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Rye cover crop increases earthworm populations and reduces losses of broadcast, fall-applied, fertilizers in surface runoff

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ABSTRACT

Corn (*Zea mays* L.) silage and soybean [*Glycine max* (L.) Merr.] rotations in the US Upper Midwest leave minimal amounts of surface residues, which can contribute to soil degradation, increased surface runoff, and reduced water quality. Planting cover crops after harvest can reduce these concerns, but their effectiveness in reducing nutrient losses in surface runoff shortly after fall planting and fertilization has not been thoroughly investigated. Therefore, we applied 65 mm of simulated rainfall in 60 min to five replicate, 1.5 by 3.0 m, field plots in a no-till, corn silage-soybean rotation into which a rye (*Secale cereale* L.) cover crop was planted for 14 consecutive years and to five replicate plots with no cover crop history. Natural slope of the plots ranged from 0.1 to 2.7%. The study was conducted in October 2014, about one month after corn silage harvest and rye planting and ~1 h after broadcast application of monoammonium phosphate and potassium chloride fertilizers. The living rye cover crop significantly ($P \leq 0.05$) delayed surface runoff by 5.7 min and decreased total runoff by 65% compared to plots with no cover crop. This resulted in a significant 68% reduction in sediment loss and even greater significant reductions in fertilizer nutrient losses (i.e., NH_4-N - 86%; total P - 83%; total dissolved P - 84%; K - 91%). Earthworm population and biomass, measured using electrical extraction shortly after the rainfall simulations, were 1.2 and 1.4 times greater in cover crop plots than in no cover plots and 3.2 and 2.5 times greater the following spring. Our results suggested that a living cover crop and their long-term usage can contribute to improvements in soil structure and increased earthworm populations that can substantially reduce sediment and nutrient losses in surface runoff due to a severe storm shortly after post-harvest broadcast application of fertilizer.

1. Introduction

Nutrient losses from cropped fields, particularly nitrogen (N) and phosphorus (P), can result in numerous undesirable effects on aquatic ecosystems (Carpenter et al., 1998; Sharpley et al., 2016). While there is increasing concern regarding losses of dissolved P in subsurface drainage, a recent review of North American studies indicated that surface runoff is usually a greater contributor to sediment and P losses (Christianson et al., 2016).

Among the factors believed to contribute to increased losses of nutrients via surface runoff to freshwater and marine ecosystems, such as Lake Erie, Chesapeake Bay, and the US Gulf Coast, are fall broadcast fertilizer applications and lack of incorporation (Smith et al., 2015; Zhang et al., 2016). This has prompted some authorities to recommend banning fall application of fertilizers (Zhang et al., 2016). Yet 60% of the fertilizer P used in the Lake Erie watershed is still broadcast-applied in the fall (44%) or winter (16%) (Ohio Department of Agriculture, 2013). When combined with no-till crop production practices, P losses are believed to be exacerbated by lack of incorporation and near-surface nutrient stratification.

Likewise, for practical and logistical reasons (e.g., lower cost, greater labor availability, better soil conditions) fall application of P and potassium (K) fertilizer is also common in Iowa and throughout the US Midwest (Sawyer and Mallarino, 2009). These investigators argued, however, that fall application can be environmental advantageous compared to spring application because of a lower probability of large, runoff-inducing, rainfalls shortly after application. Studies by this research group have demonstrated that even a short (10–16 day) delay in runoff-producing rainfalls can dramatically reduce risk of P losses associated with surface-applied manures (Allen and Mallarino, 2008; Kaiser et al., 2009; Ruiz Diaz et al., 2010). They also noted that tilling to incorporate manure or fertilizer can reduce dissolved P and N losses, but increases risk of erosion and loss of sediment-bound P. Similarly, Gildow et al. (2016) questioned recommendations that discourage fall

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fertilizer applications based on model simulations of surface runoff, which indicated that spring applications increased P loads compared to fall applications. Recognizing the importance timing plays in nutrient loss, fertilizer application is now banned in Ohio when heavy rain is forecasted (Zhang et al., 2016). Nitrogen loss through runoff and leaching are added concerns since the most commonly used P fertilizers also contain N [i.e., mono- (MAP) or di-ammonium phosphate (DAP)] (Sawyer and Mallarino, 2009; Smith et al., 2015).

