AGRONOMIC ASSESSMENT OF GRAZING METHOD OF CORN RESIDUES ON COW PERFORMANCE, RESIDUE UTILIZATION, CROP YIELD, AND SOIL PROPERTIES

BY

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THESIS

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ABSTRACT

The objectives were to evaluate the effects of beef cows grazing corn residues on cow performance, residue utilization, subsequent crop yield, and soil physical and chemical properties. Two grazing methods (strip grazing, **(SG)** and continuous grazing, **(CG)**) and a control (ungrazed, **(CT)**) were arranged in a randomized complete block design with 3 replications each yr for 3 yr. Within SG, subplots were assigned with a grazing order **(1, 2, 3)**. Thirty-six spring-calving, multiparous, Angus cows were utilized in yr 1 (BW = 648 ± 41 kg) and 2 (BW = 710 ± 71 kg) at a stocking density of 3.0 cows·ha^{-1}, and 42 winter-calving Angus heifers (BW = 566 ± 39 kg) were utilized in yr 3 at a stocking density of 3.6 heifers·ha^{-1}. Cattle grazed for 42 d beginning on 29 Sept. 2012 (yr 1), 2 Nov. 2013 (yr 2), and 4 Oct. 2014 (yr 3). Residue samples were collected on d 14 and d 28 of grazing and after grazing in yr 1, and before and after grazing in yr 2. Soil samples were collected before and after cattle grazing in yr 1 and 2. Paddock dimensions were marked during yr 1 with GPS coordinates so that the same treatment was applied to the same paddock area and location each yr. Cows within the SG treatment were heavier ($P = 0.04$) after grazing and had an increase ($P = 0.04$) in body weight change compared to CG. At d 28 in yr 1, SG residue had decreased ($P < 0.01$) acid detergent fiber and tended ($P = 0.08$) to have increased organic matter compared to CG. At the conclusion of grazing, SG had decreased ($P = 0.02$) neutral detergent fiber compared to CG. Within SG in yr 2, strip 3 tended to have increased ($P = 0.10$) total residue available compared to strips 1 and 2 after grazing. Strip 1 had increased ($P = 0.02$) acid detergent fiber and tended ($P = 0.09$) to have decreased crude protein compared to strips 2 and 3. No differences ($P = 0.19$) were detected between treatments for subsequent corn yield following two grazing seasons. However, within SG, the first strip tended ($P = 0.10$) to have reduced yields compared to the second strip, with the third strip being intermediate. Soil bulk density was increased ($P < 0.01$) in both grazing treatments compared to CT, but penetration resistance was not affected (P = 0.56) by treatment. Water aggregate stability was decreased (P = 0.01) in CG and SG compared to CT. Soil nitrate was increased (P = 0.03) in CG compared to SG, with CT being intermediate. Soil ammonium was not affected (P = 0.14) by grazing treatment. Soil pH was increased (P < 0.01) in SG compared to CG and CT. Grazing order in SG did not affect ($P \geq 0.25$) soil physical or chemical properties. Strip grazing corn residues increased cow performance. Grazing residue did not affect subsequent crop performance, yet the effects that strip grazing has on crop performance need to be further investigated. Although livestock grazing increased soil compaction, root restricting levels of compaction were not reached. Results indicate that cattle and crops can be integrated with the grazing of corn residue, resulting in minimal effects on soil properties and subsequent crop yield.

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CHAPTER 1

LITERATURE REVIEW

Introduction

The United States agriculture industry has dramatically changed since the early 20th century, as larger, more specialized farms have replaced the smaller scaled, more diversified operations that once employed nearly half of the U.S. workforce (Dimitri et al., 2005). Although grain and livestock segments have become vastly different over this time, these two segments of the industry can be very complimentary.

Within the beef industry, costs associated with feeding the cow herd account for 63% of total annual cow costs (Miller et al., 2001). In the Midwest, winter months are the leading contributor to feed inputs, when pasture growth is halted and harvested feeds are often utilized. However, forage prices have doubled since 2001 (National Agricultural Statistics Service, 2015), making the traditional method of feeding harvested forage costly during this time.

With the integration of grain and beef enterprises, producers have the opportunity to use corn (*Zea mays* L.) residue for a fall or winter forage source for the cow herd, thus lowering the amounts and costs of inputs. Grazing residue is a means of replacing other fall or winter feeding strategies that are more expensive, such as feeding hay (Klopfenstein et al., 1987).

More than twenty-four million total hectares of corn have been harvested in Illinois from 2010-2014 (National Agricultural Statistics Service, 2015), making corn residues plentiful throughout the state. During this time, the average state yield for corn has been 10,022 $kg \cdot ha^{-1}$ (National Agricultural Statistics Service, 2015), meaning corn residue may provide up to 1400 $kg \cdot ha^{-1}$ of forage at a 50% utilization rate of leaves and husks (Stockton et al., UNL Corn Stalk Grazing Cow-Q-Lator, 2013). Although beef producers can use many other forages to graze late in the season, nearly all costs associated with the production of corn residues are accounted for by the grain segment of the operation, minimizing the forage production expense toward the beef segment (Samples and McCutcheon, 2002).

Livestock grazing, however, comes with risks toward the overall system. An individual cow grazing residue can induce as much ground pressure on the soil surface as farm implements (Greenwood et al., 1997). Soil compaction, or soil structure degradation, results from decreased porosity and increased soil bulk density. Applied loads to the soil by cattle or wheel traffic from heavy machinery could affect physical, chemical, and biological properties of the soil (Whalley et al., 1995), potentially leading to decreased soil and subsequent crop productivity. Cattle trafficking has shown to increase soil strength, penetration resistance, bulk density, and surface roughness, while precipitation combined with above freezing temperatures during grazing may magnify these concerns (Clark et al., 2004). However, some studies suggest that minimal, if any, subsequent year crop yield differences have been attributed to livestock grazing corn residue (Drewnoski et al., 2015). Soil disturbance can also be minimized if cattle graze when the soil is frozen, or if spring tillage is used to offset these perceived risks (Clark et al., 2004).

Winter Feed Alternatives

Feed accounts for a major expense in beef production (Miller et al., 2001). Purchasing hay has to led to costs of $\$150 \cdot ton^{-1}$ in the last 5 yr (National Agricultural Statistics Service, 2015). Producers who have the ability to bale their own hay must also consider hidden costs, such as nutrient removal, as hay has a fertilizer value of $\$55 \cdot ton^{-1}$ (Meteer, 2014). Miller et al. (2007) also reported that *ad lib* feeding of hay can lead to 40% waste. Collectively, traditional hay feeding can surpass costs of $\$2.80 \cdot hd^{-1} \cdot d^{-1}$ (Braungardt et al., 2010). Alternative wintering methods for beef cows besides feeding hay must be evaluated to decrease producer feed input costs.

Braungardt et al. (2010) compared feeding alfalfa mixed hay to corn residue bales supplemented with corn co-products in an effort to identify lower cost winter cow rations and their effects on cow performance. Spring calving, lactating Angus and Simmental cows were utilized in two experiments. In both experiments, cows fed free-choice hay lost more body weight (BW) (30 vs. 11 kg) than cows fed corn residue bales supplemented with dried distillers grains with solubles (DDGS). Offering free-choice access to hay also resulted in increased costs compared to corn residue and DDGS diets in experiment 2 ($2.50 vs. $1.44·hd^{-1}·d^{-1}). Feeding a low quality roughage and DDGS proved to be an economical alternative to the traditional wintering method of offering free-choice hay.

Although corn residue is plentiful in the Midwest, and mechanically harvesting this residue may be a lower cost option for wintering beef cows compared to hay, substantial inputs are still necessary in the harvesting and feeding procedures. Therefore, allowing cattle to graze and harvest this forage themselves should be an economical alternative. Extending the grazing season can increase profitability for cow/calf producers and lessen the dependency on stored feeds of any kind through the winter months when compared to feeding cows in a dry lot (D'Souza et al., 1990). D’Souza et al. (1990) concluded that lengthening the grazing season for cow/calf enterprises decreases the costly inputs of machinery. Production costs become detrimental to profitability when considering hay spoilage along with the costs and labor associated with hay baling. Equipment investments are further reduced with grazing by eliminating the need for manure removal and handling, as well as feeding equipment. These expenses of baling, storing, and feeding should be considered with baled corn residue as well as hay. Therefore, the most economical and lowest cost utilization of residue from corn production is the allowance of livestock grazing (Klopfenstein et al., 1987).

Janovick et al. (2004) evaluated hay needs and animal production in a year-round (YR) grazing system compared to a conventional, minimal land (ML) system, hypothesizing that extending the grazing season would decrease hay needs without penalizing animal production. April and August calving beef cows were used for this 3-yr experiment in the Midwest. In the YR grazing system, corn crop residues replaced hay feeding for April calving cows after the conclusion of summer grazing cool season grass and legume pastures. Residue grazing for April calving YR cows was initiated on November 11th, October 28th, and October 18th, respectively. Dry lot hay feeding was initiated on the same dates for April calving ML cows. Body condition score (BCS) did not differ in any month between ML and YR April calving cows. Cows in the ML system had greater BW in the month of March compared to both April and August calving cows grazing stockpiled forage. Cows in the ML system had greater BW than April cows in the YR system at breeding, and both April and August calving cows in the YR grazing system at weaning, but rebreeding rates did not differ. April and August calving cows in the YR grazing system required 1701 kg dry matter (DM)·cow^{-1} less hay per yr. Therefore, replacing hay with both corn residue and stockpiled forage may be a feasible option for lowering costs associated with winter feeding.

