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Effects of grazing two green manure crop types in organic farming systems: N supply and productivity of following grain crops

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ABSTRACT

Grazing green manures may improve N availability and productivity in integrated crop–livestock systems. We hypothesized that grazing green manures, compared with standard soil incorporation with tillage, would increase autumn soil profile NO_3–N concentrations and grain yields in subsequent years. Three multiyear experiments were carried out for three years between 2009 and 2011 in Manitoba, Canada. For all three experiments, spring-seeded oat (*Avena sativa* cv. Leggett) and pea/oat (*A. sativa*/*Pisum sativum* cv. 40-10) green manure crops were grazed with sheep or left ungrazed in year one. Both treatments were soil incorporated with a tandem disk after grazing. Spring wheat (*Triticum aestivum* cv. Waskada) and fall rye (*Secale cereale* cv. Hazlet) test crops were grown in the second and third years, respectively. Biomass production was greater for pea/oat than oat in experiment 1; in experiment 2 pea/oat = oat; and in experiment 3 pea/oat < oat. Grazing utilization of green manure biomass averaged 62% across all treatments and experiments with no utilization differences between crop species. On average, less than 10% of biomass consisted of weeds for both green manures. Soil NO_3–N to 120 cm was significantly greater in grazed than in ungrazed plots; however soil P and K were unaffected. Nitrate content was greater in pea/oat mixture plots for all three experiments at 0–120 cm than oat plots. The absence of a significant management × green manure type interaction indicated that both crop types responded similarly to grazing. Greater availability of soil NO_3–N after grazing translated into significantly greater crop growth and N uptake in some years, although significant increases in yield of following crops were not observed. Importantly, grazing green manures never negatively affected wheat or rye yield. In conclusion, grazing green manure crops increased N supply for subsequent crop production with no negative yield effects on two subsequent grain crops.

1. Introduction

There is renewed interest in annual forages, especially for extending the grazing season and for utilizing livestock on permanent croplands (McCartney and Fraser, 2010). Ruminants in integrated crop–livestock systems can utilize cash crop residues, annual cover crops (temporary pasture) and long-term pastures (Gardner and Faulkner, 1991). In organic cropping systems, green manures should be grown as a part of the crop rotation to enrich soil with nitrogen (N) (Entz et al., 2001). In short growing season environments, such as western Canada, dedicating the entire growing season to green manures incurs a cash crop opportunity loss. Thiessen Martens and Entz (2011) suggested an integration between green manures and livestock grazing as a way of improving economic returns from the green manure year, however no experiments have tested this system under organic farm management.

Agronomic and environmental impacts of crop–livestock integration have been investigated in various cropping systems: grain–swath grazing systems of North Dakota (Tanaka et al., 2005), wheat–fallow systems of Montana (Hatfield et al., 2007a,b,c; Sainju et al., 2010, 2011), summer grain/winter cover or winter grain/summer cover crop systems of Georgia (Franzluebbers and Stuedemann, 2007, 2008a,b), winter cover crops or cool season pastures of Illinois (Tracy and Zhang, 2008; Tracy and Davis, 2009; Maughan et al., 2009), winter cover crop, corn silage systems of Ohio (Fae et al., 2009), sod–peanut–cotton systems of Florida and Alabama (Katsvairo et al., 2006), cotton–forage systems of Texas (Allen et al., 2008; Acosta-Martinez et al., 2010). These studies highlight successful integration of both cattle (*Bos taurus*) and sheep (*Ovis aries*) into various cropping systems managed under different ecoregions in the USA. In Canada, a few researchers have reviewed potential role of integrated crop–livestock systems (Entz et al., 2002; McCartney and Fraser, 2010; Thiessen Martens and Entz, 2011), but no original research has been published.

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In integrated crop–livestock systems, plant, animal and soil productivity depend on a number of factors including, but not limited to, plant nutritional composition, developmental stage, morphology, biomass production, herbivore species, age and physiological state, and most importantly grazing intensity (Carvalho de Faccio et al., 2010). Hence, selection of compatible ruminant and plant species that are adaptable to local edaphic and climatic conditions should precede other considerations when designing integrated crop–livestock systems (Ledgard, 2001). However, most integrated crop–livestock system experiments compare different cropping systems (i.e. a rotation with grazing vs. grain monoculture or pasture), not the crop species within a cropping system. Information regarding establishment, growth and nutritional value of a number of forage species is available (Fraser et al., 2004; McCartney and Fraser, 2010), but most of the reported plant species have been tested under permanent pastures, hay operations or swath grazing systems. By contrast, little information on weed competitiveness and utilization rate of potential annual green manure species is available. Such information is critical particularly in organic systems, where soil management history may produce different soil fertility levels (Van Diepeningen et al., 2006) and weed pressure (Ryan et al., 2010) than in conventional systems.