Removal of crop biomass for animal feed (i.e., silage) or biofuel feedstock prior to fall fertilizer application can also increase nutrient loss in surface runoff. In the US there is a proposed target of replacing 30% of current petroleum consumption with biomass-derived fuels by 2030 to offset CO_2 emissions (Perlack and Stokes, 2011). Corn stover, the above ground material left in the field after grain harvest, has been identified as a major source of feedstock for achieving this goal (Blanco-Canqui and Lal, 2009; Keeler et al., 2013; Perlack and Stokes, 2011). Corn stover, however, has many other functions including protecting the soil from raindrop impact, replenishing soil organic carbon thereby increasing aggregate stability, and supporting biotic communities. Its removal as silage or biofuel feedstock can result in reduced infiltration and increased runoff as well as decreased crop yields (Blanco-Canqui and Lal, 2009; Lal, 2004; Wilhelm et al., 2007). Field studies conducted with simulated and natural rainfall have indicated that removal of corn stover dramatically increased sediment loss as well as dissolved and total P in surface runoff (Beniston et al., 2015; Grande et al., 2005a, 2005b; Panuska et al., 2008). Moreover, partial or complete removal of corn stover can result in a hotter and drier soil environment and less food for earthworms that reduces their activity and decreases their populations compared to fields where it is retained (Blanco-Canqui et al., 2007; Karlen et al., 1994). By burrowing and ingesting soil and plant residues earthworms can create and stabilize soil aggregates and form macropores (Shipitalo and Korucu, 2017). Thus, reduced earthworm activity can further contribute to increased runoff and losses of nutrients and soil.

Research has shown that some of the negative effects of corn silage harvest on water quality can be reduced by increasing cutting height, thereby increasing residue cover and decreasing surface runoff (Grande et al., 2005a, 2005b). Combining manure application with high-cut silage further reduced runoff and losses of sediment and total P compared to low-cut silage. Similarly, Yagüe et al. (2011) noted that addition of manure with a high solids content reduced runoff and losses of sediment and particulate P in no-till and chisel-tilled plots where corn biomass was harvested. In situations where increased cutting height is impractical or manure is unavailable, one way to potentially counteract the negative effects of corn stover removal is to increase residue levels and improve soil structure by planting cover crops (Blanco-Canqui and Lal, 2009).

The ability of cover crops to reduce surface runoff and improve soil and water quality has been well-documented in reviews by Dabney et al. (2001), Kaspar and Singer (2011), and Blanco-Canqui et al. (2015). More recently, in a study utilizing multiple simulated rainfalls, Siller et al. (2016) determined that planting a cereal rye cover crop after corn stover harvest substantially reduced surface runoff (67%) and losses of sediment (81%), P (94%), and N (83%) compared to continuous silage corn without a cover crop. In spite of their documented benefits, the 2012 Census of Agriculture (NASS, 2014) indicated that cover crops were only grown on 1.55% of the harvested land in Iowa. Nevertheless, the effectiveness of a rye cover crop in reducing nutrient losses in surface runoff caused by a rain storm shortly after a fall broadcast application of fertilizer, when the cover crop has only been recently established and the fertilizer is highly vulnerable to transport, has not been investigated. Therefore, our objective was to use simulated rainfall to determine if long-term planting of a rye cover crop in a silage corn-soybean rotation can reduce runoff and losses of sediment and nutrients associated with a severe storm shortly after fertilizer application to a no-till soil. In addition, electrical extraction was used to determine if the rye cover crop also affected earthworm populations that could contribute to any observed effects on runoff and sediment and nutrient losses.

2. Materials and methods

2.1. Plot management and rainfall simulation

The plots used in this experiment were at the Iowa State University's Boyd Farm near Ames, Iowa USA and were part of a larger, ongoing, study in which the effects of a rye cover on crop growth and soil quality are being investigated (Moore et al., 2014). The experimental site was established in 2002 as a randomized complete block design with five replications of eight treatments consisting of various combinations of no-till, grain or silage corn, and soybean with and without a cereal rye cover crop. For the current study two of the eight treatments were investigated, a 2-yr corn silage-soybean rotation in which a rye cover crop was planted after harvest each year and an identically managed control with no cover crop. Climate in the region is characterized by cold winters with an average daily minimum of −11 °C, with precipitation mainly as snow, and hot summers with an average daily maximum of 29°C. Average annual precipitation is 848 mm with 73% occurring in April through September. Record 1-day rainfall is 104 mm with thunderstorms occurring an average of 50 days a year (Andrews and Dideriksen, 1981).

The plots were 54.9 m long and 3.8 m wide and were aligned with an approximately 2% slope in a north-south direction. Five main crop rows were planted in each plot at a 0.76 m spacing with a controlled traffic pattern (Figs. 1 and 2). The predominant soils at the site are Clarion loam, a fine-loamy, mixed, superactive, mesic Typic Hapludoll

Fig. 1. Image of the twin-nozzle rainfall simulator installed on a no cover crop (control) plot depicting position of the plot boundaries spanning two corn rows with non-wheel traffic interrows. The tarp at the upslope end of the simulator was removed in order to obtain this image.