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Monitoring runoff from cattle-grazed pastures for a phosphorus loss quantification tool

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ABSTRACT

Nitrogen (N) and phosphorus (P) loss from agriculture persists as a water quality impairment issue. For dairy farms, nutrients can be lost from cropland, pastures, barnyards, and outdoor cattle lots. We monitored N and P loss in runoff from dairy and beef grazed pastures for two years in southwest Wisconsin, USA and tested the accuracy of the Annual P Loss Estimator (APLE) model to predict runoff P from pastures using study and literature data. About 3–10% of annual precipitation became runoff from the pastures, and sediment loss was very low due to well-established vegetation. Measured annual nutrient loss in runoff was also low, averaging 1.0 kg ha^{-1} for total P and 2.9 kg ha^{-1} for total N. Runoff sediment and particulate N and P concentrations were well related to each other and tended to be greater in rainfall-induced runoff than snowmelt runoff. Conversely, dissolved N and P runoff concentrations were greater in snowmelt runoff. APLE was able to reliably predict annual P loss in runoff, estimating that the average relative contribution to total pasture P loss was about 10% from fertilizer, 15% from soil dissolved P, 30% from dung, and 45% from soil erosion. Our study has increased the ability to develop reliable models for estimating the impact of cattle grazing pastures on nutrient runoff, which will be valuable in estimating whole-farm P loss from dairy production systems and identifying areas on dairy farms where P loss remediation should be targeted.

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1. Introduction

Non-point source pollution of surface waters by nitrogen (N) and phosphorus (P) can accelerate eutrophication and limit water use for drinking, recreation, and industry (Parris, 2011). Because N and P loss from agricultural systems via surface runoff has consistently been identified as a non-point pollution source (Bennett et al., 2001), there is a need to quickly and accurately quantify runoff nutrient loss from farms, identify the major sources of farm loss, and develop management practices to reduce that loss. For cattle farms, possible sources of runoff N and P loss include cropland, grazed pastures, and outside cattle holding areas, such as feedlots, barnyards, exercise lots, or over-wintering lots. On such farms, it is necessary to estimate nutrient loss in runoff from all of these sources to effectively target remediation practices (McDowell and Nash, 2012).

There has been significant research conducted to monitor N and P loss in runoff from grazed pastures (Edwards et al., 2000; Halliwell et al., 2000; Nash et al., 2000; O'reagain et al., 2005; Haan et al., 2006; Owens and Shipitalo, 2006; Capece et al., 2007; McDowell et al., 2007; Dougherty et al., 2008). However, considerably less pasture runoff research has been conducted compared to nutrient loss from cultivated cropland, and most of it has been conducted in Australia, New Zealand, and the United Kingdom. In the U.S., only limited field-scale, natural precipitation, pasture runoff research have been conducted where the major source of nutrient addition is through grazing animals (Olness et al., 1975; Menzel et al., 1978; Chichester et al., 1979; Schepers and Francis, 1982; Owens and Shipitalo, 2006; Capece et al., 2007). The reason for this is unclear. It may be that relative to row crops, pastures constitute much fewer acres on cattle farms in areas where water quality impairment is a problem and are not seen as a major contributor to waterbody eutrophication, especially since pastures typically have less nutrient inputs and soil erosion than row crops. However, as the demand for improved water quality increases, the use of pastures and the associated decrease in nutrient loss through soil erosion may become a more attractive land use on cattle farms (Rotz et al., 2009). There is thus a need to document the potential water quality impact of cattle pastures and have tools to estimate this impact relative to other land uses on cattle farms.

As quantifying runoff nutrient loss from all sources on a cattle farm through physical monitoring is expensive and lengthy,

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simulation models can be a more rapid, cost effective ways to estimate N and P loss (Radcliffe et al., 2009). For P, quantitative agricultural loss models can generally be grouped into two categories. The first group is highly parameterized, daily time-step, process-based models like the farm-scale Integrated Farm Systems Model (IFSM) (Sedorovich et al., 2007), or field to watershed-scale models like the Soil and Water Assessment Tool (SWAT) (Arnold et al., 1998) or the Agricultural Policy/Environmental eXtender (APEX) (Gassman et al., 2010). The second group is more user-friendly, seasonal to annual time-step models, such as the Annual P Loss Estimator (APLE) (Vadas et al., 2009, 2012) and the Wisconsin P Index (WI PI) (Good et al., 2012), that are a combination of process-based and empirical P loss equations. However, all of these tools have shortcomings when simulating P loss via surface runoff from cattle-grazed pastures. The WI PI and APLE have been developed to estimate P loss from agricultural cropland, but have not been tested for grazed pastures; IFSM apparently does not simulate P loss from dung deposited during grazing; and currently available versions of SWAT and APEX do not simulate manure or dung on the soil surface, which precludes adequate simulation of P loss from dung in pastures. Therefore, these tools should be updated to better simulate P loss from dairy farms in general and cattle-grazed pastures in particular. Vadas et al. (2011) recently developed a daily time step model for P loss from grazing cattle pastures that could be integrated into models like IFSM, SWAT, and APEX. Similar updates are needed for annual models like APLE and the WI PI.

