Facilitating Crop–Livestock Reintegration in the Northern Great Plains


ABSTRACT
Integrated crop–livestock systems (ICLSs) can help increase food production while benefiting soils and the environment. This review summarizes recent impacts of ICLSs on crop and livestock production and rural economics and discusses lessons learned in the northern Great Plains (NGP). Research on ICLSs conducted in the NGP indicates that the crop residue grazing, swath grazing, and annual forage grazing can positively influence crop production; whereas, livestock performance varies with season, forage nutritional value, and grazing management. Furthermore, ICLSs can reduce the costs and risks of agricultural production. The success of ICLSs in NGP region depends on trade-offs, planning, economic benefits, policies, regulations, community acceptance, and management skills. The ICLSs could play a strategic role in future agricultural production. The lessons learned from adopting ICLSs in the NGP include the lack of available land for fertilizer (manure) management, that to implement ICLS practices skills and knowledge must be maintained, and ICLS provides an entry point for young farmers and ranchers however capital is needed. These experiences and lessons could be valuable references for producers to adopt ICLSs in the NGP or other regions.

BACKGROUND AND HISTORY
Over the last century, many agricultural producers have become specialized and highly efficient at producing specific crops or livestock to meet the demand of global population growth (MacDonald and McBride, 2009). Societal and population changes are continuing to increase food demand, necessitating intensification of existing crops and livestock production systems (Godfray et al., 2010). However, intensification can result in soil and ecosystem degradation, unsustainable resource use, and agrochemical, antibiotic, and hormone contamination (Herrero et al., 2009; Reganold et al., 2011; Tilman et al., 2001).

Integrated crop–livestock systems can provide an alternative management strategy that purportedly sustainably intensifies food production while benefiting producer income, soil, and the environment (Franzluebbers, 2007). An agricultural system that manages crop and livestock production on a single farm or among farms such that products are used to support each other is an ICLS (Franzluebbers et al., 2014; Hilimire, 2011; Russell et al., 2007; Sulc and Franzluebbers, 2014).

Recently, a special report by the International Panel on Climate Change (IPCC) highlighted that ICLSs are resource-efficient and cost-effective agricultural adaptation strategies to sustainably maintain or increase food production (IPCC, 2018). These systems recycle nutrients from livestock waste (feces and urine) back to croplands and through fodder production and use and also improve or sustain soil organic matter and fertility (Franzluebbers et al., 2014). Although farming systems that integrate crops and livestock have existed historically (Halstead, 1996; Smith, 1995), the ICLS concept re-emerged globally in 2007 and was documented through a series of international conferences and publications (Franzluebbers et al., 2014).

Core Ideas
- Integrated crop–livestock systems positively affect crop production by improving soil health.
- Common integrated crop–livestock system management techniques can enhance the northern Great Plains crop production.
- Integrated crop–livestock system livestock performance is impacted by season, forage selection, and management.
- Integrated crop–livestock systems can increase economic benefits and reduce economic risks.
- Experiences and lessons in the northern Great Plains could be valuable for other regions to adopt integrated crop–livestock systems.

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Abbreviations: ADG, average daily gain; AUM, animal unit month; ICLSs, integrated crop-livestock systems; NGP, the northern Great Plains; SOC, soil organic carbon.
Within the NGP and adjacent regions, both crop and livestock production are significant contributors to the economy (Fig. 1). In the NGP, the conversion of prairie to cropland started in the 1850s (Johnson, 1932). The mechanization of farming in the 1920s followed by the availability of synthetic fertilizers post World War II led to the widespread abandonment of many traditional farming rotations (Conkin, 2008). Grassland and cropland deterioration between 1910 and 1940 was further exacerbated by poor management and frequent droughts (Wang et al., 2016). During this period, known as the Dust Bowl, wind erosion seriously damaged soils and led to large economic and agricultural losses, and ultimately farm abandonment (Fig. 2a and 2b) (Cook et al., 2009). Geographically, climatic conditions in the NGP are controlled by the strong North–South temperature and East–West moisture gradients that make this region prone to periodic flooding and drought (Fig. 3). Taken together, the historical lessons of the NGP coupled with future forecasts of increasing severity and changing frequency of floods and droughts (Walshall et al., 2013), warrants adoption of resilient climate-adaptive management practices to make agricultural systems highly productive and sustainable.

Several general reviews on ICLSs have expanded our understanding of these systems (Allen et al., 2007; Franzluebbers, 2007; Kirschenmann, 2007; Russelle et al., 2007; Russelle and Franzluebbers, 2007; Sulc and Tracy, 2007), but region-specific issues will have a major impact on how these systems are implemented. In semiarid regions, irrigation-related water level declines in the Ogallala Aquifer (e.g., Colorado, Nebraska, and Wyoming) have accelerated over the last decades (USGS, 2017), further threatening agricultural production and ecosystem services (McGuire, 2017). In many areas of the NGP, unsustainable external dependencies and monoculture cropping are still prevalent. In South Dakota, for example, 16% of crop production was under conventional tillage cropping systems and 17% was under reduced tillage systems in 2017 (NRCSSD, 2018b), and the conventional fallow practices often allow water and nitrates to move below root zones (NRCSSD, 2018a). As a result, increasing concern regarding agricultural nitrate pollution of ground and surface waters from synthetic fertilizer application has prompting states (e.g., South Dakota and Minnesota) to pass legislation to encourage management changes (MDA, 2017; SDDOR, 2018).

