have increased with the further geographic concentration of CAFOs. Environmental contaminants from manure pose threats to human health, environmental health, and the overall sustainability of CAFOs.

Although modern CAFOs are regulated by the EPA over serious concerns such as manure application and water quality, the geographic concentration of beef operations has exceeded the EPA's ability to ensure stable environmental protection. Decreased land availability has led to nutrient overloading from manure, causing the need for alternative practices. Changing animal diet to increase feed efficiency, transporting manure off-site for use in areas with nutrient deficit, and using P-based nutrient management plans are practices with the strongest evidence for increasing environmental sustainability.

Background

The geographic concentration of CAFOs accentuates the improvement of management practices, where the effectiveness is tested by the quality of surrounding bodies of water. Water quality acts as a tell-tale sign for operation sustainability. Many operations apply manure produced to surrounding land—making this practice one of utmost concern, but there has been a continual decrease in the amount of land available for spreading. This leads to either an accumulation of manure within the operation or overapplication of manure to the soil, whether it be intentional or not. When rain events occur, the nutrients that are not absorbed into the soil runoff into nearby bodies of water. Phosphorus [P] is the primary nutrient that is lost, as many plants and crops require far less P than they do nitrogen [N], so the surplus is greater. When excess nutrients are leached into nearby bodies of water, severe negative changes occur in the existing ecosystems.

The use of additives in beef animal feeds presents an issue of lack of retention by the animal, if the diet is not properly structured; more often than not, this is the case. Additives of any kind pose a threat to ecosystems when they are not adequately used by the animal. Graham & Nachman (2010) emphasize the danger of unaltered antibiotics and hormones excreted in animal waste. They note that these often remain in manure for prolonged periods of time before decomposing, increasing the likelihood that the additives will enter surrounding waterways. Bradford, Segal, Zheng, Wang, & Hutchins (2008) concur with Graham & Nachman, finding that “as much as 80% of the administered antibiotics occurred as parent compounds in animal wastes” (p. 100). This release of additives to the environment results from improper utilization by the animal and ultimately a lack of proper manure management.

At the present, manure management systems vary based on operation size and funding. Liquid storage systems, commonly known as lagoons, are the most popular choice for waste storage. However, the waste contained in these tends to go untreated before land application and act as breeding grounds for pathogens. Pathogens are dangerous to human and animal health, as many have a low infectious dose. Pathogenic viruses, bacteria, and protozoa have a direct link to the environment when untreated manure housed in lagoons is applied to surrounding land. Waterborne disease outbreaks are frequently tied back to farm sites, further heightening the need for better waste management practices. The additional factor of geographic concentration may potentially put certain individuals and ecosystems at increased risk of disease if this issue goes unaddressed.

1. Environmental Protection Agency CAFO Regulations

As the United States continues on its trend of urbanization and industrialization, land availability required by all CAFOs has decreased substantially. Land space is necessary for proper utilization of manure produced by the animals in the operation. Historically, manure could be applied at agronomic rates consistent with the needs of the land. However, the sharp decrease in availability is forcing operations to accumulate manure and its subsequent nutrients. An unfortunate consequence of this problem is the overapplication of manure. Even the slightest overapplication can have serious consequences for the soil and nearby bodies of water.

To protect the environment, the United States' EPA instilled a set of regulations known as the CAFO Final Rule. This was designed as an extension of the Clean Water Act[1] (2002), which already required operations classified as CAFOs to obtain national pollution discharge elimination system [NPDES] permits. When an animal feeding operation [AFO] reaches 1,000 head of cattle or cow-calf pairs, they are deemed "large" and must follow certain effluent limitations within its NMP. The "large" status is what constitutes a CAFO. Another primary portion of the Clean Water Act were the requirements for manure land application, specifically for CAFOs that had pollutant discharge beyond the ideal of "none." The CAFO Final Rule (2008) added more extensive requirements for nutrient management plans, wastewater treatment (if applicable), setbacks from water sources, manure and soil sampling, best management practices [BMPs], and manure application rates. These additions were made in the hope of correcting or slowing the environmental threats that CAFOs pose.

[1] The Clean Water Act is formally the Federal Water Pollution Control Act but will be referenced as the "Clean Water Act" for brevity. It will appear as "Clean Water Act of 1972" in the references.

