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Late-season catch crops reduce nitrate leaching risk after grazed green manures but release N slower than wheat demand

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ABSTRACT

Late season catch crops could be an effective tool to conserve highly available N after grazing of green manures. An experiment was established to investigate the productivity and N capturing abilities of barley (*Hordeum vulgare* cv. Cowboy) and oilseed radish (*Raphanus sativus* L.) crops seeded after a grazed green manure. Green manure was a mix of forage pea (*Pisum sativum* cv. 40–10), soybean (*Gylcine max* cv. Prudence) and oat (*Avena sativa* cv. Legget). The experiment was repeated twice in Carman, Manitoba in 2010 and 2011. Catch crops were seeded in late summer either no-till or after soil cultivation of the grazed plots. Wheat (*Triticum aestivum* cv. Waskada) was seeded in the second year as a test crop for both experiments. Catch crop productivity and N uptake was influenced by season (greater in the wetter year) and catch crop type (barley and radish produced 1990 and 1490 kg ha^{-1}, respectively) but not tillage system. The catch crops had their greatest overall effect on soil NO_3-N content in 2010 under conditions of high autumn precipitation when N leaching was more severe. Here, the catch crops significantly reduced NO_3-N at all depths. Under drier conditions in 2011, catch crops only reduced NO_3-N in the top 30 cm. There was average 57 and 12 kg ha^{-1} more soil NO_3-N in plots with no catch crops than plots where catch crops were grown in 2010 and 2011, respectively. Wheat N uptake at maturity was reduced around 25% when grown after catch crops. Similarly, wheat grain yield was 12–31% less after catch crops than no catch crops. This study showed that catch crops can be used to capture excess nutrients after grazing, but N release from the selected catch crops in the following year was not in synchrony with the wheat N demand.

1. Introduction

Excessive nutrient application and losses occur in improperly managed conventional, organic and low-input cropping systems (Stopes et al., 2002). Catch crops are cover crops (i.e., non-commercial) that are grown with the purpose of capturing excess N and preventing leaching losses. Catch crops have been shown to be more effective in capturing excess nutrients than other management techniques such as reduced tillage and reduced N inputs (Thorup-Kristensen et al., 2003; Constantin et al., 2010). Catch crops can be included in the rotation in various ways depending on the cropping system. In conventional systems, catch crops are generally seeded after main crop harvest to capture excess nutrients (Herrera et al., 2010). In organic systems catch crops are generally seeded after animal manure application to capture excess nutrients (Olesen et al., 2000) but rarely seeded after green manures. Because of greater availability of nutrients in grazed green manure systems (Cicek et al., 2014b), an important role of catch crops may be to capture excess nutrients after green manure grazing.

Nitrate (NO_3-N) is of particular importance in catch crop research. As a result of its negative charge, NO_3-N is highly mobile and can leach when N supply exceeds crop requirements. Nitrate leaching in agroecosystems is influenced by soil type, catch crop species, precipitation, temperature, N transformation rates (mineralization, immobilization, dentrification), N input type, drainage and tillage (Campbell et al., 2006; Constantin et al., 2010). Among these factors, catch crop species selection, management and N input type are among the most effective management tools for controlling NO_3-N leaching (Thorup-Kristensen et al., 2003; Constantin et al., 2010). For instance, catch crops were found to decrease N leaching 40–50% in conventional (Aronsson and Torstensson, 1998) and 30–38% in organic systems (Askegaard et al., 2005).

Excess precipitation is one of the main reasons for NO_3-N leaching (Thorup-Kristensen et al., 2003). Therefore, catch crop

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research has been concentrated in areas where annual precipitation is generally above the crop demand (i.e., north eastern USA, New Zealand and Northern Europe). Under such conditions, catch crops can limit NO_3-N loss by direct uptake of available NO_3-N and/or utilization of excess moisture, hence preventing downward movement of NO_3-N in soil solution (Thorup-Kristensen et al., 2003). Even under the relatively dry conditions in western Canada, Campbell et al. (1994) showed that NO_3-N leaching occurred when precipitation was above the long-term average. Nitrate leaching was more severe in rotations with fallow periods than intensive rotations with crops grown every year.

Grazing of green manures is a recently proposed management technique that has not been investigated in terms of NO_3-N leaching (Thiessen Martens and Entz, 2011). Since risk of NO_3-N leaching is aggravated under grazed systems compared to ungrazed systems (Ryden et al., 1984), there is an urgent need to investigate the risk of NO_3-N leaching in novel crop-livestock integrated systems that include grazed green manures.

Nitrogen loading under cattle (*Bos taurus*) and sheep (*Ovis aries*) urine patches can reach 1000 and 500 kg N ha^{-1} respectively (Haynes and Williams, 1993). Urea in urine patches quickly hydrolyses to NH_4^+, which can be quickly converted to NO_3-N (Di and Cameron, 2002). Unlike slowly mineralizing organic N in green manure residues, inorganic N in urine patches is more susceptible to volatilization, denitrification and leaching (Clough et al., 1998; Whitehead, 2000). Further, in grazed green manure systems grazed plants are often annual species, hence, upon grazing no living plant cover is left behind. Under such circumstances risk of NO_3-N leaching may be greater than under perennial systems, where living plant cover can take up at least some of the water and/or urine N.