In terms of farmer practices, the adoption of ICLSs has increased over time. During the 1990s, excluding areas of grazed crop residues, ICLSs were practiced in less than 10% of the agricultural land in the United States (Krall and Schuman, 1996). In 2010, a USDA survey showed that grazing corn (Zea mays L.) residue represented 12% of the total corn hectarage...
across 19 states but was largely skewed to the western Corn Belt Region. For example, both Nebraska and Colorado had substantial corn residue utilization (~52 and 56% of their total corn hectares being grazed) through regionalized integration (Schmer et al., 2017). Another survey indicated that grazing of crop residue within farm systems was reported by about 70% of farmers in the U.S. NGP (Asem-Hiablie et al., 2016). A survey of South Dakota commodity crop producers indicated that 55% of farmers use ICLSs, of which 22% adopted these practices within the last 10 yr (J.D. Ulrich-Schad and A. Abulbasher, 2018 South Dakota commodity crop producer survey results. Report for the South Dakota Corn Utilization Council, unpublished data, 2018). These surveys reflect regional producer willingness to learn and adopt new management practices. The ICLSs leverage available resources but vary with local environmental conditions and concerns. Producers often prioritize short-term profits ahead of long-term sustainability (Wang et al., 2017), however, these surveys indicate that increased adoption of ICLSs can be beneficial to producers and agricultural production in the NGP region with respect to both long-term and short-term goals. The improvement of ICLS-based practices is ongoing and will continue to present further intensification opportunities.

Individual NGP research studies have evaluated the impacts of ICLSs on soil nutrients (Liebig et al., 2017), soil properties (Ganjegunte et al., 2005; Lenssen et al., 2013), soil erosion (Blanco-Canqui et al., 2016b; Burkart et al., 2005), and crop and livestock performance (Cicek et al., 2014; Jose et al., 2017; Miller et al., 2015). Studies evaluating the collective impacts of integrating crops and livestock production on economic returns and resulting services are continuing. The objectives of this review were to (i) summarize the regional impacts of ICLSs on crop, livestock, and economic returns, and (ii) identify experiences and lessons of ICLS practices within the NGP.
IMPACTS OF INTEGRATED CROP–LIVESTOCK SYSTEMS ON CROP PRODUCTION AND MANAGEMENT TECHNIQUES

The ICLS practices influence crop production primarily through impacting soil properties (Table 1). Grazing intensity affects soil surface exposure, sediment erosion, soil compaction (Hubbard et al., 2004), and ultimately soil organic carbon (SOC) (Schacht and Reece, 2008). Soil bulk density may be increased when livestock graze on crop residues or cover crops (Lenssen et al., 2013), leading in soil compaction. However, in the NGP, grazing-related soil compaction is not typical because the annual freeze/thaw and wet/dry cycles can reduce this risk (Liebig et al., 2012). Further, livestock waste (feces and urine) returns organic matter and nutrients to the soil, which build the soil structure (Chang et al., 2017; Haynes and Williams, 1993; Soussana et al., 2004).

Studies have shown that grazing management has variable effects on crop production in ICLSs (Wang et al., 2016). Some report positive effects from light to heavy stocking rates (Reeder and Schuman, 2002), negative effects by sheep grazing (Golluscio et al., 2009), or neutral effects by cattle with different stocking rates (1.8–2.4 animal unit month [AUM] ha⁻¹) (Dormaar et al., 1989). In the NGP, livestock can positively influence crop yield and quality in ICLSs, but crop production in these systems varies with crop types and local conditions (Fig. 3, Tables 2 and 3). Many of the benefits associated with ICLSs stem from crop diversification, not just livestock integration (Tables 2 and 3). Therefore, the proper selection of ICLS implementation methods (e.g., choices of crop type and diversification, grazing intensity, stocking method, and grazing date and period based on the local conditions) is critical to optimize these benefits. Forages within ICLSs can be broadly classified as annual or perennial and harvested or non-harvested. The periodicity and classifications used are variable and often indistinct because ICLSs are adaptive and dynamic management systems (Hendrickson et al., 2008a). The following sections summarize the impacts of ICLSs on agricultural production based on the common NGP ICLS management techniques.

**Annual Crop Residue Grazing**

Residue left in the fields after grain harvest of annual row crops can be grazed in situ by livestock during dormant periods in the autumn or winter. A primary reason that farmers graze annual crop residues is to reduce feed costs, however, an eventual outcome is improved nutrient cycling. For example, within a multi-crop ICLS rotation which incorporated grazing of selected years of unharvested crops in North Dakota, the nutrient cycling, soil health, and crop production was enhanced which in-turn reduced...
the need for N fertilizer (Landblom et al., 2016). Annual crop residue grazing has greatly increased in the last decade in the NGP (Asem-Hiablie et al., 2016; Ulrich-Schad and Abulbasher, 2018) and could be increased further in colder regions. For instance, in western Canada, with the development and adoption of more low heat unit corn and other warm season annual crops, the use of these crops as standing winter ICLS forages could continue to increase (Jose et al., 2017; Lardner et al., 2017).

