A cost analysis approach to valuing cover crop environmental and nitrogen cycling benefits: A central Illinois on farm case study

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ABSTRACT

The use of cover crops (CC) in row crop agricultural systems has been shown to provide numerous environmental benefits along with increasing overall soil health. The environmental benefits of CC are well known and demonstrated in the literature. However, before voluntary widespread CC adoption can occur, methods for potential CC cost recovery must be explored. Therefore, the objectives of this study were to quantify the environmental and nitrogen (N) cycling benefits observed from CC and to determine the potential of those benefits to offset the costs of CC implementation. This experiment used data collected between CC planting in 2014 and cash crop harvest in 2016 from an associated study conducted at the Illinois State University Nitrogen Management Research Field Station, in Lexington, IL. In this case study, CC were integrated into two cropping systems common to Central IL, split application of N with the dominant portion of N applied in the spring (20% fall, 80% spring) with and without CC, and a split N application with the dominant portion of N applied in the fall (70% fall, 30%spring) with and without CC. The chosen CC for the study was a 92% cereal rye (*Secale cereal L.*) and 8% daikon radish (*Raphanus sativus L.*) blend, and data were collected for both strip-till corn (*Zea mays L.*) and no-till soybeans (*Glycine max L.*). Different from existing attempts to model the economic value of CC, this model includes input variables that quantify the reduction of N loss through tile drainage, the return of N from CC residue following termination and reductions in soil erosion. We determined that valuing the impact of CC on subsurface drainage N loading, soil erosion, and CC residue N mineralization has the potential to recover an average of 61% of the costs associated with CC implementation. More specifically, the average composition of recovered costs was 34% from reductions in N loading to subsurface drainage, 57% from the tile-adjusted mineralization of N from the CC biomass, and 9% from the estimated reduction in erosion. The results of this study have the potential to provide a more comprehensive assessment of CC value that could help producers make informed N and CC management decisions.

1. Introduction

Between the years of 2010 and 2015, there was a 312% increase in total cover crop (CC) hectares across the United States from 48,393 ha to 151,157 ha (Cover Crop Survey, 2015). This increase comes at a time when the connection between agriculture and the hypoxic zone in the Gulf of Mexico has become increasingly apparent. It has been estimated that nitrogen (N) leaching from agricultural fields accounts for greater than 1.57 million Mg of N (65% of total N mass) delivered annually to the Gulf of Mexico (Alexander et al., 2000; Robertson and Saad, 2013).

Cover Crops provide soil erosion control, improved soil tilth, increased soil organic matter, increased water-holding capacity, and a medium for improved overall soil fertility (Danso et al., 1991; Hartwig and Ammon, 2002; Odell et al., 1984). However, due to the severity of

N loading from agricultural fields, CC have been studied extensively as a potential in-field adaptive management practice to mitigate N losses through subsurface tile drainage. Several studies have demonstrated the efficacy of cover crops to absorb inorganic N from the residual, fertilized, and mineralized soil N pools, which affects the distribution of inorganic N in the soil profile (Kaspar et al., 2007; Lacey and Armstrong, 2015). The presence of cover crops has been shown to decrease the concentration of soil inorganic N at lower soil depths closer to the location of the tile drainage (Cooper et al., 2017; Lacey and Armstrong, 2015), which results in actual N load reductions from tile lines (Brandi-Dohrn et al., 1997; Kaspar et al., 2007, 2008, Kaspar et al., 2012; Kladivko et al., 2004; McCracken et al., 1994; Rasse et al., 2000; Ritter et al., 1998; Staver and Brinsfield, 1990, 1998; Strock et al., 2004; Wyland et al., 1996).

In addition to CC, several edge-of-field best management practices (BMPs), such as constructed wetlands, woodchip bioreactors, and two-stage ditches have been identified as efficient methods for reducing the N load to surface waterways. However, these edge-of-field practices represent a long-term commitment for the producer and require a portion of cropland for which they are effective to be removed from production. In contrast, cover crops represent an in-field practice that requires only short-term commitments from producers, as they are planted and removed each year, and do not require the removal of cropland from production (Christianson and Helmers, 2011; D'Ambrosio et al., 2015; Roley et al., 2016). Furthermore, CC have the potential to be applicable for all cultivated acres with adjustment of a producer's current production system (Illinois Nutrient Loss Reduction Strategy, 2015; Kladivko et al., 2014).

As far as N conservation cost, cover crops represent the BMP with the lowest annual cost per hectare compared to constructed wetlands and two-stage ditches. Although, over 50 years, CC represent the least cost-effective BMP regarding cost per kilogram of N removed from surface water sources (Roley et al., 2016). This is likely due to the annual cost associated with CC planting and termination, while edge-of-field BMPs require large investments upfront and minimal maintenance costs after. However, of all the N conservation BMPs, CC have the greatest potential of allowing producers to utilize N that would have otherwise been leached below the root zone or lost to the atmosphere through denitrification with constructed wetlands, woodchip bioreactors or two-stage ditches.

Survey results demonstrate that agricultural producers are aware of the many potential environmental benefits provided by CC, but are hesitant in adoption due to economic concerns. For example, the Conservation Technology Information Center (CTIC) producer survey revealed that increased soil health and organic matter, reduced soil compaction, reduced soil erosion, N scavenging, and being a source of N are the top motivations towards CC adoption (Cover Crop Survey, 2016). However, top barriers to CC adoption amongst producers in the same survey were the costs of planting and managing the CC, the cost of the CC seed itself, and the lack of measurable economic returns following implementation (Cover Crop Survey, 2015).