The objectives of our project were to: (i) monitor N and P loss in runoff from beef and dairy-grazed pastures in southwest Wisconsin, USA, and (ii) use the runoff data, as well as data from published scientific literature, to test the ability of APLE to predict P loss in runoff from cattle-grazed pastures. The long-term goal of this research is to develop modeling tools that can estimate whole-farm P loss from dairy farms and appropriately target farm areas for P loss remediation. Assessing the pasture component of dairy farms is one step in that process.

2. Methods and materials

2.1. Pasture runoff monitoring

We established eight, hydrologically isolated basins ranging in size from 0.3 to 0.4 ha in an existing cattle pasture at the University of Wisconsin-Platteville Pioneer Farm (42.71°N, 90.39°W) (Fig. 1). The Pioneer Farm is a 174 ha production

Fig. 1. Aerial view of the field showing the location of the eight runoff basins within an existing cattle pasture.

farm located in the unglaciated area of southwest Wisconsin in the Northern Mississippi Valley Loess Hills. The dominant soil is a moderately eroded Tama soil series (fine-silty, mixed, superactive, mesic Typic Argiudoll), with B and C slope classes. The runoff basins were oriented so that four were on a south-facing slope (5–8%) and four were on a north-facing slope (5–8%), with a ridge separating the two groups. The eight basins were within existing pastures grazed by beef and non-lactating dairy cattle, and were separated from each other either by the ridge at the upslope edge or by earthen berms. The southern four basins were within a 7.3 ha pasture grazed by beef cattle, and the northern four basins were within a 6.1 ha pasture grazed by non-lactating dairy cattle. Thus, the eight basins all received generally the same management. Cattle were given free access to the pastures starting in mid-May until mid-November, with daily numbers of dairy cattle ranging from 14 to 34 and beef cattle from 18 to 28. Annual stocking rates were approximately 2.7 animal units ha^{-1}, with one animal unit defined as a mature cow at about 450 kg. Excess pasture growth was cut for hay and baled, typically in mid-July. This management for non-lactating cattle is typical for this region, with cattle generally given access to pastures for grazing from early to mid spring until late fall, with supplemental feeding as needed. Outside of this period, cattle are housed off of pastures, typically in small, dedicated lots known as over-wintering areas.

We installed runoff collection systems at the outlet of each basin. Each system consisted of wooden wing walls that channeled surface runoff into an H-flume. Ultrasonic sensors (Automated Products Group IRU-5000) measured and logged (Campbell Scientific CR206) water stage in the flumes in one-minute intervals to estimate runoff volumes. Flow-paced composite runoff samples were collected from flumes using an automated sampler (ISCO 3700), with sampling frequency adjusted remotely for each event to ensure collection of representative samples for an entire event, such that samples were collected more frequently as flow increased. Samples were pumped into 1-L containers and collected within 24 h of the end of the runoff event. A discharge-weighted sample was then produced for each runoff event by calculating the percentage of the total runoff-event volume that each discrete sample represented, collecting appropriate aliquots from each discrete sample by using a churn splitter, and combining aliquots into one composite sample. Flow-compositing monitoring is a common procedure that reliably estimates pollutant loads for runoff events (Harmel and King, 2005).

The sampling system was inside a covered shelter and was equipped with radiant heaters to allow runoff collection year round. We measured daily rainfall with existing equipment at the Pioneer Farm, and obtained snowfall data from a weather station located ~35 km to the southwest of the field site. In this region, there is predominately frozen precipitation from December through March. Runoff from snowmelt and rain-on-snow events is typical throughout February and March and can account for a majority of total annual runoff. Outside of this snowmelt period, runoff does occur, but is typically less and occurs inconsistently, often as a result of large storms.

The runoff sampling protocol described above generated a single, composite runoff sample for each event for each runoff basin. We analyzed all composite runoff samples for sediment, N, and P at the USDA–ARS Dairy Forage Research Center in Madison, WI. We measured total sediment gravimetrically by drying a known quantity (~50 mL) of a well-shaken runoff sample at 60 °C until all water had evaporated. We then determined the weight of the remaining sediment and determined sediment content ($g\,L^{-1}$) as the mass of that sediment in the original volume of sample. We filtered runoff samples through 0.45 μm filters, and analyzed filtered samples for dissolved P (Murphy and Riley, 1962), and