Numerous studies demonstrate that crop residue grazing can increase soil C and N (e.g., Burkart et al., 2005; Cicek et al., 2014; Schuman et al., 1999). However, crop residue-based ICLS studies have shown different results with respect to soil P, K, and other soil nutrients. For example, there was no significant difference in soil P and K between ICLSs and traditional approaches in Canada (Cicek et al., 2014). However, in North Dakota, a 9-yr study showed an increase in available P in ICLSs when compared with that of perennial grass (Liebig et al., 2012). Within northern, subhumid areas of the NGP, soil Na was more closely related to soil aggregate size and water management, not necessarily with ICLS management (Ruis et al., 2018). Moreover, ICLSs with sheep grazing can reduce soil electrical conductivity (Lenssen et al., 2013). Integrated crop–livestock systems have been found to have indeterminate effects on water infiltration (Liebig et al., 2012) and water use efficiency (Tanaka et al., 2005). Research conducted in Nebraska showed that erosion and nutrient losses are less when corn residues are grazed than baled (Blanco-Canqui et al., 2016a).

Late autumn or winter corn residue grazing by livestock (mostly cattle) is one of the most common NGP ICLS practices, the widespread adoption of this practice is indicative of its benefits and acceptance. Results from a long-term (16 yr) Nebraska experiment confirm that grazing corn residue can positively impact soybean [Glycine max (L.) Merr.] grain yield in a corn–soybean rotation (Drewnoski et al., 2016). To assist in corn residue management, tools such as the University of Nebraska’s Corn Stalk Grazing Calculator have been created (Stockton and Wilson, 2013), enabling corn producers to implement sustainable stocking rates and maximize grain yield.

Swath Grazing

Swath grazing is practiced in winter in NGP regions with deep snow cover. It refers to a grazing method in which the feed crops (e.g., annual crops such as barley [Hordeum vulgare L.], triticale [× Triticosecale Wittm.], and corn or perennial crops such as alfalfa [Medicago sativa L.]) are cut in the autumn and left lying in the field in swaths. These swaths can then be grazed by animals throughout the winter (AAFC, 2017). With swath

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**Table 1. Summary soil property changes under integrated crop–livestock systems (ICLSs) in the northern Great Plains.**

<table>
<thead>
<tr>
<th>Parameters†</th>
<th>Treatment</th>
<th>Results</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soil nutrients</td>
<td>ICLS vs. ungrazed</td>
<td>Increased</td>
<td>Schuman et al. (1999); Ganjegunte et al. (2005); Burkart et al. (2005); Cicek et al. (2014); Thiessen Martens and Entz (2011); Liebig et al. (2012); Landblom et al. (2016); Sentürklü et al. (2016); Krall and Schuman (1996)</td>
</tr>
<tr>
<td>Soil N</td>
<td>Light grazing vs. heavy</td>
<td>Increased</td>
<td>Ganjegunte et al. (2005)</td>
</tr>
<tr>
<td>Leachable N</td>
<td>ICLS vs. watersheds</td>
<td>Decreased</td>
<td>Burkart et al. (2005)</td>
</tr>
<tr>
<td>Soil NO₃-N</td>
<td>Grazed vs. tilled</td>
<td>Lower</td>
<td>Lenssen et al. (2013)</td>
</tr>
<tr>
<td>Available P</td>
<td>ICLS vs. perennial grass</td>
<td>Higher</td>
<td>Liebig et al. (2012)</td>
</tr>
<tr>
<td>Soil P</td>
<td>ICLS vs. conventional</td>
<td>ns‡</td>
<td>Cicek et al. (2014)</td>
</tr>
<tr>
<td>Soil K</td>
<td>ICLS vs. conventional</td>
<td>ns</td>
<td></td>
</tr>
<tr>
<td>Soil Ca</td>
<td>Grazed fallow vs. tilled</td>
<td>Lower</td>
<td></td>
</tr>
<tr>
<td>Soil S</td>
<td>Grazed fallow vs. tilled</td>
<td>Lower</td>
<td></td>
</tr>
<tr>
<td>Soil Na</td>
<td>Grazed fallow vs. chemical or tilled</td>
<td>Higher</td>
<td></td>
</tr>
<tr>
<td>Soil properties</td>
<td>ICLS vs. ungrazing</td>
<td>Higher</td>
<td>Ganjegunte et al. (2005); Reeder and Schuman (2002); Schuman et al. (1999); Sentürklü et al. (2016)</td>
</tr>
<tr>
<td>SOC</td>
<td>Light grazing vs. heavy</td>
<td>Higher</td>
<td>Ganjegunte et al. (2005)</td>
</tr>
<tr>
<td>EC</td>
<td>Grazed fallow vs. tilled</td>
<td>Lower</td>
<td>Lenssen et al. (2013)</td>
</tr>
<tr>
<td>Bulk density</td>
<td>Grazed fallow vs. tilled</td>
<td>Higher</td>
<td></td>
</tr>
<tr>
<td>WUE</td>
<td>ICLS vs. straw retained</td>
<td>Higher in oat/pea</td>
<td>Tanaka et al. (2005)</td>
</tr>
<tr>
<td>Infiltration</td>
<td>ICLS vs. perennial grass</td>
<td>ns</td>
<td>Liebig et al. (2012)</td>
</tr>
<tr>
<td>Water erosion</td>
<td>ICLS vs. watersheds</td>
<td>Minimized</td>
<td>Burkart et al. (2005)</td>
</tr>
<tr>
<td>Macroaggregate</td>
<td>Corn residue grazing vs. corn residue</td>
<td>Reduced</td>
<td>Blanco-Canqui et al. (2016b)</td>
</tr>
<tr>
<td>GMD</td>
<td>Reduced ns</td>
<td></td>
<td></td>
</tr>
<tr>
<td>WEF</td>
<td>Increased ns</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