However, instead of necessitating CAFOs to have an NPDES permit—which is crucial for preventing or correcting pollution as soon as possible—the permit became optional. The CAFO Final Rule (2008) states that a CAFO must only have a permit if pollution is detected. Centner (2012) points out that an issue with this lies with large CAFOs and their need to produce a nutrient management plan to *determine* if there is point-source discharge (pollution). Most NMPs, though, serve the purpose of managing rather than detecting. So, pollutants will be able to affect the surrounding environment before proper action is taken to correct the issue. Thus, the ironically "preventative" purpose of this regulation only comes after detectable harm to the environment.

As geographic concentration has increased, the concern over point-source pollution has become less than that of nonpoint-source pollution. The NPDES permit, originally, was a safeguard to stop environmental malpractice while CAFO geographic concentration was not as great. According to the Clean Water Act (2002), CAFOs that directly emit pollutants into the environment can be fined or shut down if the operation does not have an NPDES permit that grants permission. To be able to discharge pollutants into navigable waters, pollutants must be below the designated effluent level for each specific contaminant. As previously mentioned, the CAFO Final Rule (2008) does immediately require this permit. Even so, most operations do adhere to this guideline regardless of permit status. However, the continuing concentration is creating difficulty in determining specific point-sources, making it harder to pinpoint which CAFOs require the NPDES permit. Centner (2012) acknowledges that "approximately 14,000 CAFOs are believed to need NPDES permits" but many are able to fly under the radar, since the discharge they produce is not enough to draw attention (p. 324). Still, though, any discharge is harmful to ecosystems as it alters chemical balances and can change organisms' abilities to function beneficially.

More recently, nonpoint-source pollution has risen as a serious concern due to an excess of nutrients in the soil surrounding operations. Nonpoint-source pollution is the diffuse of nutrients during or after a precipitation event. As excess nutrients enter the soil from CAFOs as a result of NMPs being nitrogen-based, there is greater risk for nutrient run-off. Ribaudo, Gollehon, & Agapoff (2003) argue that the additional problem of decreased land availability increases the likelihood that unused nutrients will runoff or leach into water sources. Furthermore, as P is generally overloaded into the soil as a result of NMPs being N-based, the risk for severe algal blooms rises substantially. The United States EPA (2019) states that "significant increases in algae harm water quality, food resources and habitats, and decrease the oxygen that fish and other aquatic life need to survive" (par. 4). Even more concerning, Bradford et al. (2008) found that nitrate is the most common nutrient leached into waterways, prompting the question of why aren't N-based NMPs eradicating this threat. The problem is not so much of CAFOs directly emitting pollutants purposefully, but rather indirect contamination as a result of operation functions and regulations that do not sufficiently target primary nutrient issues.

Though there are laws in place for regulating CAFOs as point-source pollutants, there are no controls for nonpoint-source pollution. States have established ideal BMPs as a means to mitigate the issue, but there is no effective way to enforce these practices. Additionally, since over-application of nutrients is addressed via waste management plans—a required element for CAFOs—many states do not have meaningful nutrient management requirements since they are assumed to be addressed within waste management.

The rules and regulations established by the EPA require updating and more conscientious efforts to the modern issues if they are to be effective on a mass scale. Furthermore, greenhouse gas [GHG] and volatile organic compound [VOC] emissions are not addressed within the Clean Water Act (2002) or CAFO Final Rule (2008) at all. In addition to excess nutrients and potential for water pollution, manure and its associated processes produce more GHGs and VOCs than what should be acceptable. Thus, necessitating mindful changes to the current standards to confront these growing issues.

2. Water Pollution

The rise in CAFOs across the United States has intensified the need for waste regulation. Currently, no requirements are in place for waste treatment from beef operations, resulting in many associated health risks and environmental detriment. The EPAs CAFO Final Rule only addresses the issues of water pollution and nutrient runoff, both of which largely originate from lack of waste treatment or overapplication of manure. Graham & Nachman (2010) state that when the land cannot retain the nutrients and/or break down the manure, they are much more likely to end up in the water. Numerous pathogenic microorganisms are found in food-animal waste and are transmitted into waterways when waste is improperly handled. Disease-causing bacteria in the water increase in concentration with proximity and overall number of CAFOs. For aquatic life, the introduction of hormones can have a severely adverse effect on their ecosystem at the population level. Some populations may experience feminization, sterilization, or even negative developmental effects on individuals. For humans, certain antimicrobials that do not harm the animals have been linked to cancer and vascular issues.

