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Evaluating pest-regulating services under conservation agriculture: A case study in snap beans

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ABSTRACT

Although conservation agriculture (CA) practices including strip-tillage (ST) and cover cropping are promoted largely for their potential benefits for soil quality, uncertainty surrounding their short-term effects on pests often constrains adoption. Quantification of ecosystem services or dis-services associated with pests is an important step in identifying research and policy priorities for improving the performance of CA practices. Using insect, weed and yield data from snap beans in a three year vegetable rotation, we estimated the value of pest-regulating services associated with the adoption of CA, and compared it to establishment and management costs associated with implementing CA.

Experimental factors included tillage (full-width tillage [FWT] or ST), cover crops (winter rye [R] or none [NR]) and weed management intensity (low or high). The value of pest-regulating services associated with adoption of CA practices was estimated based on pesticide cost savings associated with reductions in pest densities given action thresholds typical of commercial snap bean production in the North Central United States. CA practices had no detectable impact on snap bean yields relative to FWT-NR, but resulted in significant tradeoffs in weed and insect abundance. For example, in at least one of two years, ST-R had lower densities of potato leafhopper, Powell amaranth and winter annual weeds, but greater densities of tarnished plant bug and large crabgrass compared to FWT-NR. CA practices had variable effects on natural enemies including ladybeetles, spiders and parasitoids, with no consistent impacts relative to FWT-NR. We estimated that CA practices resulted in net pest-regulating *dis*-services with costs of \$33 ha^{-1} for FWT-R, \$25 ha^{-1} for ST-NR, and \$14 ha^{-1} for ST-R. Under partial adoption of CA (ST-NR), pest-related costs were completely offset by savings in tillage costs, resulting in estimated short-term increases in net returns of \$26 ha^{-1}. In contrast, complete adoption of CA (ST-R) resulted in greater pest and cover crop management costs that outweighed savings due to reduced tillage, resulting in estimated short-term losses of \$165 ha^{-1}. In production systems for which effective, low-cost pesticides are unavailable (e.g. low-income countries) or prohibited (e.g. organic systems), the economic impact of pest regulation services is likely to be greater than our estimates suggest. Although CA practices provide several potential long-term ecosystem services at both the farm and landscape level, short-term impacts on pests and yields relative to the costs of implementation are likely to be the major determinant of grower adoption.

1. Introduction

Conservation agricultural (CA) practices including reduced tillage (RT), retention of crop or cover crop residues, and crop diversification, have been promoted because of their perceived benefits for soil conservation, profitability, food security and the environment (Hobbs, 2007; Reicosky, 2015). CA systems are reported to provide multiple ecosystem services including soil moisture retention (e.g. Hendrix et al., 2004), erosion and wind protection for vulnerable soils and crops (e.g. Brainard and Noyes, 2012; Overstreet and Hoyt, 2008), carbon sequestration (Ellert and Janzen, 1999; Reicosky and Lindstrom, 1993) and improvements in

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soil physical, chemical and biological properties (Reicosky, 2015). Despite these wide-ranging potential ecosystem services, adoption of CA practices in many crops has been limited in part due to lack of consistent benefits for crop yield and profitability (Giller et al., 2009; Pittelkow et al., 2015a). In some cases reductions in crop yield under CA practices are due to adverse effects of CA practices on weed, insect or disease pressure which may outweigh benefits for soils (Farooq et al., 2011; Kumar et al., 2013). Since optimization of decision making at both the farm and policy level depends on understanding the net impact of such ecosystem services, more detailed case studies quantifying ecosystem service tradeoffs are needed (Zhang et al., 2007; Pittelkow et al., 2015b).

Beans (*Phaseolus vulgaris*)—including both snap beans (also known as "green beans") and dry beans—are a critical source of nutrition for much of the world's poor and are grown on approximately 45 million acres worldwide (FAO, 2014). As large-seeded legumes, beans are relatively insensitive to problems of crop establishment and nitrogen deficiency that are sometimes associated with RT systems, and therefore represent a promising crop for realization of CA benefits. However, studies evaluating the impact of CA practices on beans show enormous variation in yield responses (Abdul-Baki and Teasdale, 1997; Pittelkow et al., 2015a). Several of these studies have reported responses of individual categories of pests to CA practices (e.g. Bottenberg et al., 1997), but few have attempted to quantify the overall impact of multiple pest responses to CA practices, or the economic implications of these pest-related effects.