† SOC, soil organic carbon; EC, electrical conductivity; WUE, water-use efficiency; GMD, geometric mean diameter; WEF, wind-erodible fraction.‡ ns, not significantly different.
grazing, the effort required for livestock to access winter forage is reduced, allowing livestock access to biomass and grain, even in deep snow. There have been numerous advances in swath grazing with the development of forage cultivars suited for frigid climates (McGeough et al., 2017). Autumn interseeding techniques have enabled small grains to be seeded and grazed following fall harvest of the primary crop (AAFC, 2017; McLelland and Brook, 2018).

The impacts of ICLSs on crop production vary with crop types and local conditions. For instance, the impacts of ICLSs on the grain and straw yield, protein, and P content in stover and grain were different under various crops in North Dakota (Tanaka et al., 2005). Variable results were reported in other studies (e.g., Baron et al., 2012, 2014). For example, the whole-plant yield declined linearly with planting delay for barley but for oat (*Avena sativa* L.) and triticale, it increased when planting was delayed from late May to early June (Baron et al., 2012). To resolve this problem, a spreadsheet calculator was developed to estimate farm-scale carrying capacities for swath grazing beef cows based on forage yield and quality data from small areas within fields or paddocks (Doce et al., 2015). Additionally, forage guides have been developed for Canadian and other producers in cold climates to extend the grazing season (e.g., GSKCA, 2018; Hutton et al., 2016).

### Annual Forage Grazing

Annual forage grazing designates that livestock are grazed on annual or short-season crops. These annual forages can also function as cover crops and can be rotated with cash crops. A survey showed that 20% of producers used cover crops with livestock integration during 2016 in South Dakota (Kolady, 2017). A 2018 survey of eastern South Dakota showed that only 6% of producers have used cover crops for more than 10 yr, but adoption has steadily grown, and 47% indicated they now use cover crops on 29% of their land on average (Ulrich-Schad and Abulbasher, 2018). In the NGP, forage cover crops commonly include turnip (*Brassica rapa* L.), millet (*Pennisetum glaucum* L.), oat (*Avena sativa* L.), pea (*Pisum sativum* L.), sorghum (*Sorghum bicolor* (L.) Moench), radish (*Raphanus sativus* L.), and berseem clover (*Trifolium alexandrinum* L.) (Davis et al., 2016; Neville et al., 2009), and other annual forages for grazing including wheat (*Triticum aestivum* L.), triticale, rye (*Secale cereale* L.), barley, rape (*Brassica napus* L.), and kale (*Brassica oleracea* L. var. *acephala*).

Cool-season annual grasses such as winter wheat, triticale, or rye can be planted in the autumn to provide earlier spring grazing. Spring oat, triticale, barley, and wheat can be planted in early spring for late-spring, early-summer grazing, and even...
Table 3. Production inventories of cattle, pig, sheep, layer chicken, and corn in the northern Great Plains from annual agricultural surveys by National Agricultural Statistics Service (NASS), USDA (NASS, 2012) and Statistics Canada (CANSIM, 2018).

<table>
<thead>
<tr>
<th>Location†</th>
<th>Beef cows inventory</th>
<th>Milk cows inventory</th>
<th>Calf crop</th>
<th>Steers on feed inventory</th>
<th>Sheep and lamb inventory</th>
<th>Chickens, layer inventory</th>
<th>Corn grain harvested</th>
</tr>
</thead>
<tbody>
<tr>
<td>AB</td>
<td>1596</td>
<td>1574</td>
<td>1574</td>
<td>1538</td>
<td>1535</td>
<td>1555</td>
<td>34</td>
</tr>
<tr>
<td>MT</td>
<td>1476</td>
<td>1476</td>
<td>1496</td>
<td>1486</td>
<td>1486</td>
<td>1486</td>
<td>34</td>
</tr>
<tr>
<td>NE</td>
<td>1815</td>
<td>1807</td>
<td>1756</td>
<td>1852</td>
<td>1920</td>
<td>1920</td>
<td>34</td>
</tr>
<tr>
<td>ND</td>
<td>1698</td>
<td>1635</td>
<td>1611</td>
<td>1670</td>
<td>1664</td>
<td>1664</td>
<td>34</td>
</tr>
<tr>
<td>SD</td>
<td>1698</td>
<td>1635</td>
<td>1611</td>
<td>1670</td>
<td>1664</td>
<td>1664</td>
<td>34</td>
</tr>
<tr>
<td>SK</td>
<td>1162</td>
<td>1134</td>
<td>1091</td>
<td>1065</td>
<td>1078</td>
<td>1078</td>
<td>34</td>
</tr>
<tr>
<td>WY</td>
<td>694</td>
<td>694</td>
<td>694</td>
<td>704</td>
<td>714</td>
<td>714</td>
<td>34</td>
</tr>
</tbody>
</table>