At the level of ecosystems, the runoff of nutrients into surrounding water sources presents serious dangers. Bradford et al. (2008) agree with Graham & Nachman (2010), arguing that an excess of nutrients and organics can completely alter or destroy aquatic ecosystems. Algae blooms, reduction in biodiversity, growth of toxic organisms, and unpleasant tastes/odors are most often a result of this. The most prominent nutrient leached into water is nitrate. Increased nitrate levels have most frequently caused blue-baby syndrome, diarrhea, and respiratory disease.

Contamination of surface and groundwater by pathogenic microorganisms is common across the United States, and farm animals have been deemed the primary source of origin. In regions where waterborne disease outbreaks are frequent, “loss of confidence in the safety of agricultural produce can have significant economic impacts” (Bradford et al., 2008, p. s100). Centner (2012) suggests two voluntary practices and one potentially state-mandated practice to correct the issues mentioned by Graham & Nachman (2010) and Bradford et al. (2008). He proposes using educational sessions to close the gap of misunderstanding between the relationship of CAFOs and water quality, so that operations owners will work harder to protect nearby sources. Centner also proposes having government subsidies for farms that implement appropriate NMPs to encourage CAFOs to improve water quality on the basis of “free money.” Lastly, as a state mandate to bring water quality up to standard, he argues for total maximum daily load [TMDL] requirements to be regulated. However, Centner emphasizes that adding more controls makes adhering to the standards more expensive for both the operations and the federal government. There is a recent progression of requirements to mitigate discharge into water sources based on the notion that an increase in animal production units calls for a need to subject the operations to more regulation. Though risks may be greater, it does not mean that larger operations have more pollutants entering water. Thus, state legislators become more reluctant to impose their own environmental controls. He notes that there must be a balance of power between federal regulations and what CAFOs themselves are able to do. Other mechanisms, rather than additional regulations, should be explored to improve environmental quality without having the same cost deficits.

In addition to nutrients and organics, antibiotics and hormones are commonly found in beef animal excreta. They are used to promote growth in food animals and are fed at heavy rates. Most of these are not fully metabolized and will be excreted by the animals. This poses a risk in antibiotic resistance and natural ecosystem function because they are getting into surrounding bodies of water. In particular, steroid hormones pose a strong threat because low concentrations cause severe adverse effects on the reproduction of aquatic species. Even more concerning, a vast majority of streams in close proximity to CAFOs have been contaminated by this type of hormone. Due to this understanding, CAFOs have been dubbed a predominant source of hormone release into the natural environment.

However, even though the use of these additives has been linked to environmental harm, there are serious concerns over the implications of removing most or all additives. Capper & Hayes (2012) acknowledge the problems surrounding hormone and steroid use but claim the removal of growth-enhancing techniques [GETs] from large scale operations would create even more significant detrimental consequences to environmental and economical sustainability. Concentrated animal feeding operation productivity would be expected to decrease, while increasing resource intake required in an attempt to maintain current production levels. To demonstrate this, Capper & Hayes conducted an experiment with two groups of roughly 3,000 head of cattle. One group was administered GETs whereas the other was not—dubbed the NOT group. Removing the use of growth-enhancing techniques required more resources (land, water, food, fertilizer) and generated more waste output and greenhouse gas emissions than operations using GETs. 265 additional hectares were required for the NOT group, as well as 2,830 tons of feed, 20,139 liters of freshwater, and 10,091 tons of fertilizers rich in nitrogen, phosphorus, and potassium. Waste output for the NOT group increased by 22,705 tons in regards to manure, nitrogen, and phosphorus excretion. A final numeric difference between the groups, most pertinent to the environment, are the additional GHG emissions from the NOT group. The greenhouse gas emissions measured consist of methane, nitrous oxides, and carbon emissions. The NOT group contributed 24,077 more tons of emissions than the group using growth-enhancing techniques.