Hitz and Russell (1998) reported on potential stored feed savings when utilizing fall grazing strategies of either stockpiled cool season grasses and legumes or corn residues. These authors used mature medium-framed Simmental × Angus × Jersey cows in a 3-yr experiment to compare grazing to dry lot feeding. Cattle grazing corn residues required 627 kg DM·cow^{-1} less stored hay, while still maintaining equal BW and energy reserves to dry lot fed cattle, showing that using corn residues to extend the grazing season and reduce dependency on stored feeds is feasible in the upper Midwest. Corn residue offered more forage yield than stockpiled cool-season forages in this study, although both are low cost alternatives compared to traditional winter feeding strategies.

Adams et al. (1994) tested grazing systems in the Nebraska sandhills and their effects on economic returns for cow/calf operations. Three treatments were used throughout the winter: 1) grazing winter range; 2) grazing subirrigated meadow; and 3) *ad lib* meadow hay. Multiparous cows were used (n = 240) for 4 yr. Hay fed to cows ranged from 3220 $kg \cdot cow^{-1}$ for cows fed *ad lib* hay throughout the winter, to 1188 $kg \cdot cow^{-1}$ for cows grazing winter range or meadow throughout the winter months. Performance variables were insignificant between winter treatments. Therefore, returns for cow/calf producers were improved by winter grazing, opposed to feeding hay.

Winter annuals and cereal grains are another option for fall and winter grazing of cattle. Introducing these forages into land used for crop production in the Midwest allows for a grazing crop in between growing seasons of the cash crop. When seeded late in the summer, cereal rye (*Secale cereale L.*) and triticale (*x Triticosecale* Wittmack) can be grazed in the fall and provide early growth in the following spring to meet hay or grazing needs (McCartney et al., 2008). Winter wheat also offers potential for late grazing of beef cattle, as well as providing a cash crop for the producer the following yr (Redmon et al., 1995). Although DM yield of these forages are largely dependent on moisture, they often provide greater levels of both protein and energy compared to grazing dormant forages, such as stockpiled fescue or corn residue.

Brassica crops also have potential for livestock grazing in the fall and winter months. Turnips have been reported to be fairly frost tolerant, surviving temperatures as low as -9°C (Bartholomew and Underwood, 2002). In Canada, Johnston et al. (2000a) grazed turnips with ewes for 42 to 58 d with BW gains of up to 166 $kg \cdot ha^{-1}$. In Wyoming, brassicas planted after a primary crop yielded over 2000 $kg \cdot ha^{-1}$ in all yr but one from 1986 to 1996 (Koch et al., 2002). Lambs grazing these brassicas (turnip, tyfon, rape, and radish) gained 0.18 $kg \cdot d^{-1}$. Utilization rates of up to 90% have been reported for turnips when grazed by sheep (Koch et al., 2002). High organic matter (OM) digestibility (85-92%) and crude protein (CP) (7.0-28.0%) have also been reported, suggesting brassicas may offer a high quality diet for livestock late in the grazing season (Kunelius et al., 1987; Yun et al., 1999; Jung et al., 1988).

There are many management options for producers in the Midwest wanting to lengthen the grazing season and decrease dry lot periods for beef cattle. Within the reported systems, allowing cows to harvest forage themselves instead of using mechanical power to harvest and provide feed through the winter months yielded lower input costs and increased profits.

Corn Residue Nutritive Quality, Disappearance, and Selectivity

Although corn residue is a mature, low quality forage, ruminants have the ability to break down and utilize these cellulose-rich, high fiber feedstuffs for nutrients (Oltjen and Beckett, 1996). This concept allows humans to better utilize rangelands that are unsuitable for row crop production, or utilize low quality, high fiber crop residues in cattle diets to yield animal products for human consumption.

Corn residue nutritive quality, utilization, and cattle grazing selectivity are dependent factors that dictate the potential length of corn residue grazing and animal performance. Livestock select the more digestible plant components first, leading to eventual decreased diet quality (Fernandez-Rivera and Klopfenstein, 1989a; Lamm and Ward, 1981). Residual grain is initially selected by grazing cattle, followed by husks and leaves (Fernandez-Rivera and Klopfenstein, 1989a; Gutierrez-Ornelas and Klopfenstein, 1991). Increased forage utilization by decreasing animal selectivity will also result in decreased nutritive quality of corn residue (Fernandez-Rivera and Klopfenstein, 1989a).

Fernandez-Rivera and Klopfenstein (1989b) conducted three grazing experiments in three consecutive yr to evaluate yield, plant part composition, and nutritive quality of corn residue, as well as forage utilization of these residues when grazed by Charolais × Angus calves. Grazing began on November 2nd, 10th, and 5th, respectively, and continued for 53, 54, and 58 d. In experiment 1, two replicates of three treatments used 60 steer and heifer calves (10 calves per pen). Calves (239 ± 30 kg BW) were grazed at either 2.47 calves·ha^{-1} on irrigated fields, or on dryland fields at stocking rates of 1.54 or 2.47 calves·ha^{-1}. In experiment 2, two treatments were investigated, dryland vs. irrigated fields, with four replicates per treatment. Equal grazing pressure of 2369 kg DM total residue·hd^{-1} between treatments was maintained by using either 8 (irrigated fields) or 11 (dryland fields) calves (272 ± 24 kg BW). In experiment 3, eighty-one calves (246 ± 20 kg BW) grazed on irrigated and dryland fields at differing stocking rates. Across all yr, grain:residue yield was similar, therefore grain yield may be used for estimating residue availability and yield. Fernandez-Rivera and Klopfenstein (1989a) constructed equations for estimating forage yields via grain yields above and below 4686 kg·ha^{-1}. Dryland residues had a lower proportion of stalk and a greater proportion of leaf and husk when compared to residues of irrigated fields. However, the authors note that total amount of leaf and husk available is more important because of animal selectivity. Daily utilization rates of 20.4 ± 4.6 kg DM·ha^{-1} were estimated. Leaf and husk components accounted for 69% of this amount. In experiment 2, 65-72% of DM utilized was leaf and husk components. Therefore, leaf and husk plant components are utilized in the greatest amounts. Total DM utilized throughout the grazing period of experiment 1 for dryland fields grazed at 1.54 calves·ha^{-1} and dryland and irrigated fields grazed at 2.47 calves·ha^{-1} were 32, 47, and 18%, respectively. Leaf and husk utilization was 37, 53, and 32%, respectively. Grain was completely utilized; however, stem components were not utilized. In the dryland and irrigated fields in experiment 2, 36 and 45% of total residue was utilized and 56 and 67% of leaf and husk were utilized, respectively. Corn residue yield can be predicted by grain yield; yet, grain yield and forage quality and can be negatively correlated. Leaf and husk portions are the plant components most utilized by grazing cattle.

Fernandez-Rivera and Klopfenstein (1989a) also studied diet composition and daily weight gain when dryland and irrigated corn residues were grazed by growing cattle at different stocking rates. Authors conducted this experiment to study the diet composition and growth rate of cattle grazing corn residue, but also to evaluate the relationship between weight gain and characteristics of residue availability. Minimal documentation on whether residue quality and quantity due to irrigation or stocking rate had been performed until this point. In experiment 1, sixty Charolais crossbred calves were allotted to six cornstalk fields, representing 3 treatments; dryland fields grazed at either 1.54 or 2.47 calves·ha^{-1}, and irrigated fields grazed at a stocking rate of 2.47 calves·ha^{-1}. Grazing started on November 2nd, 1984, and lasted 53 d. Calves were supplemented 0.454 kg of a 50% CP supplement daily, meeting NRC requirements for calves gaining 0.6 kg·d^{-1}. In experiment 2, 81 Charolais × Angus calves were used for six treatments; dryland stalks grazed at 1.24, 1.86, and 2.47 calves·ha^{-1} for 58 d and at 3.58 calves·ha^{-1} for 44 d, and irrigated cornstalks grazed at stocking rates of 2.47 and 4.69 calves·ha^{-1} for 58 d. For experiment 2, grazing began on November 5th, 1986. Calves were supplemented with 0.807 kg of a 56.8% CP supplement daily. Diet composition for both experiments were determined from extrusa samples via esophageally fistulated calves. In experiment 1, extrusa CP content was greater than CP content of the available residue, accounting for selection of plant parts with increased CP. Diet CP continued to decrease the first 4-5 weeks of grazing but then remained relatively constant. In experiment 2, CP content of the diet decreased linearly with time. Starch content in the diet decreased with time, and neutral detergent fiber (NDF) content increased as grazing continued, suggesting that initial grain consumed was being replaced by forage plant components. In vitro dry matter disappearance decreased 0.6 percentage units per d of grazing in experiment 1. However, no differences in in vitro dry matter digestibility (IVDMD) were detected between treatments. In experiment 2, roughage component digestibility values were greater, suggesting that early in the grazing season the plant component consumed the most was primarily husk. Roughage digestibility decreased with time. Daily gain was positively correlated with CP of leaf and husk of the extrusa (r= 0.80 and 0.94, respectively). Gain was not correlated with available grain or with extrusa IVDMD (r = 21 and -0.08, respectively). Therefore, authors concluded that protein intake was the most limiting during trail 1, when CP was supplemented at 0.454 $kg \cdot hd^{-1}$ daily. However, when CP was supplemented at 0.807 $kg \cdot hd^{-1}$ daily in experiment 2, daily gain was positively correlated with leaf and husk availability. Daily gain was not correlated with IVDMD of either the whole diet or the roughage fraction. However, diet digestibility late in the grazing experiment was positively correlated (r = 0.84) with daily gain for the entire experiment. In experiment 2, authors suggested that energy was the first limiting nutrient. Authors further concluded that grain and husk were selected initially in the grazing season, but the energy value of the selected diet dramatically decreases as the time of grazing increases. Complex interactions between requirements for protein and energy intake occur for growing calves grazing corn residue. Protein is the first limiting nutrient when grazing corn residue with growing calves, yet husk and leaf availability and energy values of diet consumption will become limiting when increased levels of protein are supplemented.