† AB, Alberta; MT, Montana; NE, Nebraska; ND, North Dakota; SD, South Dakota; SK, Saskatchewan; WY, Wyoming; CO, Colorado; NGP, Northern Great Plains, CAN, Canada; USA, United States.
turnip was developed to reduce fallow use and intensify livestock and crop production (Clay et al., 2017). This approach was common in many regions of early-American agriculture, including the NGP (NRCS, 2004; Clay et al., 2017). Now, this practice is primarily distributed in the southeastern US such as Alabama, Florida, and Georgia (Franzluebbers and Wilkinson, 2003; NFREC, 2016; Sulc and Franzluebbers, 2014). The main benefits are to reduce N losses (especially less nitrate leaching), improve soil structure, and increase water holding capacity, SOC, and crop yield potentials (Franzluebbers and Stuedemann, 2008; Liebig et al., 2012). These benefits are attributed to sod producing a large number of roots that allow the soil to recover from cultivation damage and fertility losses (Salton et al., 2014). For example, perennial grasses with deep roots can reduce soil compaction by penetrating through the compacted soil (Blanco-Canqui et al., 2015). When well-managed, perennial forages can accumulate more C than grain crops due to higher root biomass production (dos Santos et al., 2011) and better recycling of nutrients from manure and urine (Franzluebbers, 2007; Wang et al., 2016).

Perennial legumes have the added advantage of improving soil fertility through fixing atmospheric N (Grant et al., 2002; McGraw and Nelson, 2003), thereby reducing the need for synthetic N supplementation of the following crops. Legumes can be used in both pure stands and mixtures with grasses for animal grazing and forage conservation. Alfalfa is the main NGP perennial forage legume and is present in ~61% of the region’s cultivated forage hay land and most commonly seeded as a monoculture. Yellow-flowering alfalfa (Medicago sativa L. subsp. falcata [L.] Arcang.) has been shown to be more tolerant of grazing and produced more forage in semiarid areas than purple-flowering varieties (Misar et al., 2015). Many other legume species (e.g., red clover [Trifolium pratense L.], alsike clover [T. hybridi L.], sainfoin [Onobrychis viciafolia L.], and some nonbloating legumes) can also be used (Entz et al., 2002).

Sulc and Franzluebbers (2014) recognized the potential importance and possibility of incorporating perennial grasses as ICLS components. However, the practice of rotating cash crops with perennial forages/pastures is limited in the United States. Pastures are most commonly established on lands that are not suitable for cash crops. Even if the land were acceptable for cash crops, producers also do not want to terminate the pastures that may have been expensive to establish (Sulc and Franzluebbers, 2014). It is generally accepted that perennial pastures have the least expensive feed sources for beef cows (Entz et al., 2002). Some perennial grasses could be re-introduced into existing cropping systems as forage, forming sod-based crop rotations in the NGP. Liebig et al. (2012) in North Dakota reported that 9 yr after a perennial grassland was converted to ICLS, the surface soil properties were not adversely affected by winter cattle grazing due to NGP freeze–thaw cycles.

**LIVESTOCK PERFORMANCE AND GRAZING MANAGEMENT IN INTEGRATED CROP–LIVESTOCK SYSTEMS**

The NGP region supplies between 18 and 24% of United States and 61 to 70% of Canadian beef cattle production, 19% of United States and 29% of Canadian sheep production, and 2.1% of United States and 11% of Canadian milk production (Table 3) (CANSIM, 2018; NASS, 2012). Cattle production in the NGP is mostly cow–calf, where approximately half of the steers from these breeding operations are regionally finished on grass or grain. There are limited dairy operations in the NGP, with the 2012 U.S. Agricultural Census counting less than 80 dairy operations. In 2015, ~70% of ranches in the U.S. NGP practiced ICLSs (i.e., grazing of crop residue) (Asem-Hilabi et al., 2016). Thus, it is important for producers to evaluate the impact of ICLSs on livestock performance, which is evaluated in terms of average daily gain (ADG) or weight of livestock, milk amount, and/or net incomes of producers. Previous studies have evaluated some impacts of ICLSs on livestock performance in the NGP region (Table 2). Livestock performance research in ICLSs of the NGP region is related to the season, forage nutritive value, and grazing management.