3. Cattle-Based Emissions

There are very few regulations that protect against the production of emissions from CAFOs. Volatile organic compounds and greenhouse gas emissions have sparked serious conversation on the role CAFOs play in climate change. To assess the true values of CAFO emissions, Liu & Liu (2018) conducted a carbon footprint [CF]. A carbon footprint can be estimated from a life-cycle assessment [LCA] and then applied to other operations under similar conditions. As CAFOs generally have two stages before the end of the process, the LCA is broken down to determine how much each stage contributes to the CF. Studies agree that the cow-calf phase contributes two-thirds to nearly three-fourths of CF for the *overall* beef production system. Enteric fermentation is high in this phase, as animals are generally less able to digest feed well, making it less efficient. The feedlot phase has similar trends, where feed production itself “may account for 60% to 79% of the CF in this phase” (p. 630). Improving feed utilization, especially for the feedlot stage, is an important strategy to reduce the CF.

Beef and dairy cattle are the primary contributors in CH_4 formation from enteric fermentation, yet vary steeply when it comes to other GHG emissions from manure management. Dairy cattle make up 46.7% of manure management emissions, whereas beef cattle sit at a mere

15% (Liu & Liu, 2018, p. 627). On the flip side, beef cattle account for 71% of methane [CH_4] emissions from enteric fermentation in ruminants, whereas dairy cattle only account for 25% (Liu & Liu, 2018, p. 627-628). The CF of these operations measures the impact of a product or activity on the environment. In addition to the aforementioned emissions, the CF includes all other associated emissions with operation production as a whole. These activities include transportation, feed production, etc. The breakdown of a CF is critical to determining what types of practices should be used to mitigate GHG emissions, especially from enteric fermentation and manure management.

Enteric fermentation is a process which produces CH_4 by ruminants from the breakdown of carbohydrates in the rumen. The quantity produced varies by factors such as age and weight of the animal, as well as feed efficiency. When feed is less efficient or less digestible, there is an unproductive loss of dietary energy. Therefore, a higher feed intake will result in higher CH_4 emission when the feed is not easily digestible. Additionally, the forage-to-concentrate ratio of the diet can affect energy intake of the animals, as well. In a similar manner, if forage digestibility is greater, then CH_4 emissions are expected to decrease.

Enteric fermentation accounts for the majority of emissions from beef cattle, horses, sheep, and goats across the board. Liu, Liu, Murphy, & Maghirang (2017) argue that increasing productivity via feed efficiency is the most well-supported methods of ammonia [NH_3] and methane mitigation for CAFOs because both NH_3 and CH_4 are emitted from cattle when energy and nutrients are lost in the forms of manure and belching, respectively. Ammonia's formation can be expedited when manure is stored in anaerobic conditions, such as lagoons or tanks. Dry systems, such as stacks or piles, have demonstrated far less NH_3 emission. If this method of manure management can be "perfected," there will be substantial changes in the amount of N available for nitrification and denitrification in the soil, promotion of the aerobic metabolic path, and an even greater reduction of CH_4 during land application.

Some of the primary VOCs and GHGs often overlap, with CH_4 and carbon dioxide [CO_2] falling in both categories while NH_3 is solely recognized as a VOC. Yuan, Coggon, Koss, Warneke, Eilerman, Peischl, . . . de Gouw, (2017) claim that the production of the VOCs NH_3 and CO_2 is in direct relation with animal excreta, whereas ethanol production is in direct relation with feed storage+handling. NH_3 and CH_4 concentrations generally peak together, as they both are a result of animal action—waste production and belching, respectively. Acetic acid and acetone are VOCs that correlate positively with NH_3 and CH_4 concentrations, suggesting that animals in CAFOs contribute to the increase of those two VOCs as well. According to Liu, Liu, Murphy, & Maghirang (2017), CH_4 emissions increase when cattle cannot digest their feed in proper ratios. This also links to NH_3 emissions, since nitrogen that is not retained ends up being defecated. In moderation, NH_3 is a key part of the global ecosystem. However, it can have severe impact on individual ecosystems and lead to issues with air quality when produced in mass amounts. When broken down to its basic elements, NH_3 also contributes to the surplus of N in the soil. Liu, Liu, Murphy, & Maghirang (2017) claim that nitrogen is introduced to beef cattle through feeds but only 10% to 20% is actually retained, leaving the rest to be excreted via urination and fecal deposition. This process of NH_3 formation builds a linear relationship between feed N intake and NH_3 emissions, supporting the relationship described by Yuan et al. (2017) between NH_3 and animal excreta. In addition to the dangers of excess NH_3, Yuan et al. state that the heavy production of ethanol from feed storage+handling poses a threat regarding ground-ozone formation. Similarly, to NH_3, ethanol can play a crucial role in the atmosphere. In proper ratios, ethanol can actually reduce certain pollutants. However, the actual production, and burning if harvested, of ethanol generates CO_2 which is a GHG.

