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Integrated crop-livestock system effects on soil N, P, and pH in a semiarid region

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ABSTRACT

Integrated crop-livestock systems (ICLS) represent a potential means to sustainably intensify agriculture. Developing ICLS that concurrently achieve production and environmental goals is contingent upon efficiently managing plant nutrients in time and space. In this study, we sought to quantify residue management and field-zone effects on soil NO_3-N, available P, and soil pH over a 12 year period for an ICLS experiment near Mandan, ND USA. From 1999 to 2011, soil NO_3-N and available P were measured in three residue management treatments (grazed, mechanically harvested, and no residue removal) every third year across a 122 cm soil depth, while soil pH was measured prior to deploying ICLS treatments in 1999 and again in 2011. Residue management did not affect soil NO_3-N or available P at any depth for any year ($P > 0.1$), implying no accumulation of available N and P under grazing compared to cropping. Similarly, no differences in available N and P were observed across grazed sampling zones. Soil nutrients, however, increased or fluctuated greatly over the 12 year period, suggesting a need for adaptive nutrient management. Soils became more acidic between 1999 and 2011, with the greatest decreases in soil pH at 0–8 cm under grazing (0.74 pH unit decline; $P = 0.0581$) and mechanical harvest (0.86 pH unit decline; $P = 0.0138$). Management interventions targeting nutrient conservation may serve to mitigate N and P loss and soil acidification in ICLS.

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1. Introduction

Integrating livestock into cropping systems can improve economic returns, thereby providing a more profitable means to sustainably intensify agriculture (Russelle et al., 2007; Soussana and Lemaire, 2014). Integrated crop-livestock systems (ICLS) combine livestock and cash crops at the farm level (Ryschawy et al., 2014), whereby crops and crops by-products in ICLS are used to feed livestock, which return excreta to fertilize crops (Schiere et al., 2002). Such integration provides opportunities to reduce intensive inputs, while recoupling nutrient cycles and improving soil quality (Hendrickson et al., 2008; Krall and Schuman, 1996).

Research on ICLS globally has identified a diversity of management approaches to achieve production and environmental goals through the integration of agricultural enterprises. In France, Ryschawy et al. (2014) found ICLS using diversified ley-cereal rotations achieved positive environmental and economic outcomes when integrated with livestock. Coquil et al. (2014) found mixed crop-dairy farms in Europe became more self-sufficient and profitable through the incorporation of temporary grasslands in crop rotation. In the Amazonian region of Brazil, Bonaudo et al. (2014) found ICLS that coupled enterprise diversification with small chemical inputs improved agricultural production, reversed degradation of grazing land, and limited deforestation. Incorporation of interseeded grasses or legumes in row crops in the U.S. Corn Belt was found to increase forage availability in late fall and early spring without compromising crop production, thereby reducing livestock feeding costs and increasing profitability (Sulc and Tracy, 2007). In southern Australia, dual-purpose use of cereals and canola (*Brassica napus* L.) for forage and grain increased crop and livestock productivity by 25–75% with minimal increases in external inputs (Bell et al., 2014). Collectively, emergent findings from research on ICLS suggest reconstructing linkages among specialized production enterprises can serve to improve agricultural sustainability.

Efficient use of plant nutrients serves as a defining attribute to concurrently achieve production and environmental goals in ICLS through the recoupling of carbon and nitrogen cycles (Soussana and Lemaire, 2014). Nutrient recycling through ruminant livestock can decrease dependence on synthetic crop inputs (Powell et al., 1996), but excess nutrients from livestock on cropland can threaten water quality (Chang and Entz, 1996). Accordingly, achieving an optimal balance of plant nutrients in time and space is of paramount importance in ICLS (Hochman et al., 2013).

Abbreviations: ICLS, integrated crop-livestock system.

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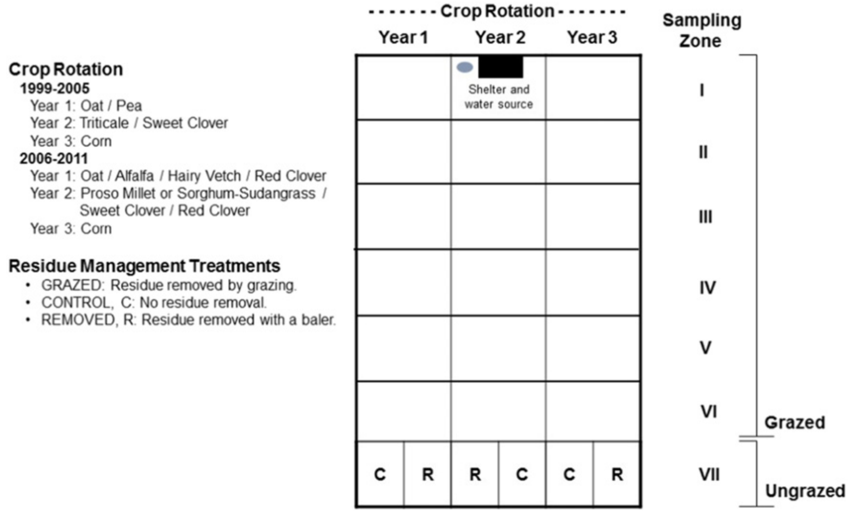

Fig. 1. Diagram of crop rotation, residue management treatments, and sampling zones (I–VII) within one replicate of an integrated crop-livestock experiment near Mandan, ND, USA. Grazed and ungrazed sampling zones are specified to the right of the diagram.

