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Use of manure nutrients from concentrated animal feeding operations

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ABSTRACT

Over the past few decades, there has been a nationwide trend away from small livestock farms and toward large Concentrated Animal Feeding Operations (CAFOs). This shift results in concentrated manure production and introduces potential problems associated with its disposal. We analyzed data from 13 permitted CAFOs in southeastern Michigan, including 1187 occurrences of manure application from 12 of the CAFOs with available field-level data. CAFOs applied excess manure nutrients to cropland by applying to fields with soil phosphorus test levels >50 ppm (42% of all cases), applying to soybeans (7% of all cases), over-estimating crop yields in calculating plant nutrient requirements (67% of all cases), and applying beyond what is allowed by state permits (26% of all cases). This represents significant potential for redistribution of manure nutrients. The total amount of manure from all instances of over-application could be redistributed to fertilize over 4775 ha (11,800 acres) per year. Significant barriers to redistribution of manure exist, however, including cost, land availability, crop and soil need, transport logistics, and farmers' reluctance to use manure instead of inorganic fertilizer due to its variable composition. These findings are relevant to the harmful algal bloom and hypoxia issues in Lake Erie, which are driven by excess nutrients, and can be used to better inform science, modeling, and policy in the region.

Introduction

Over the past few decades, there has been a nationwide trend toward large animal operations and away from small farms (Kellogg et al., 2000; Gollehon et al., 2001). While the total number of livestock has remained relatively stable, the number of livestock farms has decreased, resulting in more livestock kept in larger operations and in confinement. Concentrated Animal Feeding Operations (CAFOs) are defined by the United States Environmental Protection Agency (EPA) as operations that confine animals for >45 days a year and either meet a certain size threshold (e.g., 1000 beef cattle, 700 dairy cows, 2500 swine weighing >55 pounds) or discharge manure or wastewater directly into a waterway (USEPA, 2008). The shift from traditional smaller farms to CAFOs results in concentrated manure production and introduces potential problems associated with its disposal. There has been growing public concern about the environmental effects of CAFOs, particularly regarding potential contamination of surface water and groundwater with nitrogen (N) and phosphorus (P), the primary nutrients in manure. Excess inputs of N and P can lead to eutrophication of surface water, resulting in harmful algal blooms (HABs) and depleted dissolved oxygen concentration (hypoxia). The Clean Water Act and other federal and state laws regulate CAFOs to minimize environmental impacts, but uncertainty remains regarding the effect of CAFOs on nutrient inputs to surface water and the success of policies designed to protect against water contamination.

The manure produced in CAFOs can be used to fertilize cropland, but there may be agronomical, logistical, and economic constraints on these large operations because there may not be enough nearby cropland in need of nutrients to receive all of the manure. In these cases, manure may be applied far from CAFO barns or transferred to another operation (both of which can be expensive), stored on site, or potentially over-applied on nearby cropland. Nutrients applied above crop requirements can accumulate in the soil (especially P), denitrify (in the case of N), or wash off fields and then contaminate surface water. Studies have suggested that the amount of land needed to use CAFO manure nutrients is often underestimated (Kellogg et al., 2000; Jackson et al., 2000; Gollehon et al., 2001; Ribaudo et al., 2003a), so there is an opportunity to spread manure on more land, and potentially reduce inorganic fertilizer applications. Those studies, however, use literature-based manure nutrient composition and assumed application rates and do not consider the effect of inorganic fertilizer applications at CAFOs. Herein, we address these shortcomings by using detailed, field-level manure application data reported by CAFOs to further understanding of manure management at these operations.

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We analyzed data from 13 southeastern Michigan CAFOs that are within a 15 km (9.3 mi) radius of each other in the River Raisin and Maumee River watersheds, both of which discharge to western Lake Erie (Fig. 1). This includes six of the seven CAFOs in the River Raisin Watershed and seven of about 80 CAFOs in the Maumee River Watershed, which has most of its land area and CAFOs in Ohio and Indiana (IDEM, 2017; MDEQ, 2017; OEPA, 2017b). While this area is relatively dense with CAFOs compared to the rest of the Maumee River Watershed, it is not unique. There are over 30 CAFOs within a 30 km (18.6 mi) radius in southern Mercer County, Ohio, and CAFOs in other areas throughout mid-Michigan are even more dense. In recent years, harmful algal blooms and hypoxia in Lake Erie have increased in extent and intensity due to elevated P loadings from watersheds that drain to the lake, particularly from the Maumee River watershed. Farm fertilizers and manure are primary sources of the Maumee River's P load (Scavia et al., 2014, 2017), and it has been estimated that about 12% of phosphorus applied to cultivated cropland throughout western Lake Erie basin (WLEB) watersheds is from manure (USDA, 2017a). Policymakers have set a goal of reducing the P input to Lake Erie by 40% (GLWQA, 2012), and meeting the goal will require a better understanding of the relative contributions and the spatial distribution of nutrient sources, including manure. While a majority of the critical WLEB watershed area is in Ohio, only Michigan has publicly-available, detailed field-level data on CAFO manure nutrient application. We chose our study area because we can address key questions about CAFO practices in this region using the data provided publicly by Michigan. Our primary objectives were to 1) develop a baseline understanding of manure produced and applied at CAFOs in a critical watershed area and 2) examine agronomic and logistic potential for redistributing manure nutrients to land with greater nutrient needs.