4. Manure Management

Improper management of animal waste is single handedly the greatest cause for pollution from CAFOs, assuming they follow all other guidelines. Ribaudo, Gollehon, & Agapoff (2003) argue that inefficient manure management practices are the primary contributor to water contamination resulting from CAFO manure, as application rates are not correctly adjusted in their plans. Farms with the magnitude of a CAFO need more land to utilize manure. However, the average operation is spreading on a land area smaller than what it would need for total manure application. To accommodate, larger operations would have to increase the amount of spreadable land by a ratio consistent with the number of animals on the farm.

Nutrient management plans are crucial pieces for environmental protection, yet many are falling short. Graham & Nachman (2010) claim that the EPA's NMPs struggle to accommodate the 335+ million tons of animal waste generated by CAFOs. Almost half of the food animals are raised in CAFOs, but these operations use less than 5% of the land base (p. 648). However, a lessened land base does not mean lessened waste production. To ease the strain, Graham & Nachman emphasize assessing and addressing the problem at its root—which is waste management—needs to occur in order to promote environmental sustainability within the beef industry. Bradford et al. (2008) concur with Graham & Nachman, arguing that accommodating for a high manure output while only accounting for a single nutrient decreases the effectiveness of the NMP. Furthermore, there are also differences between nutrient composition in wastewater and uptake rate of plants. Water flow can be influenced by a number of factors, which makes it difficult to develop an appropriate plan. The danger of an increased water flow is that it accelerates the movement of contaminants through the root zone down to the groundwater.

Manure application to land largely occurs on an N basis, as more manure can be applied to meet the N needs of the crops and soil. Ribaudo, Gollehon, & Agapoff (2003) additionally note that application on a P basis is much less common in CAFOs across the board, because it heavily restricts the amounts of manure which can be applied at an agronomic rate for that particular nutrient. This restriction is due to manure containing more P than N relative to plant needs. More land would then be necessary for spread under a P limit rather than an N limit. As most CAFOs operate under NMPs designed for an N limit, requiring a P-based plan would mean greater nutrient management changes. Koelsch (2005) agrees that common NMPs allow for excess manure to be applied leading to greater runoff and suggests that BMPs be adopted since they require less regulation for greater positive impact. Koelsch's study on a single beef finisher feedlot of 2,500 head demonstrated a transfer of two for every three units of P to the environment as a loss or being stored on the farm. Annually, this would mean that the single farm will add "40,000 kg of elemental P to the soil reservoir or feedlot surface" (p. 152). Too much P in soil can lead to devastating changes. Whereas manure is typically a natural fertilizer, too much P can actually cause plants to grow poorly or even die—furthering the modern idea of manure as a troublesome product rather than an important resource.

4.1 Decreased Land Availability

As geographic concentration of CAFOs has continued, the amount of land available for manure spreading has decreased. Graham & Nachman (2010) state that many operations have been known to over apply manure on lands that are not large enough to retain it, reiterating Ribaudo, Gollehon, & Agapoff's (2003) claim that rates are not correctly adjusted. When the land cannot retain the nutrients and/or break down the manure, they are much more likely to end up in the water. The lack of available land space associated with CAFOs in relation to what is needed for total manure application places a restriction on how much can be applied at an agronomically consistent rate. Ribaudo, Gollehon, & Agapoff concluded that either expansion of available land or the transportation of manure to off-site locations for application are the primary options for fixing the issue while still using the manure in a meaningful way. Bradford et al. (2008) support Ribaudo, Gollehon, & Agapoff and Graham & Nachman by arguing that the inability to regulate contaminants reaching water sources makes reuse CAFO wastewater an unlikely option, because excess amounts of environmental contaminants negatively impact water quality and can have adverse effects on human health.