Gutierrez-Ornelas and Klopfenstein (1991) evaluated the changes in availability and nutritive value of corn residue components when grazed early (EG) or late (LG) in the corn residue grazing season. Four grazing experiments in 2 yr (1987 and 1988) utilized 224 calves. During experiment 1, 64 steers (239 kg average BW) grazed from October 30th to December 31st at a stocking rate of 2.2 steers·ha^{-1}. Steers were supplemented with 0.8 kg·hd^{-1} of a 50% CP supplement. Residue samples were collected 7 d before grazing, as well as 36 and 64 d after the start of grazing. During experiment 2, (second EG experiment) 64 steers (219 kg average BW) grazed from October 19th to December 23rd. Stocking rates were 3.96 and 1.97 steers·ha^{-1} for irrigated (IF) or nonirrigated (NIF) fields, respectively, because of residue availability differences between IF and NIF. Steers were supplemented similarly to experiment 1, and residue samples were collected at 0, 33, and 66 d after the start of grazing. Experiment 3 used 32 Hereford × Angus heifers (204 kg average BW) to graze at a stocking rate of 1.36 heifers·ha^{-1} from December 3rd to March 4th. Heifers were supplemented with 17.6% CP alfalfa hay at a rate of 2.7 kg·hd^{-1}. Residue samples were collected 0, 44, and 93 d from the start of grazing. Experiment 4 utilized 64 steers (257 kg average BW) from December 28th to March 1st at a stocking rate of 2.58 steers·ha^{-1}. All steers received 0.8 kg·d^{-1} of a protein supplement, as well as alfalfa hay at 1.86 or 2.27 kg·hd^{-1}·d^{-1}. Residue collection took place -30, 0, 34, and 57 d from the start of grazing. Husk availability was very consistent in NIF. However, leaf blade and grain availability were highly variable, potentially due to weather conditions after harvest. Greater amounts of leaf blade disappearance in EG experiments 1 and 2 could be explained by weathering, as experiment 4 leaf blade availability was reduced from 868 to 504 kg·ha^{-1} during the 30 d period before grazing. Residue:harvested grain ratios ranged from 0.60 to 0.78. Grain left in the field after harvest varied from 2 to 8.2%, but a close relationship (R^2 = 0.97) was found for these experiments between husk and grain yield. The prediction equation from the authors was: residual husk = 193.12 + 0.0531(grain yield). Husks disappeared faster than leaf blades and leaf sheaths. Leaf sheaths and stems did not disappear, suggesting that residue disappearance can be better described when husk, leaf blade, and leaf sheaths are considered separately. Greater than 90% of the grain disappeared from the fields during grazing. Grain disappearance was 88.4% after 36 d of grazing, opposed to 33.4% of leaf blades and 39.7% of husks by d 36 of experiment 1. Low disappearance of stem and sheath were noted in experiments 2 and 4, implying that these components were not well utilized by the grazing calves. Grain was the greatest quality plant component. The amount of CP and escape protein (EP) decreased and acid detergent insoluble nitrogen (ADIN) increased in both husk and leaf samples as the grazing season continued. Stem and sheath components had similar CP to leaf blades and husks, but lower EP. However, husks had the greatest IVDMD (61-72%) of all the roughage components. Cobs had the lowest CP. Husk digestibility was reduced, and acid detergent fiber (ADF) and NDF both increased as the grazing season progressed. The authors conclude that residual grain left in the field was the most important source of protein for calves grazing residue. However, disappearance of the grain was rapid; therefore, protein supplementation may be required as the grazing season progresses. Nutritive value of grain, husks, and leaves should determine animal performance, as grain, husk, and leaf components have the greatest disappearance. Husks were the roughage fraction with greatest digestibility after residual corn was consumed.

Lamm and Ward (1981) looked into the compositional changes in corn crop residues when grazed by mature beef cows. A single 48.6 ha field was divided into six 8.1 ha paddocks, each grazed by 10 Hereford × Angus cows (454 kg average BW). Following grain harvest on October 8th, grazing began on October 23rd, and was terminated on January 17th; therefore, cows grazed for a total of 86 d. Cows were fed protein supplements daily throughout the study, as well as corn stalk stacks when snow prohibited grazing. Before grazing, sample enclosures were fenced within each paddock to eliminate grazing. This allowed for a grazed and ungrazed residue sample to be collected both before and after grazing. Final residue samples were collected on March 22nd, because snow limited sampling at the completion of grazing. Samples were sorted by plant component, including residual grain, stalks, leaves and husks, and cobs. Comparisons of the pre and post-grazing residue samples showed that considerable selective grazing had occurred. Grain composed only 1.4% of the total sample DM after grazing, compared to 11.2% before grazing. Leaves and husks decreased by 30.6%, while stalks and cobs increased by 54.8 and 13.1%, respectively. Authors noted that grain yield from fall harvest was below average (5037 $kg \cdot ha^{-1}$) and observed that a considerable amount of grain was left on the ground. Cows were able to selectively consume grain, leaves and husks, cobs, and stalks in order. In the ungrazed enclosures, approximately half of the grain and leaves/husks had disappeared, while nearly two-thirds of the cobs and stalks still remained. This change in the ungrazed enclosures was attributed to both deterioration and wind loss during the grazing season. In the first residue collection, grain was greater in CP and in vitro organic matter digestibility (IVOMD) than any other plant parts (12.6 and 95.2%, respectively). Leaves and husks were more digestible than cobs or stalks and were 7.3% CP. Stalks had less hemicellulose than cobs or leaves and husks, and more cellulose (43.7 vs. 34.7 and 34.5%). For the post grazing residue collection, grain was still greater in CP and IVOMD than any other plant parts. Leaf and husk IVOMD was 38% lower than the corresponding value before grazing, but still remained greater in CP compared to cobs and stalks. Spring harvested cobs and leaves/husks were greater in acid detergent lignin (ADL) compared to pre-grazing. Percentages of NDF and ADF also increased in all plant parts, except stalks, which remained similar for ADF. When pooling data for all plant parts within sampling time, residue in the fall had greater CP and IVOMD values of 8.8 and 72.0%, respectively, while spring residue had values of 8.2 and 59.2%, showing the decline in residue nutritive quality as the grazing season progresses.

Russell et al. (1993) showed that weather can also play a key role in residue grazing performance. In a 3-yr corn residue grazing experiment, heavy precipitation followed by warmer temperatures in yr 3 led to lower nutritive quality corn residue. Cows had lower weight gains in yr 3 compared to yr 1 and 2 due to these inclement weather conditions.

Grazing Management

Implicating management strategies in corn residue grazing may prove profitable for producers wanting to maximize harvest efficiency or lengthen the grazing season. Traditionally, continuous grazing of corn residues has been the easiest and cheapest method for utilization. Producers with large field capacities for grazing may prefer this less intensive management plan. However, forage and land availability is poorly controlled without the regulation of stocking rate or grazing management, as an abundance of forage early in the grazing season leads to wasted or trampled feed that is not available later in the season. Strip grazing corn residue allows cattle access to a fresh allotment of forage on a regular basis. By limiting access to only small portions of a field at a given time, a greater nutritive quality, more uniform diet can be expected throughout the season, as cattle are forced to consume more forage early on (Wilson, 2009). Controlling corn residue grazing can also counterbalance several concerns with grazing. For example, overconsumption of residual grain can result in acidosis, founder, and poor performance in beef cattle (Goad et al., 1998), and is more likely to occur in a continuous grazing system. In addition, the selectivity of grazing cattle leads to declined diet quality as grazing continues (Fernandez-Rivera and Klopfenstein, 1989a). In the Midwest, this decline occurs as temperatures fall and spring calving cows have increased nutrient requirements further into gestation (NRC, 1996). These issues, combined with decreased hoof trample may make controlled grazing or increased stocking rates advantageous.

The concept of controlled grazing has been evaluated in more depth with stockpiled tall fescue relative to corn residue. Research has shown that continuous grazing of stockpiled tall fescue can result in more rapid declining forage quality and poorer forage utilization (Poore et al., 2000). Stockpiled forage has been shown to be better utilized by restricting access with strip grazing (Rayburn and Abaye, 2007) or increased stocking rate, proving this management scheme works when grazing mature, dormant forages. Providing only what the herd will consume in a small amount of time can reduce wasted forage, as more will be consumed with decreased animal selectivity. When cattle are allowed access to large amounts of stockpiled forage, increased animal selectivity leads to more trafficking, resulting in much of the forage being trampled into the ground. Wet weather will cause trampling effects to be even greater, resulting in more unutilized forage. Strip grazing stockpiled tall fescue can allow producers to increase stocking densities and in result, increase pasture utilization and cow/calf performance per hectare.

Curtis et al. (2008) evaluated the effect of different forage allocations on the performance of fall calving cow/calf pairs grazing stockpiled tall fescue. Treatments in this study included forage allocations of 2.25, 3.00, 3.75, and 4.50% of cow/calf pair $BW \cdot d^{-1}$. Pairs grazing at high forage allocation (4.50%) had 31% greater dry matter intake (DMI) than those grazing at low forage allocation (2.25%). However, pasture utilization decreased as allocation of forage increased (59 vs. 85%). Calf gain increased linearly with forage allocation, but gain per hectare of pasture decreased linearly as forage allocation increased. When considering gain per hectare, pairs grazing at a high forage allocation gained nearly 40% less compared to low forage allocation pairs. Strip grazing corn residue, like tall fescue, should increase forage utilization and decrease selectivity of grazing cattle.