**Seasons and Overwintering**

In the NGP, the greatest cost of maintaining livestock is winter feed. If traditional feedlot methods (livestock primarily fed hay in feedlots [Sulc and Franzluebbers, 2014]) are used, the wintering cost for a cow is often higher than that of other seasons (McGrath, 2017). Because snow cover can limit the availability of forages for livestock grazing during the winter (Grings et al., 2005), a concern is forage availability and accessibility (Karn et al., 2005). Therefore, finding easily accessible forages or management practices amenable to local winter grazing conditions is key. Areas of the NGP with inconsistent or light snow cover can use multiple ICLS forage sources and techniques. Deep snow cover can restrict winter grazing of crop residues or grasslands, and livestock may lose weight when forage accessibility is reduced. A wide range of annual plant species such as barley, oat, fall rye, wheat, and perennial grasses have been used to extend the grazing season (Entz et al., 2002). However, different ICLS techniques are necessary to improve livestock forage accessibility during deep snow cover. Swathing small grain crops, perennial grasses, and/or residues is an effective method that can concentrate forage resources into one location, thereby improving forage accessibility. Alternatively, tall row crops (e.g., corn and sunflower [Helianthus annuus L.]) can be left unharvested and standing for winter grazing, again enabling livestock to more easily access forage (Sentürklü et al., 2016). More importantly, reliance on a single forage management practice during winter weather could be risky in livestock production. Methods selected for use in one area may be effective in other areas. Therefore, a combination strategy including traditional feeding of stockpiled forage, bale grazing, standing corn grazing, and use of bale processors and bale feeders can reduce these risks. For example, combining swath and bale grazing increases flexibility for most producers and reduces economic risks (Glen, 2016).

**Forage Nutritive Value**

Amount of forage consumed as well as nutritive value impact livestock performance, and as a result, forage selection is important in ICLSs. Cash et al. (2009) found that winter wheat was an excellent winter forage in Montana due to greater forage yield potential than alfalfa, spring barley, and perennial grasses at low-precipitation rainfed sites (Cash et al., 2007). Winter wheat had well-balanced crude protein and energy for growth rations or winter maintenance diets for pregnant cattle and sheep (Cash...
et al., 2009). Barley is a cool-season annual forage that provided grazing opportunities similar to that of winter wheat (Kelln et al., 2011; McCartney et al., 2004). Low heat unit corn varieties provide grazing opportunities similar to that of winter wheat (Kelln et al., 2009). Barley is a cool-season annual forage that provided similar grazing opportunities. Within ICLSs, producers need to invest time, energy, and effort to learn, apply, and improve management techniques to reduce costs and enhance animal performance.

Grazing intensity needs to consider animal and soil health, resources available, and ICLS management goals. In the NGP, if crop residue grazing intensity averages are greater than 1.2 animals (beef cattle) ha\(^{-1}\) (Asen-Hlabie et al., 2016), excessive forage removal can reduce soil cover and yield of subsequent crops. Ganjegunte et al. (2005) reported that SOC and total N contents at the 0- to 5-cm depth were significantly greater in light grazing (0.16–0.23 steers ha\(^{-1}\), which is 35% lower than the NRCS recommended rate for this area) (SOC-13.8 Mg ha\(^{-1}\); total N-1.22 Mg ha\(^{-1}\)) than heavy grazing (0.56 steers ha\(^{-1}\), which is 33% higher than the NRCS recommended rate) (SOC-10.9 Mg ha\(^{-1}\); total N-0.94 Mg ha\(^{-1}\)) or non-grazing (SOC-10.8 Mg ha\(^{-1}\); total N-0.94 Mg ha\(^{-1}\)) in Wyoming and concluded that the light grazing is the most sustainable grazing management system for that area. Blanco-Canqui et al. (2016a) found that light (2.5 AUM ha\(^{-1}\)) and heavy grazing (5 AUM ha\(^{-1}\)) in western Nebraska resulted in similar losses of sediment C and N. However, the loss of nutrients in runoff under light grazing was lower than heavy grazing. For example, runoff losses of total N, total P, NO\(_3\)\(-\)N, NH\(_4\)\(-\)N, K\(^+\) were 0.81, 0.001, 0.49, 0.001, and 2.05 kg ha\(^{-1}\) under light grazing and 1.06, 0.003, 0.85, 0.003, and 2.90 kg ha\(^{-1}\) under heavy grazing. In Nebraska, Blanco-Canqui et al. (2016b) reported that corn residue cover under the light grazing (~72%) was higher than heavy grazing (~55%), that heavy grazing increased the geometric mean diameter of dry soil aggregates. The concentration of SOC under the light grazing (14.3 g kg\(^{-1}\)) was lower than that under the heavy grazing (14.5 g kg\(^{-1}\)) in fall 2015, but they were not significantly different. Moreover, as grazing duration increases, livestock grazing leads to decreases in forage nutritive value (Klopfenstein et al., 2013), and poorly balanced diets leading to decreasing livestock health, maintenance, and growth (Gerber et al., 2013). In addition to grazing intensity, grazing management in an ICLS needs to follow climatically and seasonally appropriate grazing duration and consider livestock nutritional needs, the existing soil fertility, and needs of the following crop.