Historically, land application of manure was an automatic and effortless practice, as rates were agronomically consistent with the needs of the soil. Ribaudo, Gollehon, & Agapoff (2003) claimed that although land application of manure is a preferred method of disposal, restrictions on the amount of land required for application makes full implementation difficult because N-based and P-based NMPs often require more space than large operations have available. Additionally, as the number of animals per operation has been continually increasing, available land space has been on the decline. Graham & Nachman (2010) associate the decreasing land availability with further urbanization and industrialization in the United States. They highlight that, historically, the waste produced by animals could be used at agronomically consistent levels as there was less output. Today, the intensiveness of industrial farming exceeds the levels which would be considered sustainable due to this decreased land availability for application. Koelsch (2005) states that because current land space is inadequate for the amount of manure produced to be applied at agronomic rates, a build-up of manure and its nutrients occurs within operations.

Build-up within operations can be extremely detrimental when precipitation events occur, as the nutrients have little to anchor to. Soil at least acts as an anchor for nutrients, even when they are overloaded.

The removal of nutrients from CAFOs and decreasing the intensity of spreading on the same land over and over is necessary for promoting environmental sustainability. Animal production is continuing to increase but is ultimately limited by the availability of land. However, Liu & Liu (2018) claim that while this lack of land space places strain on manure management, it actually promotes the improvement of feed and animal production efficiency. Those are major opportunities to mitigate the carbon footprint and create balance among land use, feed production, and animal production. Improving feed and animal production can reduce land use per unit and reduce feed required per unit, respectively. Even so, Ribaudo, Gollehon, & Agapoff (2003) note that some operations may end up "competing" to get land which they can spread upon. Operations are known to buy land for this purpose because manure accumulation is costly, and it can be difficult to find others willing to take the manure for use.

4.1a Transportation of Manure to Off-Site Locations

Manure transfer to off-site users significantly reduces the excess nutrients lost to the environment by the extra manure which cannot be applied to the land at the operation. Bradford et al. (2008) emphasize that an accumulation of manure in CAFOs will occur if manure is applied on a P-basis, which would be at a truly agronomic rate. Due to this accumulation, an alternative source or method to reduce leftover manure after spreading is needed. Ribaudo, Gollehon, & Agapoff (2003) suggest that one solution to this would be application of manure throughout county limits to meet the nutrient demands of *all* land within the county limits, assuming that landowners would be willing. At the very least, the manure can be applied to county-owned lands. The manure from CAFOs in counties could provide at least half of the total N need for the soil in a given county affected by CAFO geographic concentration. Thus, the transportation of excess manure elsewhere is necessary.

Manure transfer to off-site users significantly reduces the excess nutrients lost to the environment by the extra manure which cannot be applied to the land at the operation. Koelsch (2005) deduced that if 50% of manure from the 2,500 head case-study farm is transferred, P imbalance will be reduced by almost 18,000 kg, annually. As P is almost always the most heavily overloaded into the soil, a reduction of 18,000 kg from even just a fraction of CAFOs would be monumental. Though if additional nutrients can be removed from animal waste prior to its excrement, more manure can be applied since it will contain fewer nutrients.

4.2 Dietary Manipulation

Beef animal diets often consist of additives meant to push rapid growth above all else. Frequently, much of what goes into the animal comes out in the manure unaltered. This poses a threat to environmental safety, as the risk of nutrient runoff increases substantially. Maguire, Dou, Sims, Brake, & Joern (2005) recognize that many operations overfeed P as a method of insurance feeding or safety margin. Animals only retain partial amounts of the P in their diet, and the rest exits their bodies via manure—increasing the concentration of P in the manure.

Modified feeding strategies are crucial to deal with P surpluses associated with the intensity of modern animal agriculture because there is a direct link between P solubility in manure and P losses from manure amended soils. Maguire et al. (2005) name three ways to counteract the surplus of P that yield the greatest positive results when combined: reduction of P overfeeding, use of feed additives to enhance dietary P utilization, and development of high available phosphorus [HAP] grains. These alternatives have been shown to decrease fecal P excretion without impairing animal performance. Since most current feeding programs use products that produce a high ratio of P, excess is excreted in the manure which contributes to a higher whole-farm nutrient imbalance. Koelsch (2005) determined that the removal of ethanol production and corn processing by-products is the simplest way to reduce P not used by the animal. In terms of manure, lessened P excretion means that NMPs could potentially still operate on an N-basis with less negative environmental impact.