In Delaware, Jones et al. (1998) showed that strip grazing stockpiled fescue increased animal grazing d by nearly 75%, from 262 to 452 $d \cdot ha^{-1}$, opposed to continuous grazing. Gerrish (1996) also suggested that intensifying strip grazing increased animal grazing d by 40% when animals were allowed access to new stockpiled forage every three d opposed to every two weeks.

Russell et al. (1993) evaluated the effects of grazing allowance and method on residue removal and performance of beef cows grazing corn crop residues for three consecutive yr, starting in 1988. Grain harvest took place on September 10th, October 9th, and October 15th. Grazing was initiated 28, 10, and 16 d after grain harvest, respectively, and continued for 56 d for yr 1 and 2, and 51 d for yr 3. In yr 1 and 2, experiments took place under relatively dry conditions. However, heavy precipitation occurred during yr 3. Mean temperatures in yr 2 and 3 were considerably cooler compared to yr 1. Grazing allowances of 0.41, 0.82, and 1.64 $ha \cdot cow^{-1}$ were evaluated in a continuous grazing system in all 3 yr. A strip grazing system was also tested in yr 2 and 3 at a grazing density of 0.41 $ha \cdot cow^{-1}$. Strip-grazed fields were divided into four equal areas via electric fence. Cows in this system were allowed access to previously ungrazed residues every two weeks. Grazing allowances of 1.64 $ha \cdot cow^{-1}$ had greater BW gains compared to those grazing at lesser allowances. Increased gains by cows grazing at the greatest grazing allowance were related directly to residue intake. Cows grazing in the strip stocking system tended to have greater BW gains than cows in the continuous grazing system in yr 3, but no other differences were detected between grazing methods. This difference indicates the weather dependency of the strip stocking system. Minimal documentation on the effects of strip grazing corn residue have been reported.

Although strip grazing is a more intensified grazing strategy that limits the amount of available forage to cattle, increasing stocking rates in a continuous system can yield similar results, as more cattle compete for available nutrients. Fernandez-Rivera and Klopfenstein (1989a) tested several different stocking rates when grazing calves. In experiment 1, calves were grazed at either 2.47 calves·ha^{-1} on irrigated fields, or on dryland fields at stocking rates of 1.54 or 2.47 calves·ha^{-1}. In experiment two, dryland and irrigated fields were grazed at 2.07 or 3.56 calves·ha^{-1}, respectively. In experiment 3, dryland fields were grazed at stocking rates of 1.24, 1.86, or 2.47 calves·ha^{-1}, and irrigated fields were grazed at 2.47 or 4.69 calves·ha^{-1}. In experiment 1, dryland fields grazed at increased capacities (2.47 vs. 1.54 calves·ha^{-1}) tended to have greater utilization rates. Utilization was also greater for irrigated fields compared to dryland fields, possibly due to increased stocking rates resulting in greater residue consumption and increased trampling losses. Authors concluded that residue utilization increased with stocking rate. Increasing stocking rates increased the drop in IVDMD of leaf and husk components, possibly due to animal selection for more digestible forage components.

Increasing stocking rates may also lead to decreased diet quality. Fernandez-Rivera and Klopfenstein (1989b) showed that calves grazing at greater stocking rates had diets lower in CP, as well as decreased roughage digestibility and starch content as grazing progressed. Therefore, calves grazing at a lower stocking rate tended to gain faster (0.61 vs. 0.56 kg·d^{-1}). Increased stocking rates increased competition for the greatest quality components of the diet, resulting in lower quality components being a larger portion of the diet later in the grazing period. Total calf gain per hectare was not analyzed in this experiment. However, this also reiterates that grazing cattle at increased stocking rates increases the competition for residual corn, potentially decreasing rumen health issues. Because all residue is available and at the greatest quality when grazing is initiated, increased stocking rates should lead to increased utilization when residue is at the greatest nutritive quality. Controlled grazing should allow corn residue to maintain forage quality longer in the grazing season.

Nutritional Considerations for Corn Residue Grazing

Corn residues are only available for utilization after the plant has reached physiological maturity. Therefore, protein content and digestibility is typically low, potentially warranting supplementation. Furthermore, improvements in harvesting efficiency and decreased stalk lodging of corn over the last several decades may reduce the amount of available corn that is left in the field for cattle consumption, leading to a lower quality diet when grazing residue. Diet quality declines later in the grazing season, when animals have previously selected residual grain and the most nutritious forage components (Fernandez-Rivera and Klopfenstein, 1989a). Protein supplementation can increase OM intake and OM and NDF digestibility, resulting in improved BW and BCS when cows are consuming a low quality roughage (Sletmoen-Olson et al., 2000). However, results on performance of cattle being supplemented protein while grazing corn residue is mixed (Ward, 1978; Larson et al., 2009). Therefore, many factors effecting residue quality from yr to yr and site to site may contribute to supplementation needs and strategies. Additionally, the stage of production and class of cattle grazing residue will determine proper supplementation strategies to maximize production.

Throughout the production yr, nutritional requirements of the mature beef cow varies. For example, a 533 kg mature cow with 8 kg peak milk production has a maintenance requirement of 8.87 $Mcal \cdot d^{-1}$ and 436 $g \cdot d^{-1}$ metabolizeable protein (MP) while not lactating and in midgestation

(NRC, 1996). During the fall, requirements are low for spring calving cows, as their calves have typically been weaned and pregnancy requirements in the second trimester are low. This progression is complimentary to the corn production cycle, as fields are harvested in the fall, and residues become available for grazing immediately. Corn residue nutritive values when grazed are 1.50 Mcal·kg^{-1} NE_{ma} and 6.5% CP (NRC, 1996), exceeding maintenance requirements for spring calving cows at the start of grazing. However, if corn residue is used for grazing immediately after corn harvest for fall calving cows, supplementation is necessary. The same 533 kg mature cow with 8 kg peak milk production requires 15.99 Mcal·d^{-1} and 840 g·d^{-1} MP during peak lactation. Milk production, mature cow size, breed, and temperature can all affect nutritional requirements for beef cows grazing residue.

Ward (1978) noted that dry cows may show little response to protein supplementation early in the grazing season. However, as time elapses and forage quality declines, research indicated that cows fed 0.23 kg·d^{-1} of CP from soybean meal resulted in an increase in weight gain, and nonprotein nitrogen supplementation did not result in as much gain as protein from natural sources. Fernandez-Rivera and Klopfenstein (1989b) concluded that protein was the first limiting nutrient when calves grazed corn residue, resulting in the need for protein supplementation as the diet decreases in CP over time. Similar protein supplementation strategies were noted by Gutierrez-Ornelas and Klopfenstein (1991). When increased levels of protein were fed, Fernandez-Rivera and Klopfenstein (1989b) noted that calf gain may be maximized with supplementing energy, as protein requirements are met.

Warner et al. (2011) conducted a 5-yr study to evaluate if protein supplementation to cows grazing corn residue had effects on cow performance. Simmental × Angus crossbred, multiparous, spring calving cows (n = 832) were randomly assigned to 1 of 2 treatments: 1) supplemented with a 24% CP range cube (SUPP), or 2) not supplemented (CON). Changes in BW and BCS were measured 3 times annually (October, February, and May) to predict nutritional status. These times represented corn residue grazing initial BW/weaning, end of residue grazing/pre-calving, and pre-breeding, respectively. Corn eardrop was estimated each yr, averaging 11.2 kg·ha^{-1} across all yr. Grazing began the first week of November and concluded the first week of February. Supplemented cows began receiving 1 kg·hd^{-1}·d^{-1} supplement 20 d after the initiation of grazing (November 1st) until the end of corn residue grazing (February 1st). Cow BW was not different at the start and end of grazing, or at the start of breeding. However, BCS was greater for SUPP cows at the end of residue grazing. This difference (5.6 vs. 5.4 BCS) is small, and likely has no biological difference, although a numerical, non-significant BW increase of 11 kg was also reported for SUPP cows at this time. Even though corn residue is normally low in CP, mid and late gestation cows may be able to meet their relatively low nutritional requirements if they have the opportunity to selectively graze plant components with increased nutritive quality. Warner et al. (2011) concluded that protein supplementation is not necessary for mid to late gestation cows grazing corn residue, if they begin the grazing period above a BCS 5.

Cow supplementation, along with winter grazing system, was also evaluated by Larson et al. (2009) in a 2x2 factorial. Authors grazed Red Angus × Simmental, (n = 109) spring-calving cows (498 ± 15 kg initial BW) in a 3-yr study in which cows grazed either winter range (WR) or corn residue (CR) and received a protein supplement (PS) or received no supplement (NS). Supplemented cows received 0.45 kg·d^{-1} of a 28% CP supplement from December 1st to February 25th. Diet nutrient composition was evaluated using esophageally fistulated cows. Cows were assigned to their respective winter grazing system from November to March (start of calving). Body weight and BCS were recorded each yr at pre-calving, pre-breeding, and weaning. Supplement costs were approximately $32·cow^{-1}·yr^{-1}. Although corn residue analyzed with lower CP (5.2 vs. 6.8%) and TDN (52.7 vs. 54.4%) compared to winter range, cows grazing CR were 42 kg heavier than cows grazing WR. Cows receiving supplement were 23 kg heavier than NS cows. Pre-breeding BW and BCS were increased for cows grazing CR and receiving supplement. However, PS did not affect milk production, cow BW and BCS at weaning, or pregnancy rate. Supplying protein supplement to cows returned less value at weaning ($16) compared to NS, due to the cost of the supplement.

