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Vegetated treatment area (VTAs) efficiencies for *E. coli* and nutrient removal on small-scale swine operations

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ABSTRACT

As small-scale animal feeding operations work to manage their byproducts and avoid regulation, they need practical, cost-effective methods to reduce environmental impact. One such option is using vegetative treatment areas (VTAs) with perennial grasses to treat runoff; however, research is limited on VTA effectiveness as a waste management alternative for smaller operations. This study evaluated the efficiencies of VTAs in reducing bacteria and nutrient runoff from small-scale swine operations in three counties in Central Texas. Based on 4 yr of runoff data, the Bell and Brazos VTAs significantly reduced loads and concentrations of *E. coli* and nutrients (except NO_3-N) and had treatment efficiencies of 73–94%. Most notably, the Bell VTA reduced loads of *E. coli*, NH_4-N, PO_4-P, total N, and total P similar to that of the background (control). In spite of significant reductions, runoff from the Brazos VTA had higher concentrations and loads than the control site, especially following installation of concrete pens and increased pen washing, which produced standing water and increased *E. coli* and nutrient influx. The Robertson VTA produced fewer significant reductions and had lower treatment efficiencies (29–69%); however, *E. coli* and nutrient concentrations and loads leaving this VTA were much lower than observed at the Bell and Brazos County sites due to alternative solids management and enclosed pens. Based on these results and previous research, VTAs can be practical, effective waste management alternatives for reducing nutrient and bacteria losses from small-scale animal operations, but only if properly designed and managed.

1. Introduction

Vegetated Treatment Areas (VTAs) are inexpensive waste management systems that facilitate natural processes to help reduce sediment, nutrient, and bacteria runoff from agricultural operations. Agriculture remains a significant contributor of nutrients to Texas and US surface water bodies (TCEQ and TSSWCB, 2012; USEPA, 2002), with commercial fertilizer and animal manures being substantial sources. Although the number of animal production facilities has steadily declined (Burkholder et al., 2007; Hooda, Edwards, Anderson, & Miller, 2000; Osterberg & Wallinga, 2004) since the 1950s, the number of animals produced in confined animal feeding operations (CAFOs) has greatly increased, and the increased concentration of animal production has led to regional manure excesses. Under US federal law, CAFOs are required to manage their waste by adopting nutrient management plans (Federal Register, 2003). They are regulated as point sources and must obtain a National Pollutant Discharge Elimination System (NPDES) permit. Smaller animal feeding operations (AFOs) are unregulated nonpoint sources that typically manage their waste by voluntary efforts (Centner, Wetzstein, & Mullen, 2008; USDA and USEPA, 1999). These efforts; however, can be very costly for smaller operations.

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Animal manure is usually regarded as a valuable byproduct, adding nutrients to the soil and encouraging plant growth; however, excess nutrients can be transported via runoff into surface water, lost through erosion, or accumulated in the soil and leached into the groundwater (Khaleel, Reddy & Overcash, 1980). Excessive nutrients can negatively impact aquatic life, human health, recreation, and aesthetics (see review in Dodds & Welch, 2000). Phosphorus (P) has traditionally been thought to bind tightly to the soil and thus assumed to be relatively immobile except via soil erosion (Brady & Weil, 1999); however, P runoff and leaching, especially in the soluble form (i.e., orthophosphate) has recently been shown to contribute to water quality degradation (Jarvie et al., 2017; Smith et al., 2015). In contrast, nitrogen (N) is more mobile and tends to be easily lost in runoff and leaching (Espinoza, Norman, Slaton, & Daniels, 2005; Heathwaite, Johnes, & Peters, 1996).

Manure can also contain high concentrations of microorganisms, some of which are known human pathogens. Swine manure can contain more than 100 microbial pathogens that can cause human illness and disease (Burkholder et al., 1997). Pathogens, specifically indicator bacteria such as fecal coliforms and *Escherichia coli (E. coli)*, are the leading causes of surface water impairment in the US (USEPA, 2009). Fecal contamination of surface water results from point and nonpoint source pollution such as runoff from rural, agricultural, and urban landscapes; wastewater treatment systems; and other legal and illegal domestic point-source discharges (Paul et al., 2006; Teague, Karthikeyan, Babar-Sebens, Srinivasan, & Persyn, 2009). If not well managed, livestock manure from AFOs can be a significant source of fecal microorganisms including *E. coli*.