In addition to those changes, there are other general aspects of dietary manipulation that have risen to the top as being effective. Liu, Liu, Murphy, & Maghirang (2017) reported that feed must be easily digestible for the animal so the nutrients and energy are retained. A lower forage-to-concentrate ratio is necessary to improve digestibility. Increasing the proportion of concentrate should be utilized to also increase animal productivity. Capper & Hayes (2012) agree and emphasize the use of growth-enhancing techniques as well, as they are proven to increase animal productivity. GETs have the additional benefits of requiring fewer resources (land, water, space) for greater gain and generating less manure and GHG emissions. Liu, Liu, Murphy, & Maghirang recognize the value of improving feed efficiency to increase animal productivity, especially as it is a supported way to decrease enteric CH_4 and NH_3 emissions in cattle CAFOs. In terms of effectiveness, numerous studies have shown that a combination of those practices yield greater positive results than any single one.

When considering dietary modification, it is important to ensure that the plan is designed to reduce P without increasing manure water-soluble phosphorus [WSP]. Maguire et al. (2005) concluded feeding closer to species' P requirements or using HAP corn both lead to similar decreases in WSP. Phytase, which is designed to increase digestion of dietary phytate-P, generally has little to no change on WSP, but cases have seen it increase WSP which creates controversy over the environmental benefits of the additive. However, when it is combined with HAP corn, phytase becomes more effective in reducing manure WSP.

WSP to total P ratio is gaining importance, as areas with intense agricultural production are moving towards P-based NMPs. Some instances of dietary manipulations have resulted in increased manure WSP which would cause greater concerns about WSP application due to dissolved reactive phosphorus [DRP] runoff losses. However, there is no consistent trend for specific strategies that could increase DRP losses. Even so, this variation in data suggests that further research is required to ensure that P is reduced consistently at all levels. The researchers found that dietary modification to reduce P was shown to be cost effective and can save money in some cases. More importantly, strategies to reduce P do not impair animal performance.

Feed digestibility is arguably the most important aspect of dietary manipulation. If feeds are not easily digestible, the animal will lose the nutrients in the same way as occurs in a growth-promoting diet. Liu & Liu (2018) argue that there is significant evidence that dietary manipulation through feed management or supplements is effective in its reduction of gases from enteric fermentation. If feed digestibility is improved, then feed intake can be increased to finish the animal sooner. The addition of more concentrates in feed is crucial in that process, as it results in the ability for the animal to take in more feed and have greater digestibility. Thus, the animal is more productive as well. Emissions from manure can be mitigated in a manner similar to enteric emissions but with greater positive results. The strongest strategy is to optimize animal diet to improve nitrogen use efficiency and reduce the amount of N excreted. Liu, Liu, Murphy, & Maghirang (2017) concur, finding that a lower forage-to-concentrate ratio is necessary to improve digestibility. Increasing the proportion of concentrate should be utilized to also increase animal productivity. When the animal is more productive, enteric CH_4 emissions decrease per unit of animal product. Additionally, the state of the cattle - either grazing or housed - contributes to feed digestibility, where housed cattle have a higher rate. A higher digestibility rate could potentially influence feed intake level, but further research is required to determine the extent of the relationship. The most documented effect was low digestibility on low intake.

5. Conclusions

Beef CAFOs generate excessive amounts of animal waste that the EPA struggles to accommodate within its CAFO Final Rule. As a result, degraded water quality in sources within proximity to the operation occurs in significant measures. The runoff of surplus nutrients placed into the soil by manure application is the primary cause of this, leading to a need for change in NMP regulation. Currently, NMPs are based on nitrogen levels. However, mandating P-based plans proves beneficial in reducing the superfluous amount of nutrients, therefore reducing the degradation of surrounding bodies of water. An extra measure to be taken to reduce the amount of nutrients in the manure itself is through dietary manipulation.

The waste that is produced by beef cattle and associated animal processes also generates excess GHGs and VOCs. Modern animal diets are focused on promoting fast-paced animal growth that does not always guarantee that the animal retains everything that is put into it. Beef cattle diets should be modified with emphasis on greater digestibility, a lower forage-to-concentrate ratio, a combination of reduced P and enhanced nutrient utilization, and higher levels of concentrates in the feeds. Thus, manure produced by the animals should have lower levels of nutrients so that more can be spread while maintaining agronomic rates. Additionally, there are notable areas of nutrient deficit located near CAFOs but that are not owned by the operations, so they cannot spread on those lands without owner permission. The transportation of manure to these areas would provide an efficient, healthy way to use manure without risking oversaturating nutrients into the soil.

