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Integrating remote sensing with nutrient management plans to calculate nitrogen parameters for swine CAFOs at the sprayfield and sub-watershed scales

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HIGHLIGHTS

- Remote sensing identifies annual nitrogen parameters for swine sprayfields.
- Using sprayfield instead of farm location improves estimates for swine wastewater.
- Crop rotations impact sub-watershed scale nutrient balance.

GRAPHICAL ABSTRACT

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ABSTRACT

North Carolina (NC) regulates swine concentrated animal feeding operations (CAFOs) using five-year nutrient management plans (NMPs) requiring the plant available nitrogen sprayed (PANspray) to be less than that utilized by crops (PANcrops), i.e. the PAN balance (defined as PANbal = PANspray − PANcrops) remains negative, which avoids over-spraying liquid effluent onto crops. Objectives of this research are first to characterize Duplin County sprayfields and PANbal by creating the first, open-source sprayfield spatial database created for swine CAFOs in NC (for Duplin County). Second, this paper finds that for two sub-watershed scales 199 additional catchments and 1 additional HUC12 were identified as having permitted lagoon effluent applied compared to using CAFO point locations for a total of 510 catchments and 34 HUC12s with swine CAFO sprayfields. Third, a new method disaggregates annual PANbal from NMPs using remote sensing crop data. And finally, probability that sprayfields have excess PANbal is estimated due to k, a PAN availability coefficient. The remote sensing approach finds that 9–14% of catchments in a given year and 24% of catchments over a five year period have a positive PANbal. An additional 3–4% of catchments have probability of a positive PANbal due to variability in k. This work quantifies the impact of crop rotations on of sprayfields at the catchment spatial scale with respect to PANbal and highlights some of the limitations of NMPs have for estimation of PANbal. We recommend that NMPs be permitted based on the crop rotation scenario utilizing the least PAN and that swine producer compliance to manure management practice be encouraged.

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1. Introduction

Swine industrial animal operations, termed concentrated animal feeding operations (CAFOs), are of concern to public and environmental health (Wing et al., 2000) due to their effects on respiratory health of neighboring communities (Mirabelli et al., 2006), as well as nutrient, pathogen, pesticide, heavy metal and antibiotic resistance trait loads to surface water and groundwater (Burkholder et al., 2007; Hribar, 2010; Harden, 2015; Nadimpalli et al., 2014; Mallin et al., 2015). Swine CAFOs in North Carolina (NC) customarily store centralized, large volumes of swine waste (i.e. liquid effluent) in open air lagoons and sprayed as fertilizer for crops onto sprayfields. CAFO effects on water quality include lagoon ruptures and breaks during extreme weather events such as during hurricanes, but also chronic water quality impacts which include nutrients carried offsite from sprayfields (Mallin and Cahoon, 2003) or from underground drainage tiles (Harden, 2004) as runoff or also as groundwater transport of nutrients (Karr et al., 2001). Watersheds with CAFOs had a measureable effect on surface water quality with higher total nitrogen compared to control watersheds in a two year USGS study (Harden, 2015). In addition to experimental data, a land use regression model found that density of CAFOs is associated with increased groundwater nitrate and may act as reservoir to surface water nitrate recharge (Messier et al., 2014).

NC has the second largest hog industry in the United States with 90% of swine CAFOs having 1000 swine or more. Duplin County, NC has the highest density hog-population of any County in the United States (USDA National Agricultural Statistics Service, 2012). In NC, environmental safeguards for swine CAFOs regulate nutrients and heavy metals but do not manage swine CAFOs for any microbial or pathogen load. Nutrient regulation is conducted based on NC public law 626 (General Assembly of North Carolina, 1995) that created the swine permitting system in NC and an interagency guidance committee provides assistance for creation of nutrient management plans (NMPs).(Hardee et al., 2009).

The Animal Operations unit of the Water Resources division of NC's Department of Environmental Quality (DEQ), regulates and permits swine CAFOs, defined as having 250 or more swine, requiring NMPs for each one. The NMPs regulate over application of swine liquid effluent onto sprayfield crops by permitting swine CAFOs if the pounds plant available nitrogen sprayed (PANspray) is less than pounds PAN utilized by sprayfield crops (PANcrops), i.e. the PAN balance (defined as PANbal = PANspray − PANcrops) remains negative. A negative PANbal should theoretically ensure that no excess nitrogen is transported to nearby surface water or groundwater. However Messier et al. (2014) showed that groundwater nitrogen is higher near CAFOs, but it remains unclear how the aquifer is contaminated. Therefore, work is needed to identify whether there are any catchments with positive PANbal despite the NMPs.