**INTEGRATED CROP–LIVESTOCK SYSTEM ECONOMICS**

With globally increasing food production stress and limited productive farmland areas, there is pressure on farmers "to do more with less" and increase input-use efficiency. Unfortunately, most ICLS studies, do not consider changes in input-use efficiency (Duru and Therond, 2015). Greater input-use efficiency can result from (i) the production of more products at less cost per unit; (ii) lower costs for large farms (i.e., economy of scale); and (iii) the diversification of income streams. In the NGP ICLSs, livestock have the potential to convert relatively low-value crops to high-value protein, thereby increasing total farm returns (Anderson and Schatz, 2003). For example, winter feed for maintaining non-lactating pregnant cows is considered to be one of the greatest single costs in beef cattle production (Rasby et al., 1989). There was a significant cost reduction in winter feed when unharvested stockpiled forage and corn stalk residue were grazed during winter period compared to hay feedlots in North Dakota (Karn et al., 2005; Sentürklü and Landblom, 2014). Furthermore, there are
The inclusion of risk in economic calculations provides information on net return stability (Just and Pope, 1979). The importance of risk is related to individual producer attitudes (Coelli et al., 2005). If producers are risk averse, they can reduce the risks by spreading them over multiple enterprises. The reduced risk of crop–livestock systems in marginal crop production areas has long been recognized as a cost recovery mechanism in the event of crop failure (Held and Zink, 1982). Livestock production from ICLSs under good market conditions can produce more income to offset crop income reductions during years when there are poor crop growth or adverse crop markets (Wishart, 2004). Diversification is a regionally recognized agronomic resiliency mechanism to overcome periods of economic or climatic instability (Lawrence et al., 2018), however, the adoption of improved management practices is closely related to economic viability. Crop and livestock insurance and government subsidies may reduce financial risks and improve the economic viability of ICLSs (Motamed et al., 2018). However, crop insurance and government subsidies may discourage farm diversification (Archer et al., 2003) and provide an incentive to plant crops in marginal areas and soils, which may not be agroecologically suitable (Wang et al., 2017).

Some benefits from ICLSs are not directly tied to the income from the products produced. These non-market effects are associated with the ecosystem services such as pollinator habitat, C and nutrient cycling, and wildlife habitat. However, non-market values are difficult to measure, so are not often assessed. Non-market evaluations have indicated that ICLS benefits could be higher if the non-market values are accounted (Ouma et al., 2003). However, while non-market values reflect the value to the common good, they may not produce economic returns. Some examples of incentives include payments for implementation of conservation practices, selling C credits for sequestering C in the soil, or marketing beef produced with ICLSs as a premium labeled product.

![Fig. 4. A flow diagram showing the relationships among the types of integrated crop–livestock system (ICLS) in the northern Great Plains (NGP), benefits to soils, crops, and livestock in ICLS, economics for producers and society, and adoption of ICLSs in this study.](image-url)
EXPERIENCES AND LESSONS IN THE NORTHERN GREAT PLAINS INTEGRATED CROP–LIVESTOCK SYSTEM PRACTICES

The success of NGP enterprises is dependent on many factors including past choices, planning, trade-offs, economic benefits, policies and regulations, local community perceptions (Auger and Haggerty, 2016), and proper management skills. Implementing new management practices such as ICLSs can initially increase day-to-day workloads and require resource investment and in some instances, community acceptance, and support (Kolady, 2017). For example, farmers may be prevented from expanding livestock operations by local community concern about manure management (Ogejo, 2010), even though manure is quickly used by crops and well distributed across fields. In ICLSs, there is typically low stockpiling of manure, often avoiding the need for lagoons or other forms of manure treatment. Another growing concern among NGP rural residents and academia is about mega-farming and farm agroecological sustainability (Laforge et al., 2017). Corporate agriculture is perceived to undercut traditional family farms and rural economies (Roberts, 2017). The result has been rural community animosity toward farm expansion and change. Because ICLSs can be tied to older, more traditional practices; regional producers are often more willing to learn and adopt ICLS practices. It is frequently easier for many regional agronomic producers to accept ICLSs than other proposed management changes. Farming and ranching are a way of life in the NGP which require a lifetime of commitment (Schulz et al., 2017). Therefore, the increasing awareness and impacts to rural residents of agrochemical pollution, manure handling, and other agroecological repercussions of crop and livestock production when combined with rural economic and regulatory trade-offs have polarized many NGP rural communities (Laforge, 2017).

Grazing livestock on land managed by other farmers provides an opportunity for young farmers to enter the profession. Creation of ICLSs sharing resources between established and starting farmers can be mutually beneficial. These partnerships can increase access to land, build cash reserves, and develop and share experience for new producers while supplying the labor, ICLS benefits, and additional revenue to land owners. The ICLSs could become a strategic role in future agronomic production (Asai et al., 2018). Whether more producers make the choice to use ICLSs will likely be closely related to economics, policies, and demonstrated risk reductions (Roese-McNally et al., 2018).