With the ever-decreasing availability of land and continually growing demand for beef cattle products, CAFO practices cannot remain stagnant. The health of the environment is greatly affected by what we put into it. CAFOs generate emissions and waste with various nutrients and contaminants, of which most have direct contact with the environment. Further research needs to investigate the combinations of dietary elements to determine which best satisfy the requirements of: greater digestibility, a lower forage-to-concentrate ratio, a combination of reduced P and enhanced nutrient utilization, and higher levels of concentrates in the feeds. Additionally, the implications of a large-scale shift to P-based NMPs needs to be studied to prepare for any economic changes and gauge environmental effects. The knowledge gained should eventually be translated for other types of CAFOs to use.

References

Bradford, S. A., Segal, E., Zheng, W., Wang, Q., & Hutchins, S. R. (2008). Reuse of concentrated animal feeding operation wastewater on agricultural lands. *Journal of Environmental Quality*, *37*(5), S97-S115. Retrieved from http://proxy.library.vcu.edu/login?url=https://search.proquest.com/docview/347866376?accountid=14780

Capper, J. L. & Hayes, D. J. (October 2012). The environmental and economic impact of removing growth-enhancing technologies from U.S. beef production, *Journal of Animal Science*, *90*(10), 3527–3537, https://doi.org/10.2527/jas.2011-4870

Centner, T. J. (2012). Regulating the land application of manure from animal production facilities in the USA. *Water Policy, 14*(2), 319-335. doi:http://dx.doi.org/10.2166/wp.2011.086

Clean Water Act of 1972, 33 U.S.C. § 102-607 (amended November 2002).

Concentrated Animal Feeding Operation Final Rule, 33 U.S.C. § 122-447 (amended 2008).

Environmental Protection Agency. (2019, February 4). The Issue. Retrieved December 3, 2019, from https://www.epa.gov/nutrientpollution/issue.

Graham, J. P., & Nachman, K. E. (December 2010). Managing waste from confined animal feeding operations in the united states: The need for sanitary reform. *Journal of Water and Health*, *8*(4), 646-670. doi:http://dx.doi.org/10.

Koelsch, R. (2005). Evaluating livestock system environmental performance with whole-farm nutrient balance. *Journal of Environmental Quality, 34*(1), 149-155. Retrieved from http://proxy.library.vcu.edu/login?url=https://search.proquest.com/docview/197376686?accountid=14780

Liu, Z. and Liu, Y. (2018), Mitigation of greenhouse gas emissions from animal production. Greenhouse Gases: Science and Technology, *8*(4): 627-638. doi:10.1002/ghg.1785

Liu, Z., Liu, Y., Murphy, J. P., & Maghirang, R. (2017). Ammonia and methane emission factors from cattle operations expressed as losses of dietary nutrients or energy. *Agriculture, 7*(3), 1-12. doi:http://dx.doi.org/10.3390/agriculture7030016

Maguire, R. O., Dou, Z., Sims, J. T., Brake, J., & Joern, B. C. (2005). Dietary strategies for reduced phosphorus excretion and improved water quality. *Journal of Environmental Quality, 34*(6), 2093-2103. Retrieved from http://proxy.library.vcu.edu/login?url=https://search.proquest.com/docview/197393754?accountid=14780

Morrison, R., Melton, A., Kassel, K. (September 2019). Ag and food sectors and the economy. *United States Department of Agriculture*. Retrieved from https://www.ers.usda.gov/data-products/ag-and-food-statistics-charting-the-essentials/ag-and-food-sectors-and-the-economy/

Ribaudo, M. O., Gollehon, N. R., & Agapoff, J. (2003). Land application of manure by animal feeding operations: Is more land needed? *Journal of Soil and Water Conservation, 58*(1), 30-38. Retrieved from http://proxy.library.vcu.edu/login?url=https://search.proquest.com/docview/220953417?accountid=14780

Yuan, B., Coggon, M. M., Koss, A. R., Warneke, C., Eilerman, S., Peischl, J., . . . de Gouw, J., A. (2017). Emissions of volatile organic compounds (VOCs) from concentrated animal feeding operations (CAFOs): Chemical compositions and separation of sources.

Atmospheric Chemistry and Physics, 17(8), 4945-4956.

doi:http://dx.doi.org/10.5194/acp-17-4945-2017