1.1. Objectives

NMPs are a rich data source, however regulatory barriers prevent easy public access to them. Regulatory barriers include the five-year permit review timeframe, public record request protocol, and proposed legislation. Because NMPs are re-submitted every five years, the paper permits are typically housed in DEQ's Central Office Files, and public access requires a staff member to take time to travel to the basement, identify individual animal waste permit files, and deliver them to the person requesting public records. Additionally, extensive public records requests are subject to fees, and in May 2014, although not passed into law, Senate Bill 762 (General Assembly of North Carolina 2014) proposed that aerial photographs and locations of CAFOs, which are in NMPs, be removed from public record.

Currently, the only readily accessible spatial data for an NC swine CAFO is the physical address, latitude and longitude of the CAFO available from DEQ online (NC Department of Environment and Natural Resources, 2015). NMPs provide spatial information on the location of sprayfields. Because a swine CAFO almost always includes sprayfields, and watershed boundaries may divide a CAFO's sprayfields, knowing the sprayfield location improves currently known spatial data regarding swine CAFOs and provides more accurate and meaningful data for those studying the effects of swine CAFOs on surface waters.

NMPs also include proposed sprayfield-specific crop rotations and maximum permitted nutrient application data but the plans do not aggregate PAN data at the watershed scale. Identifying watersheds with large volumes of liquid effluent production, i.e. high PANspray and high PANbal, may be beneficial for targeted water quality monitoring and crop rotation management.

Finally, NMPs are unable to disaggregate PANbal by calendar year because NMPs provide multiple approved crop options or rotations throughout the five year permitting process. Remote sensing, however, can be used to identify crops grown on sprayfields for a given calendar year and used to identify PANbal annually.

Objectives of this research are to review all NMP permits in Duplin County to create the first and open source sprayfield spatial database created for swine CAFOs in NC (for Duplin County). Second, this paper quantifies the difference in aggregated PANbal between known CAFO point and newly identified sprayfield locations at two sub-watershed spatial scales in Duplin County, NC. Third, a new method was developed to identify PANbal on sprayfields using remote sensing data and PANbal was re-calculated annually using sprayfield location in Duplin County between 2010 and 2014 to identify inter-annual variability. And finally, estimated probability that sprayfields have excess PANbal is identified.

2. Methods

Three methods of calculating PANbal are presented. Two use permitted NMP data and compare CAFO point and sprayfield locations aggregated at two watershed scales. Then, using sprayfield locations, remote sensing identifies crop data on sprayfields to calculate aggregated PANbal at sprayfield and two watershed scales. Point locations of CAFOs regulated by DEQ are publically available online (NC Department of Environment and Natural Resources, 2015). Fig. 1 displays all CAFOs in NC with an inset of the study area, Duplin County, and displays that swine CAFOs are primarily in eastern NC. DEQ does not regulate dry poultry operations and these facility locations are not publically available.

2.1. Nutrient management plan data description

Point locations for swine CAFOs are based on the 2015 updated list of permitted swine CAFOs which was obtained from NC DEQ's website in 2015 (see Supporting information) (NC Department of Environment and Natural Resources, 2015). All point locations were manually reviewed by comparing the DEQ-provided latitude and longitude location of a swine CAFO with NMP maps and satellite imagery to ensure correct identification of each swine CAFO. The latitude/longitude points were re-assigned to the centroid of lagoon locations, for the instance in which a swine CAFO had more than one lagoon, or between the hog houses and the lagoon, for the instance in which the swine CAFO had one lagoon. NC swine CAFOs have three types of permits: animal waste swine (AWS), animal waste individual (AWI), and the federal National Pollutant Discharge Elimination System (NPDES) permit for North Carolina Animals (NCA). Of 492 unique swine CAFOs in Duplin County, 483 are AWS, 7 are AWI, and 2 are NCA. A total of seven facilities were removed from this analysis because one AWS facility is not yet built, three AWI permits double as AWS permits, two AWI are zero-animal and have lagoons but no longer have permitted animals, and one AWI is a livestock market with no active sprayfields. Waste management systems for zero-animal facilities were not found and are not included in this analysis. Thus in Duplin County and in this analysis, there are 485 permitted active swine CAFOs in 2015.

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