Designing ICLS to maximize efficient use of nutrients relies on an understanding of nitrogen (N) and phosphorus (P) dynamics in the soil profile. Unfortunately, there is a paucity of published findings on soil nutrient dynamics for ICLS. Use of tillage increased soil NO_3-N, while grazing and/or no-tillage served to moderate soil NO_3-N accumulation in ICLS (Franzluebbers and Stuedemann, 2013; Lenssen et al., 2013). High grazing intensity was found to increase soil N loss compared to treatments with moderate and light grazing intensities, underscoring the importance of identifying optimal grazing pressure in ICLS (Assmann et al., 2014). Grazing of cover crops and crops grown for winter forage were found to increase or have no effect on near-surface total and labile P stocks in ICLS (Costa et al., 2014; da Silva et al., 2014; Liebig et al., 2012). Soil acidification, an indirect indicator of nutrient-use efficiency (Smith and Doran, 1996), was less severe under treatments including livestock regardless of grazing intensity compared to no grazing due to greater retention of divalent cations (i.e., exchangeable Ca^{2+} and Mg^{2+}) in the former (Martins et al., 2014; da Silva et al., 2014).

There is a need to better understand management effects on soil nutrient stocks over time within ICLS, particularly in semiarid regions where soil attributes change slowly in response to management due to limited biomass production. The objective of this study was to determine management and field-zone effects on soil NO_3-N, available P, and soil pH for an ICLS experiment conducted in a semiarid region. Three hypotheses guided the study: 1) soil NO_3-N and available P would not be elevated under ICLS management compared to cropping alone, 2) soil acidification would be mitigated by livestock integration, and 3) soil nutrient and pH responses to livestock integration would be intensified with increased proximity to shelter/water.

2. Materials and methods

2.1. Site and treatment description

The study site was located approximately 5 km south of Mandan, ND USA (46°46′, −100°54, 593 m elevation). The site is within the temperate steppe ecoregion (Bailey, 1995), with long-term (1914–2010) mean annual precipitation of 416 mm. Mean annual temperature is 4 °C, and the average frost-free period is 131 days. Topography at the site is gently rolling (0–3% slope), and soils are a mix of Temvik-Wilton silt loams (Fine-silty, mixed, superactive, frigid Typic and Pachic Haplustolls) (USDA, 2016).

The experiment was initiated in 1999 by spraying two 6.0 ha crested wheatgrass [*Agropyron desertorum* (Fisch. ex. Link) Schult.] pastures with glyphosate [N-(phosphonomethyl) glycine; 0.7 kg a.i. ha^{-1}] twice in mid-May and converted to a three-year crop rotation designed to meet the nutritional needs of dry bred cows during winter. Initially, the rotation consisted of oat/pea (*Avena sativa* L./*Pisum sativum* L.),

Table 1
Precipitation and air temperature for dormant and growing season periods near study site, 1999–2010.

	Dormant season (Jan–Mar)		Growing season (April–Sep)		Dormant season (Oct–Dec)	
Year	Precipitation (mm)	Temperature (°C)	Precipitation (mm)	Temperature (°C)	Precipitation (mm)	Temperature (°C)
1999	36[a]	−5.0	556	15.0	15	2.4
2000	81	−4.0	385	15.5	86	−3.6
2001	32	−7.4	464	16.2	24	1.2
2002	20	−6.1	243	15.5	30	−0.7
2003	21	−8.6	317	16.2	42	−0.5
2004	51	−7.2	381	14.6	23	1.2
2005	15	−6.1	411	16.1	63	0.7
2006	15	−3.6	195	17.2	59	−0.2
2007	46	−6.6	457	16.1	19	−0.7
2008	23	−7.6	305	15.0	185	−2.4
2009	72	−10.2	412	14.5	74	−1.4
2010	26	−7.9	440	15.6	26	−1.9
Long-term (1914–2010)	36 ± 2	−8.4 ± 0.3	331 ± 10	15.4 ± 0.2	49 ± 3	−1.2 ± 0.4

[a] Precipitation and air temperature data summaries obtained from Global Historical Climatology Network-Daily (GHCN-D), National Oceanic Atmospheric Administration, National Climatic Data Center (http://www.ncdc.noaa.gov/cdo-web; accessed 14 November 2016). Long-term values reflect mean ± 1 standard error.