If well implemented, ICLS practices can reduce both risks and costs of agricultural production and benefit soils and the environment at a variety of scales using different resources. An ICLS does not need to be a particular size or technique to improve agroeconomics or agroecologies (Asai et al., 2018). Regionalized adoption of ICLSs often occurs through gradual and sometimes unnoticed shifts toward more adaptive management techniques and resource use efficiency. In this manner, residue grazing has become a well-established technology in the NGP. Partnerships between crop and livestock producers can serve as a low-cost and generally well-accepted gateway to ICLSs for new or established producers. Corn residue grazing could play an important role in increasing global food production because the crop is planted worldwide (FASUSDA, 2018). Winter swath grazing techniques will likely continue in the NGP and spread to other temperate regions due to associated cost reductions. Annual forage grazing (annual forages include some annual cover crops and annual crops such as winter wheat, rye, oat, and barley etc.) is likely to increase and spread as a relay, double, and cash cover cropping is expanded northward. Furthermore, the long-term decline in corn, wheat, and soybean prices with respect to inflation is likely to continue. This, when coupled with climate change exacerbated droughts and loss of irrigation water, will encourage farmers to diversify revenue sources to reduce production costs. In-field grazing can provide a cost-recovery option to obtain revenue from cover crops, especially, during periods with low grain yields, quality, or prices (Kandel, 2017; Lardy, 2017; Schroeder, 2017). Producers have become wary of producing crops which fulfill only one market need, they are more willing to produce crops with multiple uses and markets (Embaye et al., 2018). Producers are likely to look toward sod- and perennial crop-based rotations, which can assist in restoring soil health and fertility, to provide multiple use options (Guillickson, 2015). Many kinds of grass both annual and perennial, (winter wheat, rye, triticale, switchgrass, intermediate wheatgrass (Secale cereale L.),) can be harvested for forage or grain or biofuel feedstock and/or grazed in situ. Agricultural producers are likely to continue to gradually adopt ICLS practices by combining older elements such as in-field bale grazing with newer techniques such as relay cropping. Producers are likely to adopt new techniques which can reduce risk while complying with or gaining from U.S.- and state-level policies, for example, U.S. Farm Bill (it is renewed every 5 yr and the current farm bill is the Agricultural Act of 2014 [U.S. Congress, 2014] and Minnesota Groundwater Protection Rule (MNDCA, 2018).

Producer adoption of ICLSs is a complicated process, and several common lessons in the process of ICLS implementation in the NGP were identified. (i) There is a lack of available land for fertilizer (including manure) management. For example, many NGP soils have low to moderate soil test P levels. In South Dakota, 73% of the soil samples require additional P, whereas, in Wisconsin, only 30% of the samples require P (Fixen et al., 2007). Previous studies have shown that grazing can reduce P level (Cheng et al., 2016; Ebrahimi et al., 2016). Therefore, even with ICLSs, producers need to use soil tests to improve fertilizer management. (ii) The lack of management skills and knowledge of ICLSs could delay producer decisions to practice ICLSs (Dunlap et al., 2000; Krall and Schuman, 1996). Individual and community attitudes toward environmental stewardship and awareness of environmental sustainability affect behaviors of landowners/producers and their production practices (Dunlap et al., 2000). Familiarity and experience with traditional production methods may deter producers from adopting new models (e.g., ICLSs) of agricultural production (Krall and Schuman, 1996). Training to improve the management skills of producers, especially, young farmers and education to foster awareness of environmental issues and improve traditional production methods could be beneficial strategies. (iii) The lack of capital for the greater initial costs and time commitments in ICLSs can increase the difficulties of ICLS adoption. For example, lack of infrastructure (e.g. fence or water) or ownership of land or livestock could result in higher initial ICLS adoption cost than specialized grazing or cropping systems (Krall and Schuman, 1996; Prokopy et al., 2015). It could be expensive to reseed or establish perennial plants in the sod-based crop.
rotations. Capital support from loans or government subsidies could enhance the adoption and implementation of ICLSs in the future. However, not every farm requires both crops and livestock, the producers may have separate enterprises for each enterprise. Livestock operations provide an opportunity for young ranchers to enter farming or for farmers to introduce livestock, but whether the producers make the decision to adopt ICLSs can be a complicated process.

**CONCLUSIONS**

Reviewed literature suggests that ICLS practices in the NGP can positively impact crop production primarily through improved soil properties stemming from diversified ICLS management techniques such as annual crop residue grazing, swath grazing, annual forage grazing, perennial forage crops, and pasture renovations. Moreover, livestock performance in NGP ICLSs is strongly related to the season (winter has the largest cost), forage nutritive value (forage selection is a key), and grazing management by integrating grazing intensity, duration, and animal needs with forage availability. Furthermore, ICLSs can increase economic benefits and reduce total cost and economic risks of producers. Therefore, ICLSs could have a strategic role in the future of agricultural production. Trade-offs, planning, economics, governance, public perceptions, and management skills affect the success of NGP ICLSs. Lack of available land for fertilizer (manure) management, skills and knowledge of ICLSs, and capital can affect regional ICLS adoption. These ICLS experiences and lessons could be a valuable reference for producers in the NGP or other regions.

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