Nitrate is considered “lost” only when it leaches beyond the root zone (Thorup-Kristensen et al., 2003). Therefore, the “leaching” of NO_3-N down the soil profile is not equivalent to “leaching loss” of NO_3-N. Nitrate leaching losses under grasslands grazed by sheep with no synthetic N inputs is reported to be 6–7 kg N ha^{-1} y^{-1} in New Zealand (Ruz-Jerez et al., 1995). In the northeastern USA, Stout (2003) applied synthetic urine with N content of 440 to 1340 kg N ha^{-1} in a region where annual precipitation is around 930 mm. It was shown that regardless of the urine volume, approximately 25% of the applied urine was lost through leaching.

The proposed catch crop system represents a new frontier for the optimization of organic cropping systems. This new approach intensifies the green manure phase of organic rotations by adding grazing animals and catch crops. Grazing animals utilize green manures which otherwise is a lost revenue opportunity for the farmer, while catch crops increase biomass production on the same land base within one growing season. Long-term experiments have shown that adding organic matter and fertility through the use of late-season catch crops increases productivity of the agroecosystems (Constantin et al., 2010; Doltra and Olesen, 2013).

Species selection in catch crop studies is an important factor because N uptake capacity of catch crops is determined by speed of establishment, growth rate, rooting depth and cold tolerance (Munkholm and Hansen, 2012). The species selection not only affects N uptake, but also N availability to the subsequent cash crop from decomposing catch crop residue. Therefore, C:N ratio, lignin and N content of the catch crop species are important characteristics to be considered when selecting a catch crop species or mixtures (Thorup-Kristensen et al., 2003). One of the main challenges in legume-based systems is achieving the synchrony of N mineralization from green manures and cash crop demand (Crews and Peoples, 2005; Tonitto et al., 2006). In general N mineralization in crops with low C:N ratio (e.g., some brassicas and legumes) is faster than crops with high C:N ratio (e.g., grasses) (Ranells and Wagger, 1997; Constantin et al., 2011). Accordingly, the ideal catch crop species should readily capture available N after grazing and readily release N to the next crop, resulting in an effective N synchrony. Grasses such as barley (*Hordeum vulgare*) may be effective in capturing N because of its fast growth but release N slower because of its high C:N ratio. Brassicas such as oilseed radish (*Raphanus sativus*) are also known to have rapid N uptake (Thorup-Kristensen et al., 2003), but are thought to release N more quickly as a result of their lower C:N ratio.

Current attempts to reduce tillage in organic agriculture have focused on the green manure phase of the rotation (Peigné et al., 2007; Vaisman et al., 2011) and the system is referred to as organic rotational no-till (Halde et al., 2012). In organic agriculture tillage is applied to control weeds, improve nutrient mineralization and prepare a seedbed. Grazing animals in integrated crop-livestock systems may provide these services by consuming the green manure biomass. For example, after grazing green manures, weeds and biomass left on the soil surface could be minimal (Hatfield et al., 2007). Additionally, nutrients in faeces would reduce the need for tillage to mineralize nutrients. Hence, grazing animals may facilitate no-till seeding of catch crops after grazing of green manures.

An experiment was established to explore the soil NO_3-N uptake and release patterns of catch crops grown after a grazed green manure. The objectives of this study were to investigate: (i) the biomass production and N uptake of two different catch crop species (barley and oilseed radish) seeded after a grazed green manure using no-till and tillage methods, (ii) the effectiveness of catch crops in capturing N released in autumn by the grazed green manure, and, (iii) the N availability to a following wheat crop. As a result of faster N mineralization under tillage (Varco et al., 1993), it was hypothesized that catch crops will produce more biomass and take up more N when grown in tilled plots as opposed to no-till seeded plots. It was also hypothesized that soil NO_3-N content would be lower in catch crop plots than no catch crop plots. Lastly, conservation of N in catch crop plots will increase the wheat productivity compared to no catch crop plots where N is not conserved in catch crop biomass.

2. Materials and methods

2.1. Site description and experimental design

Experiments were conducted at the University of Manitoba Ian N. Morrison Research Farm in Carman, Manitoba (49°29′48″ N, 98°2′ 26″ W, 267 m above sea level). The region is characterized by an extreme continental climate with very cold winters and warm summers. Frost-free period for crop production is 115–125 days, and occurs primarily between May and September (MASC, 2013). Long-term average temperatures, precipitation, as well as 2010–2012 growing season monthly temperatures and precipitation are provided in Table 1. The soil at Carman is an Orthic Black

Table 1
Average monthly growing season air temperatures and precipitation for Carman, Manitoba, Canada from 2010 to 2012.

	Air temperatures (°C)				Precipitation (mm)			
	2010	2011	2012	Average[a]	2010	2011	2012	Average[a]
April	8.7	4.5	6.2	4.2	35	44	19	42
May	11.6	10.4	12.1	12.5	159	72	61	53
June	16.3	16.7	17.7	16.9	63	59	86	73
July	19.6	20.3	21.9	19.4	48	38	28	69
August	18.7	19.3	19.0	18.2	138	12	47	65
September	11.8	14	12.5	12.2	107	65	3	49
October	8.3	8.2	4.2	5.5	57	8	85	34
Total					607	297	328	386

[a] from 1961 to 1990.