Corn residue is also low in minerals and vitamins, such as Ca, P, and vitamin A (Wright and Tjardes, 2004). A salt, vitamin, and mineral mix should typically be offered free-choice to grazing cattle, especially if protein supplements do not provide adequate levels of Ca and P. Spring calving cows require P and Ca at 0.12 and 0.15% of dietary DM in the fall, respectively. Grazing corn residue will not meet the P requirements of beef cows (0.09% of DM) (NRC, 1996).

Animal Grazing and Trampling Effects on Soil Properties

Although residue grazing is an economical management tool for cattle producers, the impacts on soil properties from cattle trafficking on soils used for grain crops are not yet fully understood or explained, leading some producers to potentially question the profitability of integrating the two sectors. Minimal documentation on this specific management system has shown that cattle grazing could lead to negative effects on soil physical properties (Tracy and Zhang, 2008; Clark et al., 2004).

Soil Physical Properties

The effects of livestock trafficking on soil physical properties vary with region, and few comparisons of different soil types and climatic regions across the globe have been made. Compaction via livestock grazing can result in the degradation of soil physical properties and soil structure (Lipiec and Hatano, 2003), but the destruction of soil structure by high intensities of trampling, or poaching, typically occurs only in wet, frequently visited areas with poor drainage (Sheath and Carlson, 1998). Penetration resistance (PR) is an important soil strength measurement that has been found to be susceptible to animal trampling. Increased values for PR have been associated with increased animal weight and water table depth. Scholz and Hennings (1995) showed that a critical value of 800 kPa for trampling damage to grass corresponded to a groundwater level of 30 cm and cattle weighing 300-500 kg. In Canada, Mapfumo et al. (1999) concluded that heavily grazed meadow resulted in increased soil surface bulk density (BD) and (PR) compared to medium and lightly grazed meadow. However, the effects of livestock grazing on soil BD are normally confined to only the soil surface (Greenwood et al., 1997). Ferrero and Lipiec (2000) reported that compaction from livestock ranged in depth from 5 to 20 cm, depending on soil moisture and animal weight. Severity of soil compaction may increase with increased clay content (Lal, 1996) and will depend on soil moisture. Van Haveren (1983) reported an interaction between soil texture and grazing intensity, as a fine textured soil had greater BD than a coarse textured soil when grazed at increased stocking rates. Betteridge et al. (1999) reported that grazing cattle when soil was wetter than the plastic limit increased soil displacement and surface roughness. In these wet conditions, soil is displaced, or molded, rather than being compacted (Lamond, 1996). However, increased dispersion of soil particles after compaction may cause a loss of porosity and decreased aggregation.

Complex interactions exist between soil and plant properties, and how soil compaction affects plant performance. For most situations, there is an upper limit, or threshold, for soil BD values where plant roots are restricted, inhibiting plant growth (O'Connell, 1975). Soil texture is the most important property in most instances for determining these thresholds. Voorhees et al. (1989) found that surface soil compaction from wheel traffic did not cause a significant yield loss in corn. Compaction from cattle grazing will only affect shallow depths of the soil, and it is unlikely that soils would become compacted enough to reach their root restricting thresholds.

In Illinois, Tracy and Zhang (2008) saw severe soil physical disturbance when grazing corn crop residues. With concerns of livestock presence yielding negative soil effects, authors compared grazing a corn-oat-pasture (COP) system with an ungrazed continuous corn (CC) system. February and March calving cows grazed corn residues and cool season annuals from November to March at a stocking rate of 1 $cow \cdot ha^{-1}$. After oats planted for grain were harvested in July, a cool-season annual mixture of oat, cereal rye, and turnip was sown for fall and winter grazing. Residues and cool-season annuals were strip grazed, with cows allowed access to both forage sources in the same strip. During grazing, the combination of precipitation and cattle trafficking caused soil disturbance. Penetration resistance measurements suggested that the presence of cropland grazing may compact soils when compared to CC plots. However, authors suggested that spring cultivation likely reduced shallow compaction that developed over the winter months of grazing.

Similar experiments have been conducted under crop rotation, where soybeans [*Glycine max* (L.) Merr.] were planted the following yr after residue grazing. Clark et al. (2004) conducted a split-split plot design experiment to evaluate the effects of corn residue grazing during the winter on soil physical properties under two different spring tillage practices; disking and no-till. Each block was divided into 6 paddocks. One paddock per block was designated an ungrazed control, while the remaining 5 paddocks were grazed in 4 week intervals, totaling 20 weeks of residue grazing. The authors predicted that grazing residue when temperatures fell below freezing would decrease the likelihood of soil compaction. Mature Angus cows were grazed at a stocking rate of 3.7 cows·ha^{-1} for this 3-yr study on primarily Marshall silty clay loam soils. Post-grazing soil BD and PR from 10-20 cm did not differ. However, PR post grazing in the topsoil (0-10 cm) was increased during the second grazing period of yr 1 (29% increase), first and second periods during yr 2 (28 and 21% increase, respectively), and first, second, and fifth periods during yr 3 (44, 39, and 25% increase, respectively). Soil moisture content did not differ between grazed and ungrazed paddocks during sampling times, therefore the increase in PR was assumed to be due to the interaction between cattle trafficking, above freezing temperatures, and increased moisture content from precipitation during respective grazing periods. Soil surface roughness was increased in grazed paddocks during the third and fifth periods of yr 1, as well as the second and fifth periods in yr 3 when using the 2-m chain method. The authors concluded that negative soil physical properties are minimized if corn residue is grazed when soil temperatures are below freezing. However, if economic aspects of cow herd management warrant grazing as an inexpensive feed source in above freezing temperatures, producers can expect cattle trafficking to be localized within the upper 10 cm of the soil, and possibly alleviated with spring tillage.

Krenzer et al. (1989) evaluated the effects of animal traffic on soil compaction in Oklahoma wheat pastures. This study was conducted on silt loam and sandy loam soils to evaluate the extent of soil compaction from animal traffic, with a growing concern that subsequent conservation tillage may not fully eliminate this compaction. Both mature cows and stocker cattle were used in this analysis. Soil BD and soil strength, measured with a penetrometer, were increased after grazing at all study locations, although depth of compaction varied. In the surface zones, PR and BD were increased as much as 270% and 16%, respectively. In the sandy loam soil, BD was increased to a depth of 20 cm compared to only 12.5 cm in the silt loam soils. Soil strength was increased to a depth of 30 cm in the sandy loam soil, indicating that compaction occurs below the depth of cultivation, and may not be eliminated with some tillage practices. The degradation of soil structure and loosening of the soil by mechanical tillage, as in an integrated crop-livestock system, may increase the likelihood of increased soil BD, and decreased porosity and water infiltration.

Field management by the row crop producer could also become a limitation to the integration of cattle onto crop fields. In Illinois, the practice of conventional fall tillage accounts for 47.9% of corn acres, and no-till also accounts for 16.7% of corn acres (Frazee et al., 2006). Therefore, both of these systems may prevent residue grazing, if conventional tillage producers are unwilling to delay fall tillage, or if previously mentioned soil disturbance from livestock grazing diverts no-till producers from grazing livestock.

Soil Chemical Properties

Integrated crop-livestock systems may provide benefits of improved nutrient cycling compared to specialized systems (Entz et al., 2005). In addition to improved nutrient cycling, incorporating animals with cultivated crops may also increase biodiversity and reduce economic risk (de Faccio Carvalho et al., 2010). Grazing ruminants may reduce the energy supply to soil decomposers (Wardle et al., 2004), making a major influence on carbon cycling. However, within a continuous corn system, ruminants can aid in enhancing the decomposition of high carbon corn residue and return nutrients back to the soil more rapidly.

Tracy and Zhang (2008) found that cattle integration within a grain rotation can increase both quality and quantity of soil organic matter compared to continuous cropping of corn in Illinois. The authors suggested that inputs of organic matter via manure, cool-season annuals, and residues likely increased C pools and offset compaction from hoof traffic of the cattle, providing a positive change in the productivity of the overall system. Total C and N were increased with grazed COP treatments, while total C and N in CC treatments were unchanged. Total C and N stocks were also increased with time in an integrated system in southern Brazil when cattle grazed a winter oat crop in a soybean/oat rotation, while P and K levels remained high (de Faccio Carvalho et al., 2010).

Manure from livestock grazing may be beneficial toward soil fertility. Sandy soils in Zimbabwe had increased soil organic C, aggregate stability, and readily available water with cattle manure application (Nyamangara et al., 2001). Urine from grazing cattle has been estimated as an application of 400-1200 kg $N \cdot ha^{-1}$ in the deposited area (Addiscott et al., 1991). Large sources of Ca and Mg are also applied to the soil from urine patches (Early et al., 1998). Haygarth et al. (1998) also estimated soil P gains of 26 kg $P \cdot ha^{-1}$ annually in a UK dairy farm with a 2.26 $animals \cdot ha^{-1}$ grazing intensity.

However, cattle treading on hill land may also increase erosion and nutrient loss via runoff. Nguyen et al. (1998) simulated rainfall on 15-39° slopes after a short cattle treading event. Since treading reduced water infiltration, an increase in the transport of suspended solids, total N, and total P occurred.

Results on nutrient cycling with the grazing of livestock on less fertile soils have varied. Steffens et al. (2008) found that organic carbon, total N, and total S concentrations decreased with increasing grazing intensity in China. In Niger, Hiernaux et al. (1999) reported a decrease in soil pH, organic C, N, and P concentrations after 4 yr of grazing by sheep and goats on soil that had previously been left in fallow.