There is also limited information regarding the environmental impact (i.e. nitrate leaching potential) of grazing in integrated crop–livestock systems, as well as subsequent crop nutrient uptake, biomass production and yield. To be considered effective, integrated systems must at least maintain the productivity of alternative, less diverse systems and have no negative environmental impact from excessive nutrient availability. Studies using labelled ^{15}N showed that N losses and crop recovery from sheep manure (urine + faeces) were similar to losses and recovery from synthetic fertilizers when applied at similar rates (Thomsen et al., 1997; Bosshard et al., 2009). However, urine N may be lost to leaching when deposited at rates exceeding plant uptake (Stout, 2003; McGechan and Topp, 2004).

Most nutrients (i.e. N, P, K) ingested by ruminants are returned to the soil in excreta, but the amount of nutrients retained and returned is directly influenced by plant nutritional composition (Duncan and Poppi, 2008). Thus, subsequent crop response to grazing is mainly a function of green manure species productivity and nutritional composition. In general, N contained in plant material can be partitioned by ruminants into metabolizable N (3–15%) and plant available N (85–95%) in faecal output, but considerable variation exists in the N, P and K cycles depending on the system and region (Whitehead, 2000). Phosphorus deficiency in organic systems is well-documented (Cornish, 2009; Welsh et al., 2009). Livestock integration in organic systems has been suggested as a means to recycle and transfer P from plant material to rumen and back to the soil in more plant available forms. Faecal matter decomposition studies have shown that grazing increases plant-available soil inorganic P (Aarons et al., 2004). Ingested plant material contains less inorganic P than faecal material, and plant uptake of faecal derived P can be as effective as synthetic P fertilizers (Williams and Haynes, 1995). Potassium in organic systems is also a limiting nutrient, and plant demand for K increases with increasing availability of N (Fortuna et al., 2008). Most of the K is excreted in urine and little is known of the fate of K in urine patches. In grazed grasslands, productivity and K uptake by plants increase around urine patches with high-K concentrations (Kayser and Isselstein, 2005).

Objectives of this experiment were to investigate: (i) productivity, herbivore consumption and weed competitiveness of oat and pea/oat green manures as potential annual forages, (ii) effects of grazing on soil NO_3–N, P (Olsen) and K responses, and (iii) effects of grazing on biomass production, N uptake and yield of subsequent spring wheat and fall rye crops. We hypothesized that productivity, herbivore consumption and weed competitiveness will be significantly greater for pea/oat green manure than oat green manure. Consequently, grazed pea/oat plots will contain greater amount of soil NO_3–N than oat plots. We also hypothesized that soil NO_3–N, P and K levels will be greater when green manures are grazed than when they are left ungrazed. This difference, in turn, will be reflected in increased wheat and fall rye N uptake, biomass and yields in grazed treatments.

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 2009–2012 growing season monthly temperatures and precipitation are provided in Table 1. The soil at Carman is an Orthic Black Chernozem (Udic Boroll) (Soil Classification Working Group, 1998) with a fine sandy loam texture, pH (0–30 cm) of 6.0, and organic matter content (0–30 cm) of 25 g kg^{-1}. Soil background nutrient samples were collected at 0–30 cm for experiments 2 and 3. Soil NO_3–N, P (Olsen) and K levels in experiment 2 were 11, 20 and 569 kg ha^{-1}, and in experiment 3 were 13, 17 and 477 kg ha^{-1}, respectively. No background soil samples were collected for the experiment 1. Oat was the preceding crop for all experiments. Previous investigations of integrated crop–livestock systems have been exclusively conducted under conventional management with fertilizer inputs. The present study was conducted under long term organic management (since 2004) with no external inputs.

The experimental design was a split-plot design, with four blocks (replications). The whole-plot treatment was green manure species, and the sub-plot treatment was green manure management. Two green manure species (pea/oat and oat) and two green manure management systems (grazed and incorporated) were included. Green manures were incorporated into soil with tandem disk, which is a common practice in this region. The grazing green manures experiment started with an experiment in 2009 (Experiment 1) and was repeated in 2010 (Experiment 2) and 2011 (Experiment 3) on neighboring sites within the experimental station. Table 2 shows the field operations and dates for all three experiments. In the first year of the experiments, green manures were seeded in the spring, and grazed or incorporated in mid- to late-summer. In the second year, a spring wheat crop was seeded in May on the grazed and incorporated green manure plots. In the third year, a fall rye crop was grown. Experiment 1 and experiment 2 included all three phases of the experiment, but experiment 3 only included two phases (green manure year and spring wheat year).

Spring wheat establishment in experiment 2 failed as a result of higher than normal precipitation in fall 2010 and spring 2011. Spring wheat contained more than 60% weed biomass, therefore was incorporated into soil at stem elongation stage. Redroot pigweed (*Amaranthus retroflexus*) grew over these plots comprising more than 90% of the plant biomass. Therefore, the decision was made to consider redroot pigweed biomass as the test crop in place of wheat.

2.2. Green manure species and management

The pea/oat mixture was seeded at 50 kg ha^{-1} of oat (*Avena sativa* cv. Leggett) and 100 kg ha^{-1} of pea (*Pisum sativum* cv. 40-10).