Weeds represent one of the biggest pest-related constraints to adoption of CA practices. (Brainard et al., 2013; Hoyt et al., 1994; Kumar et al., 2008; NeSmith et al., 1994; Walters and Kindhart, 2002). Indeed, only with the advent of herbicide-resistant crops has adoption of CA practices taken off in many cropping systems (Givens et al., 2009). In RT systems, weed management effects are complex and vary considerably depending on weed species, weed life-stage, edaphic conditions, crop competitive ability, and the availability and effectiveness of alternative weed management strategies (Brainard et al., 2013). In general, RT systems result in lower rates of weed emergence, but higher rates of seedling survival. For example, reduced emergence of weeds under strip-till (ST), compared with full-width tillage (FWT), has been observed for summer annual species in pickling cucumber (Wang and Ngouajio, 2008), carrot (Brainard and Noyes, 2012), and corn (Hendrix et al., 2004). In contrast, weed seedling survival—particularly of winter annual or perennial species—is typically higher under RT systems, since tillage is not used to sever, uproot or bury seedlings (Brainard et al., 2013). The effects of tillage on weeds are further complicated by interactions with crop or cover crop residue that may be present on the soil surface in CA systems (Haramoto and Brainard, 2016). If residues have sufficient biomass to form a thick mulch they may inhibit weed emergence by excluding light, providing a physical barrier, or exuding allelochemicals Teasdale, 1998; Teasdale and Mohler, 2000). On the other hand, low levels of cover crop residue left on the soil surface may promote weed emergence by creating more favorable edaphic (e.g. higher moisture) conditions for seed germination without inhibiting growth (Brainard et al., 2013; Wallace and Bellinder, 1989). Despite its importance in determining the feasibility of successful adoption of CA systems, the effects of tillage, cover crop and herbicide interactions on weeds have received relatively little attention. For example, Pittelkow et al. (2015a,b) state that the absence of tillage in CA practices involving no-till "generally requires changes in herbicide management", but do not attempt to disentangle herbicide use or weed suppression as factors determining impacts of CA practices on crop yield.

CA effects on insects are also complex and may result in pest-regulating services or dis-services depending on the cropping system. Complex habitats, such as untilled strips with cover crop surface mulch, are expected to reduce pest populations by interfering with the movement, landing, and oviposition of pests in the field (Andow, 1988, 1990; Broad et al., 2008; Finch and Collier, 2000). According to the natural enemy hypothesis (Elton, 1958), complex habitats can provide refuge, alternative prey, additional resources, and protection from intraguild predation (Sunderland and Samu, 2000), leading to greater predation and parasitism (Andow, 1988; Landis et al., 2000; Letourneau, 1990; Schellhorn and Sork, 1997; Wilkinson and Landis, 2005). On the other hand, some beneficial insects are well adapted to disturbance (Shearin et al., 2007), and populations of plant pests including slugs (Luna and Staben, 2002), plant-parasitic nematodes (Overstreet et al., 2010), and insect pests such as the imported cabbage worm (*Pieris rapae*) sometimes increase in CA systems (Bryant et al., 2014). While tradeoffs associated with insect management have been discussed in previous work involving some components of CA adoption (Shipanski et al., 2014), few studies have attempted to quantify the economic value of insect-regulating services associated with CA.

Although CA practices have several potential long-term economic and environmental benefits, their widespread adoption is likely to depend critically on their short-term impact on profitability due to changes in both yield and input costs. RT is often reported to reduce labor and fuel costs relative to FWT, since fewer tractor passes are required (Archer and Reicosky, 2009; Haramoto, 2014; Luna and Staben, 2002). In contrast, cover cropping generally entails increases in costs associated with establishment and management, as well as opportunity costs in cases where cash crop revenue is forgone in order to accommodate the cover crop (Snapp et al., 2005). Costs of other inputs including herbicides or insecticides may increase or decrease depending on the impact of ST and cover crops on weed and insect pests. Given these important potential tradeoffs, surprisingly few studies have attempted to quantify the net effects of cover crops or tillage on pests or profitability.

A growing body of literature has attempted to value ecosystem services associated with natural pest control, but only a few such studies have addressed monetary values of pest control services at a farm scale, or net effects of multiple pests (e.g. Cleveland et al., 2006; Colloff et al., 2013). Most studies evaluate impacts on a single pest or category of pests (e.g. thrips in Toews et al., 2010 or winter annual weeds in Hayden et al., 2012) and thus provide limited information on potential pest management tradeoffs, and the net effects on pest-regulating services (Zhang et al., 2007). Several reviews have included general discussion of ecosystem services associated with various components of CA practices, including tradeoffs associated with the use of cover crops (Schipanski et al., 2014; Snapp et al., 2005). Among the challenges cited are inherent variability and uncertainty surrounding estimates, and difficulty assessing the relative functional significance of ecosystem service estimates (Schipanski et al., 2014). The cost-avoidance approach (Cleveland et al., 2006; Colloff et al., 2013) partially addresses the latter challenge by quantifying the functional significance of pest-regulating services in monetary terms. Under this approach, the value of pest-regulation of a particular practice is based on the costs (e.g. pesticide costs) and/or revenue losses (due to pest damage) that are avoided when adopting that practice (Cleveland et al., 2006; Colloff et al., 2013).

The primary goal of this study was to estimate the value of pest-regulating services associated with CA practices relative to the short-term costs of implementation of those practices. Specific objectives were to: 1) evaluate the interactive effects of tillage (FWT or ST), cover crops (none or winter rye [*Secale cereale*]) and weed management intensity (low or high) on weeds, insects, and yields in snap beans; 2) estimate the net value of insect and weed