Economic studies that have involved CC have focused primarily on CC adoption cost variables such as CC establishment, termination, and resultant cash crop yield change. The goals of these studies are to establish the expense of reducing N loss using CC and to perform a comparative cost analysis to equate the expense of N conservation of CC to all other in-field and edge of field N removal BMPs (Christianson et al., 2013; Kladivko et al., 2014; Roley et al., 2016). The comparative cost methodology is useful in educating policymakers, producers, and the public of estimated initial and long-term costs of N conservation depending on the practice selected. However, this analysis does not quantify the measurable short-term potential benefits or risks of CC that relate to potential CC adoption cost recovery. Pratt et al. (2014) used a benefit-cost analysis approach to determine the value of agronomic benefits associated with CC to recover the CC adoption costs. Variables considered were N credits, increased grain yields and soil organic matter, reduced soil compaction and erosion, and the scenario of a hypothetical bioenergy market for corn stover. They found that without corn stover removal leguminous CC resulted in the largest net benefits due to large N credits. However, with corn stover removal, treatments that contained low C:N ratio CC resulted in lower net benefits relative to high C:N ratio CC, due to their inability to potentially replace soil organic matter.

It is important to note that although the studies above gave critical analyses of the N conservation cost when using CC and valued trade-off benefits; there was no comprehensive valuation of the potential nitrogen cycling from CC residue back to the soil for cash crop use unless biological fixation of N from leguminous CC was considered (Kladivko et al., 2014; Pratt et al., 2014). In fact, studies have concluded that cover crop residue N has the potential to be available to cash crops for

use and should be valued. However, the methodology to perform this analysis can be difficult (Jahanzad et al., 2016). Therefore, there is a vital need to establish a methodology to valuate environmental benefits of CC and to relate the potential befits to the recovery of CC adoption costs. Thus, the objectives of this study are (i) to develop a method for the valuation of quantifiable environmental and N cycling benefits of cover crops, and (ii) define the potential for the value of cover crop environmental and N cycling benefits to recover the total costs associated with cover crop adoption.

2. Materials and methods

The field study which forms the basis for this case study was conducted in Lexington, Illinois at the Illinois State University Nitrogen Management Research Field Station (ISU-NMRFS) (Roth, 2017; Ruffatti, 2016). The predominant soil types found within the approximately 10-hectare field are Drummer and El Paso silty clay loams, as well as Hartsburg silty clay loam, all of which are poorly drained Mollisols with slopes of 0–2%. The cropping history for the ISU-NMRFS includes an 8-year rotation of strip-tilled corn (*Zea mays L.*) and no-till soybeans (*Glycine* max *L.*), which are harvested and sold for grain. This experiment was a continuation of these common cultural practices. The N management strategy was to apply a total rate of 224 kg N ha^{-1} across various N application timings. The N rate for this study was the suggested MRTN (Maximum Return to Nitrogen) value of 224 kg N ha^{-1} for the central Illinois region as calculated by the Iowa State University N rate calculator (Sawyer et al., 2006). The cover crop chosen for the study was an 8% daikon radish (*Raphanus sativus L.*) and 92% cereal rye (*Secale cereal L.*) blend calculated by weight. The cover crop treatments were first established in September 2014 and CC are grown in the same plots each year. The site was divided into fifteen individually tile drained 0.65-hectare (72 corn rows spaced 76.2 cm apart) plots, each possessing its own independent controlled drainage structure and tile-water monitoring systems. The plots were arranged in a complete randomized block design with three replications of each experimental treatment. The experimental treatments for this site included a fall dominated (70% fall, 30% spring) N application system with (FCC) and without (FN) CC, and a spring dominated (20% fall, 80% spring) N application system with (SCC) and without (SN) CC.

All valuations outlined in this study have been converted to January 2014 dollars using the consumer price index inflation calculator available through the United States Bureau of Labor Statistics, which uses the consumer price index for all urban consumers (CPI-U) as its basis for calculation (USBLS, 2017).

2.1. Cover crop costs

Variables that contribute to CC establishment costs include seed cost, seeding rate, and planting cost (Table 1). Cover crop seed and planting costs were provided by the seed distributor and contracted planter, respectively. The cover crop mixture for this study was interseeded into standing cash crops using a Hagie STS12 modified with an air-seeding box at the seed distributor suggested broadcast rate of 84 kg ha^{-1}, which they determined based on species mix, seeding method, and climate. CC establishment costs were calculated by obtaining the \$ kg seed^{-1} and multiplying by the kg seed ha^{-1}, then adding the \$ ha^{-1} for planting (Eq. (1)).

$$\text{EC \$ ha}^{-1} = (\text{CCSC \$ kg}^{-1} \times \text{CCSR kg ha}^{-1}) + \text{CCPC \$ ha}^{-1} \qquad (1)$$

where EC is cover crop establishment costs, CCSC is cover crop seed cost, CCSR is cover crop seeding rate, and CCPC is cover crop planting cost.

The collaborating producer provided the data relating to the cost of herbicide, herbicide application rate, and herbicide application cost (Table 1), which were all considered when calculating the CC terminating (P. Brown, personal communication, 16 March 2017). The