Methods

CAFO data and manure application records

The state of Michigan requires all CAFOs to submit to the Michigan Department of Environmental Quality (MDEQ) Comprehensive Nutrient Management Plans (CNMPs) and Annual Reports that include field-level manure application records. These data are available through

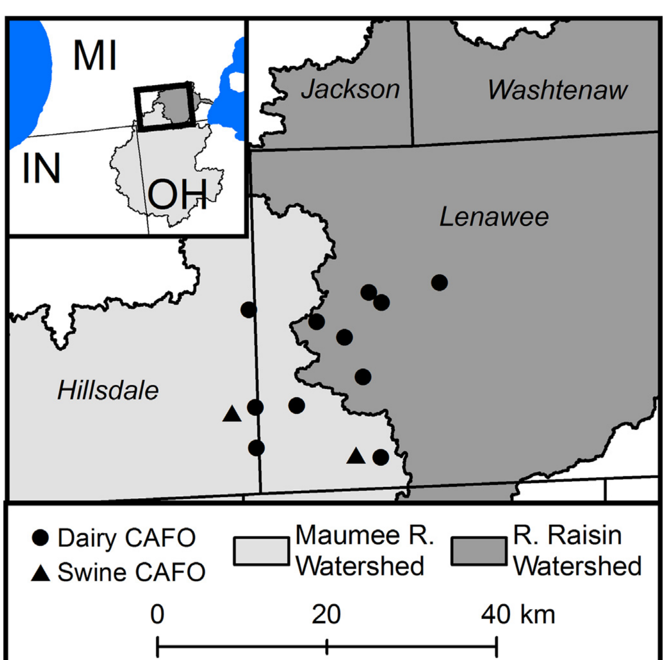

Fig. 1. Locations of CAFOs included in this study.

Michigan's MiWaters online database (MDEQ, 2017). We compiled the most recent CNMPs and three years (2013–2015) of annual reports for 11 dairy CAFOs and two swine CAFOs in southeastern Michigan (Fig. 1). The annual reports have two main components: general operation data and field-level manure application data. The general data include average and maximum number of animals confined, estimated total waste generated, estimated total waste transferred off-site to another operation, total number of acres available for land application, and total number of acres used for land application for each calendar year. The field-level application data include field size, soil P level, date of soil test, planted crop, yield goal, actual yield, manure application rate, manure N application rate, available N, N credit, manure P application rate, fertilizer N application rate, fertilizer P application rate, total N, total P, and the basis for rate calculation (e.g., N-based, 1 year P-based, 2 year P-based) for every field to which manure was applied during the crop year. Fields must be 40 acres or smaller. Data are not provided for fields that received only inorganic fertilizer or were not fertilized. After omitting the field-level information from one CAFO due to reporting errors (R. Burns, MDEQ, pers. comm., February 13, 2017), we compiled a database of 1187 manure application records from the remaining 12 CAFOs. The annual reports' general data described above were retained and analyzed for all 13 CAFOs.

Missing data and data calculations

There were some inconsistencies in reporting among CAFOs, and records were occasionally missing information. When a field's size was not reported (8% of records), we used the average size of all other fields fertilized with manure by the given operation in calculations. Other cases of missing data are described below when relevant. The CAFO permits require that soil P tests use the Bray P1 method unless an alternate method is approved (MDEQ, 2015). Because no exceptions were noted on any reports, we assumed Bray P1 tests were used in all cases. When applicable, units for P application were converted from P to P_2O_5 and units for soil P test levels were converted from lb./acre to ppm using conversion factors from Warncke et al. (2004) and assuming a 16.96 cm (6.67 in) soil depth. All other data were used as reported. Herein, "P_2O_5" (phosphate) is used instead of "P" for discussion of phosphorus application rates and manure composition in accordance with U.S. agricultural convention. Unless otherwise noted, manure N refers to first-year plant-available N, which can be less than total manure N applied, as this is what is reported as the final rate in the CAFOs' annual reports.

Total liquid and solid manures applied by each CAFO each year were calculated by multiplying application rates by field areas. Total manure accounted for was this amount plus manure transferred off site. Manure N and P_2O_5 contents for each reported field application were calculated by dividing the total manure N and P_2O_5 application rates by rates of total manure applied.

Recommended and allowed application rates

The maximum allowed manure nutrient application rates for CAFOs in Michigan are based partially on Tri-State Fertilizer Standards established in 1995 by Michigan, Ohio, and Indiana (Warncke et al., 2004). P_2O_5 recommendations are based on soil P level and yield goal, and it is recommended to apply no P_2O_5 when soil P levels are >40 ppm (for corn and soybeans) or 50 ppm (for wheat and alfalfa). In Michigan, CAFOs are allowed to apply at 1, 2, or 4 times the Tri-State recommended P_2O_5 rate, depending on soil P levels, and application is allowed on soils with P levels up to 150 ppm (MDEQ, 2015). The MDEQ allowances follow the Tri-State N recommendations, which are based on previous crop and yield goal, except they allow application on soybeans and alfalfa, which the Tri-State Standards do not recommend.

We compared the reported CAFOs' N and P_2O_5 application rates to the Tri-State Standard recommended rates and to MDEQ-allowed

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