Vegetative treatment areas (VTAs), as the name implies, are vegetative areas composed of perennial grasses or forages used for the treatment of runoff from open lot production systems or other process waters (USDA-NRCS, 2006). VTAs are typically part of a vegetative treatment system (VTS) that includes additional practices to remove solids, such as a settling or vegetative infiltration basin (USDA-NRCS, 2006). VTAs are designed to reduce nutrient runoff by plant uptake, sedimentation, and infiltration into the soil profile (Koelsch, Lorimor, & Mankin, 2006). Nutrient reduction effectiveness increases with sheet flow, downslope distance, and proper site selection and management (Edwards, Owens, & White, 1983; Higgs et al., 2015; Ikenberry & Mankin, 2000; Koelsch et al., 2006; Komor & Hansen, 2003; Woodbury, Nienaber, & Eigenberg, 2005). According to Koelsch et al. (2006), the most important design consideration in smaller AFOs is the ratio of the VTA area relative to the contributing area, and Chaubey, Edwards, Daniel, Moore, and Nichols (1994) showed increasing nutrient treatment efficiencies as the ratio increased; however, Roodsari et al. (2005) and Sullivan et al. (2007) reported that vegetated buffer size had little effect on the efficiency of bacteria removal. According to Coyne et al. (1998), the greatest reduction in bacteria concentration occurred within the first 4.5 m of vegetated filter strips; however, the efficacy of removing solids is affected by site-specific conditions such as vegetation, slope, soil type, size and geometry, and influent solids concentration (Koelsch et al., 2006). Chaubey et al. (1994) examined runoff at different downslope distances on a vegetated filter strip treated with swine manure and reported 71–99% reductions in ammonium N (NH_4-N) loads and 67–92% reductions in total P loads. Hawkins, Hill, Rochester, and Wood (1998) observed similar reductions in NH_4-N (58–93%) and total P loads (75–92%) relative to inflow from a vegetated filter strip with swine lagoon effluent application, mostly due to retention of 85–100% of the runoff. Hawkins et al. (1998) concluded that the reduction of nutrient loads was typically greater than for nutrient concentrations in large part due to runoff retention.

Fewer studies have directly evaluated VTA effectiveness for bacteria reduction in runoff from swine operations, and those often conflict ranging from 'virtually complete removal' (Roodsari et al., 2005) to 'did not reduce fecal coliform numbers' (Entry, Hubbard, Theis, & Fuhrmann, 2000). These contradictions could be related to climatological factors (e.g., rainfall, temperature, sunlight), microbial population dynamics (e.g., initial microbial populations and die-off), and soil conditions (Edwards et al., 1997; Gerba, Wallis, & Melnick, 1975; Sullivan et al., 2007). Cardoso, Shelton, Sadeghi, Shirmohammadi, and Pachepsky (2012) concluded that the dominant factor in reducing bacteria runoff is infiltration, which depends greatly on soil type and depth to the water table. Because of the need for additional field-scale research on VTA effectiveness for bacterial treatment, the present study was designed to evaluate the effectiveness of VTAs in reducing bacteria as well as nutrient runoff from small swine operations. The VTAs in this study were designed to be simple and inexpensive to install, establish, and maintain and allow infiltration, vegetative nutrient uptake, and filtration/sedimentation to reduce offsite transport.

2. Materials and methods

2.1. Site description

Study locations were established in the fall of 2012 at small swine AFOs in Bell, Brazos, and Robertson Counties in Central Texas (Fig. 1, Table 1). Locations were selected based on size of operation, availability of suitable land for VTA establishment, and relative distance to laboratory facilities. At each of the three locations, three sampling sites were installed to monitor runoff water quantity and quality (i.e., VTA inlet, VTA outlet, control). Management consisted of hay removal and over-seeding a cool-season grass (wheat or oats) in the fall. Data collection began in January 2013 and lasted 4 yr through December 2016.

The Bell County location consisted of 0.15 ha of barn and outdoor pen areas that contained approximately 30–100 boars, sows, and young pigs. The soil in this location is Houston Black clay (Fine, smectitic, thermic, Udic Haplusterts) which is a moderately well drained, highly expansive clay that is very slowly permeable when wet (USDA-NRCS, 1997a). Waste from the enclosed barn with farrowing crates was drained via pipe directly to the upper end of the VTA. Runoff from the unsheltered pens drained to the VTA inlet. The VTA was 0.34 ha of coastal Bermuda grass, overseeded with oats or wheat in the winter, and isolated from surrounding fields with earthen berms. The control site was 0.48 ha of ungrazed pasture and a garden area above the pens that drained through a grassed waterway. Runoff into the VTA inlet was routed through a 0.46 m H-flume by berms. For the VTA outlet and control site, a 0.61 m H-flume was used in conjunction with berms.

In Brazos County, the facility was 0.03 ha of barn and outdoor pens that held approximately 20–35 sows. Soils are a mix of Boonville fine sandy loam (Fine, smectitic, thermic, Udertic Paleustalfs) and Zack fine sandy loam (Fine, smectitic, thermic, Udertic Paleustalfs), which are poorly to moderately well-drained and very slowly permeable soils (USDA-NRCS, 1997b, 2002a). Runoff and drainage water from the pens entered the 0.10 ha VTA, which was composed of native prairie grasses over-seeded with oats in the winter. A 1.21 ha rural residential area with a few animal pens was monitored as the control area. H-flumes of 0.30 m and 0. 46 m were used for the VTA outlet and inlet, respectively. The control area drained through a culvert in which an area-velocity meter was installed to monitor flow.

The Robertson County operation consisted of a 0.03 ha area with an outdoor walking pen and barn that housed an average of 5–20 animals. The soils are dominated by Tabor fine sandy loam