Effects of Cattle Grazing on Subsequent Crop Yield

Reductions in crop yield have been reported from changes in soil structure (Flowers and Lal, 1998). Yield loss may also occur from increased BD resulting in poor aeration (Lal, 1996) and reduced water infiltration (Willatt and Pullar, 1984). Voorhees (1992) also reported impaired root growth following soil compaction. Although relationships between soil degradation and crop performance have been documented, minimal reports on the effects of cattle grazing on fields utilized for grain production have been analyzed.

Drewnoski et al. (2015) conducted two experiments to test the effect of corn residue removal on subsequent crop yields. Experiment 1 evaluated the long term effects of grazing corn residue in either the fall/winter (November – January) or spring (February – April) on soybean and corn yields. This experiment was conducted on a 36 ha irrigated field under a corn-soybean rotation. Half of the field was planted into corn each year, with the other half being planted in soybeans, and crops were alternated yearly. After corn crops were harvested, three grazing treatments were then applied to each quarter of the field; 1) fall/winter grazed 2) spring grazed 3) ungrazed. Soils in this field were either silty clay loams or silty loams. Stocker cattle (227 – 318 kg average BW) were utilized for the grazing treatments at a stocking rate of 3 $hd \cdot ha^{-1}$ for fall/winter grazing and spring grazing for the first 5 yr. After yr 5, a stocking rate of 7.4 $hd \cdot ha^{-1}$ was used in the spring grazing treatment. No-till planting was used for the fall/winter grazing areas for all 16 yr. However, 3 tillage treatments were applied to the spring grazed and ungrazed treatments until 2007; no-till, ridge-till, or disk till. After 2007, only no-till was used. No-till was also always used after the soybean crop, which was not grazed. No interaction between spring grazing and tillage method was observed for both subsequent soybean and corn yield (1997-2006). Therefore, spring grazing of stocker cattle had the same effect on subsequent yield regardless of tillage method. Spring grazing of no till areas (1997 – 2013) increased soybean yields (3995 vs. 3894 $kg \cdot ha^{-1}$) and had no effect on corn yields. Fall grazing increased soybean yields compared to spring grazing and ungrazed areas. Spring grazing tended to increase soybean yields compared to ungrazed areas. Across all tillage treatments, spring grazing of corn residue increased soybean yields (3941 vs. 3840 $kg \cdot ha^{-1}$) and had no effect on corn yields compared to ungrazed areas. Grazing residue in either season had no effect on corn yields. This long term evaluation suggests residue grazing by stocker cattle can have slightly positive or no impact on subsequent corn and soybean yields. Grazing may also offer an economical alternative to tillage for residue management.

Clark et al. (2004) showed that grazing corn residue with beef cows had little to no effect on soybean yields the following growing season. Soybean plant populations did not differ between grazed and ungrazed paddocks for all 3 yr of this study. With or without spring tillage, soybean yields were not different for grazed or ungrazed paddocks through yr 1 and 2. However, yields from the no-till treatment in paddocks grazed during the second period of yr 3 were 8% lower when compared to the ungrazed treatment. No yield difference was detected when all 3 yr were averaged between grazed and ungrazed areas (2899 vs. 2892 $kg \cdot ha^{-1}$). The authors concluded that subsequent yield can be maximized if corn residue is grazed when soil temperatures are below freezing.

As previously highlighted, producers can increase forage utilization via increased stocking rates or by strip grazing. These management practices should prove beneficial for the cattle sector for various reasons when grazing corn residue. However, the impact that these grazing management decisions have on the performance of subsequent crops is unknown.

Conclusion

Winter feed costs associated with cow-calf production in the Midwest represent a large portion of total annual expenses. Strategies to alleviate these costs are a necessity to lower inputs and increase profitability for cattle producers. Corn residues are an abundant feed resource that can be utilized by integrated grain and beef enterprises. Although baling residues is a lower cost feeding method compared to the traditional feeding of hay, grazing is still the most effective way to utilize corn residue in a low cost manor.

Corn residue is a low quality feedstuff due to physiological maturity, but animal selectivity allows for the greatest quality and most palatable portions of the residue to be utilized. Still, diet quality declines as the length of grazing increases, or if increased stocking rates are used. Strip grazing residues may provide benefits for the cattle producer, but the effects of this system on soil and subsequent crop performance is unknown.

Grazing residue leads to increased soil strength, bulk density, and soil surface disturbance, but these effects are dependent on the soil type, timing of grazing, temperature, and precipitation. These effects may also be countered by spring tillage. Subsequent corn and soybean performance is not hindered by grazing, but more years of analysis with different weather patterns, soil types, and grazing methods are necessary to fully understand the effects of corn residue grazing on crop performance.

LITERATURE CITED

Adams, D. C., R. T. Clark, S. A. Coady, J. B. Lamb, and M. K. Nielsen. 1994. Extended grazing systems for improving economic returns from nebraska sandhills cow/calf operations. J. Range Manage. 47: 258-263.

Addiscott, T. M., A. P. Whitmore, and D. S. Powlson. 1991. Farming, fertilizers and the nitrate problem. CAB International (CABI).

Bartholomew, H. M., and J. F. Underwood. 2002. Brassicas for forage. Dept. of Agronomy, Ohio State University, Columbus, OH. AGF-020-92.

Betteridge, K., A. Mackay, T. Shepherd, D. Barker, P. Budding, B. Devantier et al. 1999. Effect of cattle and sheep treading on surface configuration of a sedimentary hill soil. Soil Research. 37(4): 743-760.

Braungardt, T. J., D. W. Shike, D. B. Faulkner, K. Karges, M. Gibson, and N. M. Post. 2010. Comparison of corn coproducts and corn residue bales with alfalfa mixed hay on beef cow-calf performance, lactation, and feed Costs. Prof. Anim. Sci. 26: 356-364.

Clark, J. T., J. R. Russell, D. L. Karlen, P. L. Singleton, W. D. Busby, and B. C. Perterson. 2004. Soil surface property and soybean yield response to corn stover grazing. Agron. J. 96: 1364-1371.

Curtis, L. E., R. L. Kallenbach, and C. A. Roberts. 2008. Allocating forage to fall-calving cow-calf pairs strip-grazing stockpiled tall fescue. J. Anim. Sci. 86: 780-789.

de Faccio Carvalho, Paulo César, I. Anghinoni, A. de Moraes, E. D. de Souza, R. M. Sulc, C. R. Lang et al. 2010. Managing grazing animals to achieve nutrient cycling and soil improvement in no-till integrated systems. Nutr. Cycling Agroecosyst. 88(2): 259-273.

Dimitri, C., A. B. Effland, and N. C. Conklin. 2005. The 20th century transformation of US agriculture and farm policy.

Drewnoski, M. E., L. A. Stalker, J. C. MacDonald, G. E. Erickson, K. J. Hanford, and T. J. Klopfenstein. 2015. Effect of corn residue removal on subsequent crop yields. Nebraska Beef Report. : 53-55.

D'Souza, G. E., E. W. Maxwell, W. B. Bryan, and E. C. Prigge. 1990. Economic impacts of extended grazing systems. Am. J. Alternative Agr. 5(3): 120-125.

Early, M., K. Cameron, and P. Fraser. 1998. The fate of potassium, calcium, and magnesium in simulated urine patches on irrigated dairy pasture soil. N. Z. J. Agric. Res. 41(1): 117-124.

Entz, M., W. Bellotti, J. Powell, S. Angadi, W. Chen, K. Ominski et al., 2005. Evolution of integrated crop-livestock production systems. Grassland: A Global Resource.Wageningen Academic Publ., Wageningen, the Netherlands. : 137-148.

Fernandez-Rivera, S., and T. J. Klopfenstein. 1989b. Yield and quality components of corn crop residues and Utilization of these residues by grazing cattle. J. Anim. Sci. 67(2): 597-605.

Fernandez-Rivera, S., and T. Klopfenstein. 1989a. Diet composition and daily gain of growing cattle grazing dryland and irrigated cornstalks at several stocking rates. J. Anim. Sci. 67(2): 590-596.

Ferrero, A., and J. Lipiec. 2000. Determining the effect of trampling on soils in hillslope-woodlands. International Agrophysics. 14(1): 9-16. Retrieved 15 May 2015, from the SCOPUS database.

Flowers, M., and R. Lal. 1998. Axle load and tillage effects on soil physical properties and soybean grain yield on a mollic ochraqualf in northwest ohio. Soil Tillage Res. 48(1): 21-35.

Frazee, B., A. Gulso, and M. Hirschi. 2006. Illinois erosion and tillage trends. Land & Water.

Gerrish, J. R. 1996. Extending the grazing season. Missouri Grazing Manual. Univ. Missouri Ext. Publ. M157. Univ. Missouri Ext., Columbia.: 113.

Goad, D. W., Goad, C. L., & Nagaraja, T. G. (1998). Ruminal microbial and fermentative changes associated with experimentally induced subacute acidosis in steers. J. Anim. Sci. 76(1), 234-241.

Greenwood, K. L., D. A. Macleod, and K. J. Hutchinson. 1997. Long-term stocking rate effects of soil physical properties. Aust. J. Exp. Agric. 37: 413-419.

Gutierrez-Ornelas, E., and T. Klopfenstein. 1991. Changes in availability and nutritive value of different corn residue parts as affected by early and late grazing seasons. J. Anim. Sci. 69(4): 1741-1750.

Haygarth, P., P. Chapman, S. Jarvis, and R. Smith. 1998. Phosphorus budgets for two contrasting grassland farming systems in the UK. Soil use Manage. 14(s4): 160-167.

Hiernaux, P., C. L. Bielders, C. Valentin, A. Bationo, and S. Fernandez-Rivera. 1999. Effects of livestock grazing on physical and chemical properties of sandy soils in sahelian rangelands. J. Arid Environ. 41(3): 231-245.

Hitz, A. C., and J. R. Russell. 1998. Potential of stockpiled perennial forages in winter grazing systems for pregnant beef cows. J. Anim. Sci. 76(2): 404-415.

Janovick, N. A., J. R. Russell, D. R. Strohbehn, and D. G. Morrical. 2004. Productivity and hay requirements of beef cattle in a midwestern year-round grazing system. J. Anim. Sci. 82(8): 2503-2515.

Johnston, J., M. Lenover, S. Burnett, S. Slaght, and B. Garners. 2000a. Performance of ewes grazing stubble turnips. Northern Stations Research Updates, New Liskeard Agricultural Research Station, New Liskeard, ON.

Jones, E. R., S. Swain, R. A. Peiffer, and S. Jacobsen. 1998. Year-round grazing on the delmarva peninsula. Bull. A-111. : Delaware State Univ., Dover.

Jung, G., J. Shaffer, W. Stout, and M. Panciera. 1988. Harvest frequency effects on forage yield and quality of rapes and rape hybrids*. Grass Forage Sci. 43(4): 395-404.

Klopfenstein, T., L. Roth, S. Fernandez-Rivera, and M. Lewis. 1987. Corn residues in beef production systems. J. Anim. Sci. 65(4): 1139-1148.

Koch, D. W., C. Kercher, and R. Jones. 2002. Fall and winter grazing of brassicas-a value-added opportunity for lamb producers. Sheep and Goat Research Journal. 17(2): 1-13.

Krenzer, E., C. F. Chee, and J. Stone. 1989. Effects of animal traffic on soil compaction in wheat pastures. J. Prod. Agric. 2(3): 246-249.

Kunelius, H., J. Sanderson, and P. Narasimhalu. 1987. Effect of seeding date on yields and quality of green forage crops. Canadian Journal of Plant Science. 67(4): 1045-1050.

Lal, R. 1996. Axle load and tillage effects on crop yields on a mollic ochraqualf in northwest ohio. Soil Tillage Res. 37(2-3): 143-160. Retrieved 15 May 2015, from the SCOPUS database.

Lamm, W. D., and J. K. Ward. 1981. Compositional changes in corn crop residues grazed by gestating beef cows. J. Anim. Sci. 52(5): 954-958.

Lamond, R. Cattle grazing and soil compaction. Forage Facts, Kansas State University.

Larson, D. M., J. L. Martin, D. C. Adams, and R. N. Funston. 2009. Winter grazing system and supplementation during late gestation influence performance of beef cows and steer progeny. 87(3): 1147-1155.

Lipiec, J., and R. Hatano. 2003. Quantification of compaction effects on soil physical properties and crop growth. Geoderma. 116(1): 107-136.

Mapfumo, E., D. Chanasyk, M. Naeth, and V. Baron. 1999. Soil compaction under grazing of annual and perennial forages. Can. J. Soil Sci. 79(1): 191-199.

McCartney, D., J. Fraser, and A. Ohama. 2008. Annual cool season crops for grazing by beef cattle. A canadian review. Canadian Journal of Animal Science. 88(4): 517-533.

Meteer, W. T. 2014. Hay: Nutrient value and cost of production. Univ. Ill. Ext.

Miller, A. J., D. B. Faulkner, T. C. Cunningham, and J. M. Dahlquist. 2007. Restricting time of access to large round bales of hay affects hay waste and cow performance. Prof. Anim. Sci. 23: 366-372.

Miller, A. J., R. K. Faulkner, R. K. Knipe, D. R. Strohbehn, D. F. Parrett, and L. L. Berger. 2001. Critical control points for profitability in the cow-calf enterprise. Prof. Anim. Sci. 17: 295-302.

National Agricultural Statistics Service. Corn grain yield - bu/acre (5 yr average 2010-2014). 2015(March 4th) from the http://quickstats.nass.usda.gov/results/3432372A-AF84-355D-8506-8FB543859607 database.

National Agricultural Statistics Service. Corn, grain - acres harvested (5 yr average). 2015(March 4th) from the http://quickstats.nass.usda.gov/results/D0AED1A9-04EA-3EB2-88C2-95FABD220497 database.

National Agricultural Statistics Service. Crop values annual summary. 2015(Feb. 17) from the http://usda.mannlib.cornell.edu/usda/nass/CropValuSu//2000s/2003/CropValuSu-02-13-2003.txt database.

National Agricultural Statistics Service. Hay - price recieved, $/ton (150). 2015(March 4) from the http://quickstats.nass.usda.gov/results/D1132F83-3ADB-393A-A157-5769B760A348 database.

Nguyen, M. L., G. W. Sheath, C. M. Smith, and A. B. Cooper. 1998. Impact of cattle treading on hill land. 2. soil physical properties and contaminant runoff. New Zealand Journal;New Zealand Journal of Agricultural Research. 41: 279-290.

NRC ed. 1996. Nutrient Requirements of Beef Cattle. 7th Revised Edition ed. ed. National Academy Press. Washington, D. C.

Nyamangara, J., J. Gotosa, and S. Mpofu. 2001. Cattle manure effects on structural stability and water retention capacity of a granitic sandy soil in zimbabwe. Soil Tillage Res. 62(3): 157-162.

O'Connell, D. J. 1975. The measurement of apparent specific gravity of soils and its relationship to mechanical composition and plant root growth. Soil Physical Conditions and Crop Production. (Bulletin 29): 298-313.

Oltjen, J. W., and J. L. Beckett. 1996. Role of ruminant livestock in sustainable agricultural systems. J. Anim. Sci. 74(6): 1406-1409.

Poore, M., G. Benson, M. Scott, and J. Green. 2000. Production and use of stockpiled tall fescue to reduce beef production costs. Proceedings of the american society of animal science.

Rayburn, E., and B. Abaye. 2007. Assessing species composition and forage quality. Forage Utilization for Pasture-Based Livestock Production, NRAES-173.Natural Resource, Agriculture and Engineering Service, Ithaca NY.

Redmon, L. A., G. W. Horn, E. G. Krenzer, and D. J. Bernardo. 1995. A review of livestock grazing and wheat grain yield: Boom or bust? Agron. J. 87(2): 137-147.

Russell, J. R., M. R. Brasche, and A. M. Cowen. 1993. Effects of grazing allowance and system on the use of corn-crop residues by gestating beef cows. J. Anim. Sci. 71(5): 1256-1265.

Samples, D., and J. McCutcheon. Grazing corn residue, Ohio State University fact sheet.

Scholz, H., and H. Hennings. 1995. Bearing capacity for grazing in connection with the rewetting of fens. Zeitschrift Fuer Kulturtechnik Und Landentwicklung (Germany).

Sheath, G., and W. Carlson. 1998. Impact of cattle treading on hill land: 1. soil damage patterns and pasture status. N. Z. J. Agric. Res. 41(2): 271-278.

Sletmoen-Olson, K., J. Caton, K. Olson, and L. Reynolds. 2000. Undegraded intake protein supplementation: I. effects on forage utilization and performance of periparturient beef cows fed low-quality hay. Journal of Animal Science-Menasha then Albany then Champaign Illinois. 78(2): 449-455.

Steffens, M., A. Kölbl, K. U. Totsche, and I. Kögel-Knabner. 2008. Grazing effects on soil chemical and physical properties in a semiarid steppe of inner mongolia (PR china). Geoderma. 143(1): 63-72.

Stockton, M., R. Wilson, and A. Stalker. Corn stalk grazing cow-Q-lator, University of Nebraska.

Tracy, B. F., and Y. Zhang. 2008. Soil compaction, corn yield response, and soil nutrient pool dynamics within an integrated crop-livestock system in Illinois. Crop Sci. 48(3): 1211-1218.

Van Haveren, B. P. 1983. Soil bulk density as influenced by grazing intensity and soil type on a shortgrass prairie site. J. Range Manage. : 586-588.

Voorhees, W. B. 1992. Wheel-Induced Soil Physical Limitations to Root Growth. Pages 73-95 in Limitations to Plant Root Growth.

Voorhees, W., J. Johnson, G. Randall, and W. Nelson. 1989. Corn growth and yield as affected by surface and subsoil compaction. Agron. J. 81(2): 294-303.

Ward, J. 1978. Utilization of corn and grain sorghum residues in beef cow forage systems. J. Anim. Sci. 46(3): 831-840.

Wardle, D. A., R. D. Bardgett, J. N. Klironomos, H. Setala, W. H. van der Putten, and D. H. Wall. 2004. Ecological linkages between aboveground and belowground biota. Science. 304(5677): 1629-1633.

Warner, J., J. Martin, Z. Hall, L. Kovarik, K. Hanford, and R. Rasby. 2011. The effects of supplementing beef cows grazing cornstalk residue with a dried distillers grain based cube on cow and calf performance. The Professional Animal Scientist. 27(6): 540-546.

Whalley, W., E. Dumitru, and A. Dexter. 1995. Biological effects of soil compaction. Soil Tillage Res. 35(1): 53-68.

Willatt, S., and D. Pullar. 1984. Changes in soil physical properties under grazed pastures. Soil Research. 22(3): 343-348.

Wilson, M. 2009. Stalk up on strip-grazing. Angus Journal, August Edition.

Wright, C., and K. Tjardes. 2004. Grazing corn stalks. SDSU, Cooperative Extension Service.

Yun, L., D. W. Koch, F. A. Gray, D. W. Sanson, and W. J. Means. 1999. Potential of trap-crop radish for fall lamb grazing. J. Prod. Agric. 12(4): 559-563.

CHAPTER 2

AGRONOMIC ASSESSMENT OF GRAZING METHOD OF CORN RESIDUES ON COW PERFORMANCE, RESIDUE UTILIZATION, AND CROP YIELD

ABSTRACT

The objectives were to evaluate the effects of beef cows grazing corn residues on cow performance, residue utilization, and subsequent crop yield. Two grazing methods (strip grazing, **(SG)** and continuous grazing, **(CG)**) and a control (ungrazed, **(CT)**) were arranged in a randomized complete block design with 3 replications for 3 yr. Within SG, subplots were assigned with a grazing order **(1, 2, 3)**. Thirty-six spring-calving, multiparous, Angus cows were utilized in yr 1 (BW = 648 ± 41 kg) and 2 (BW = 710 ± 71 kg) at a stocking density of 3.0 cows·ha^{-1}, and 42 winter-calving Angus heifers (BW = 566 ± 39 kg) were utilized in yr 3 at a stocking density of 3.6 heifers·ha^{-1}. Cattle grazed for 42 d beginning on 29 Sept. 2012 (yr 1), 2 Nov. 2013 (yr 2), and 4 Oct. 2014 (yr 3). Residue samples were collected on d 14 and d 28 of grazing and after grazing in yr 1, and before and after grazing in yr 2. Paddock dimensions were marked during yr 1 with GPS coordinates so that the same treatment was applied to the same paddock area and location each yr. Cows within the SG treatment were heavier (P = 0.04) after grazing and had an increase (P = 0.04) in body weight change compared to CG. At d 28 in yr 1, SG residue had decreased (P < 0.01) acid detergent fiber (ADF) and tended (P = 0.08) to have increased organic matter compared to CG. At the conclusion of grazing, SG had decreased (P = 0.02) neutral detergent fiber compared to CG. Within SG in yr 2, strip 3 tended (P = 0.10) to have increased total residue available compared to strips 1 and 2 after grazing. Strip 1 had increased (P = 0.02) ADF and tended (P = 0.09) to have decreased crude protein compared to strips 2 and 3. No differences (P = 0.19) were detected between treatments for subsequent corn

yield following two grazing seasons. However, within SG, the first strip tended ($P = 0.10$) to have reduced yields compared to the second strip, with the third strip being intermediate. Strip grazing corn residues increased cow performance. Grazing in the fall did not affect subsequent crop performance, yet the effects that strip grazing has on long term crop performance need to be further investigated.

INTRODUCTION

In the beef industry, costs associated with feeding the cow herd account for over 60% of total annual expenses (Miller et al., 2001). Integrating grain and beef enterprises allows Midwestern beef producers to utilize corn (*Zea mays* L.) residue as a low cost alternative to traditional fall and winter cow feeding strategies.

Corn residue is abundant in the Midwest and can be used to provide nutrients to ruminants due to their ability to digest cellulose rich feeds (Oltjen and Beckett, 1996). Although residue can be baled and fed, extending the grazing season by allowing cows to graze residue in the field is the most economical strategy for utilization (Klopfenstein et al., 1987).

Corn residue is a low quality feedstuff due to its physiological maturity. Grazing allows for cattle to selectively consume the greatest nutritional quality and most palatable portions of the residue first, while leaving lower quality, less palatable portions in the field (Lamm and Ward, 1981).

Residue quality declines as it continues to decompose throughout the fall and winter. Nutritive quality of residue available for grazing also declines if increased stocking rates are used, due to increased trampling and cattle selection of more digestible portions (Fernandez-Rivera and Klopfenstein, 1989). Strip grazing has been shown to increase utilization of grazed dormant forages (Poore et al., 2000; Rayburn et al., 2007). However, the effects of strip grazing corn residues on cow performance may be weather dependent (Russell et al., 1993).

Previous research has shown that cattle grazing can lead to negative effects on soil properties (Krenzer et al., 1989; Betteridge et al., 1999; Mapfumo et al., 1999), potentially resulting in decreased subsequent crop yield. Yet, studies that have introduced cattle onto land used for grain crop production have not reported decreased crop yields following the grazing of cattle (Clark et al., 2004; Drewnoski et al., 2015). However, the effects of strip grazing corn residues on crop yield are unknown.

We hypothesized residue in the strip grazing method would have a more favorable nutrient composition, leading to an increase in cow performance, and that residue grazing would not affect subsequent corn yield. Our objectives were to evaluate the effects of grazing method on cow performance and residue utilization, and to evaluate the effect of grazing and grazing method on subsequent corn yield.

MATERIALS AND METHODS

All animal procedures were approved by the University of Illinois Institute of Animal Care and Use Committee and followed the guidelines recommended in the Guide for the Care and Use of Agricultural Animals in Agricultural Research and Teaching (FASS, 2010).

Experimental Design

A 3-yr experiment was initiated in 2012 to investigate the effects of beef cow grazing method (continuous or strip-grazing) of corn residues on cow performance, residue utilization, and subsequent crop yield at the University of Illinois Dudley Smith Farm near Pana, Illinois (39°39' N, 89°08' W). Thirty-six spring-calving, multiparous, Angus cows were utilized in yr 1 (BW = 648 ± 41 kg) and 2 (BW = 710 ± 71 kg) at a stocking density of 3.0 cows·ha^{-1}, and 42 winter-calving Angus heifers (BW = 566 ± 39 kg) were utilized in yr 3 at a stocking density of 3.6 heifers·ha^{-1}.

Two grazing methods (strip grazing, **(SG)** and continuous grazing, **(CG)**) and a control (ungrazed, **(CT)**) were arranged in a randomized complete block design with 3 replications, allowing for 9 grazing paddocks. Within SG, subplots were assigned for grazing order **(1, 2, 3)**.

Each paddock was 1.97 ± 0.03 ha. The same field was utilized each of the three yr. Paddock dimensions were marked during yr 1 with GPS coordinates (GARMIN eTrex personal navigator, 12 channel, GARMIN International, Inc, Kansas, USA), so that the same treatment was applied to the same paddock area and location each yr. Cows were randomly allotted to 1 of 2 grazing treatments, CG or SG. Cows grazed corn residue fields for 6 weeks (42 d). Continuous grazing treatments were allowed access to the entire paddock throughout the entire duration of grazing. In the SG treatments, paddocks were divided into 3 strips using one strand of temporary electric fence. Cows were allowed access to a new strip every 14 d so that the first 14 d period cows were grazing on the first third of the paddock. They were then allowed access to the first and second strip for the next 14 d. The last 14 d of the experiment allowed strip treatments to have access to the entire paddock (first, second, and third strip). Each individual grazing paddock contained a water source and mineral feeder. Cows and heifers were supplemented in stationary feed bunks 3 times weekly to receive 1.8 $kg \cdot hd^{-1} \cdot d^{-1}$ of a 50% pelleted corn gluten feed and 50% soybean hull mix (supplement analysis in table 2.1). In yr 2, supplement feeding was increased to 4.5 $kg \cdot hd^{-1} \cdot d^{-1}$ during the last 14 d of the experiment due to low temperatures. At the conclusion of the experiment (d 42), cows were placed on a common diet for 7 d, consisting of stockpiled cool season forage. At the onset and conclusion of grazing, cow body weight (BW) was taken on 2 consecutive d and body condition score (BCS) was assigned. Average daily temperature during the grazing experiments were 9.9, 1.4, and 8.7°C and total precipitation was 66.5, 37.3, and 62.5 mm for yr 1, 2, and 3, respectively.

Corn was harvested on 28 Aug. 2012 (yr 1), 21 Oct. 2013 (yr 2), and 19 Sept. 2014 (yr 3) with a John Deere S680 combine (Deere and Company) equipped with a 16-row head. Yield data was collected during harvest with APEX Farm Management Software (Deere and Company).

Cattle grazing began on 29 Sept. 2012 (yr 1), 2 Nov. 2013 (yr 2), and 4 Oct. 2014 (yr 3). Spring tillage was applied to the entire field before planting in all 3 yr. A 550 Case IH Quadtrac tractor (Fargo, ND, USA) and Case IH 330 Turbo Vertical Tillage implement (CNH America LLC) was used for tillage, to a depth of approximately 5 cm. Corn was planted in 76-cm rows with a 16-row John Deere 8230 (Deere and Company). Stone 6148 (Stone Seed Group, Monsanto) seed corn was planted to obtain a density of 93,860 plants·ha^{-1} on 20 May 2013 and 24 April 2014.

Corn Yield Measurements

Corn yield was calculated by a yield monitor at discrete locations during harvest, and the yield data were further imported as point shapefiles into ArcGIS (ESRI, Redlands, CA) for analysis. The Inverse Distance Weighted (IDW) interpolation tool in ArcGIS was used to convert point-based yield data into a raster image with a uniform cell size of 10 m by 10 m. The raster cell values were determined using a linearly weighted combination of a set of nearby sample points. This interpolation method assumes that corn yield being mapped decreases in influence with distance from its sampled location. Sampled points that are closer to the prediction location have greater weights, and the weights diminish as a function of distance. Based on the spatial resolution of yield data, a circle with the radius of 20 m was used as the search radius to limit the sampled points used in interpolation for estimating yield at prediction locations. Mean yield were calculated for each subplot and main plot.

Corn Residue Measurements

Corn residue samples were collected during yr 1 and 2. On d 14 of grazing in yr 1, 3 residue samples were collected in each CG paddock. In SG paddocks, one residue sample was collected in the second strip, which until d 14 had not yet been grazed. On d 28, the same sampling protocol was used as on d 14, except residue samples in the SG paddocks were collected in the third strip, which had not been previously grazed. After the completion of grazing, 3 samples were collected from each paddock, yielding 27 samples. Each sample was collected using a 1.8 m^2 sampling square so that available residue could be expressed in $kg \cdot ha^{-1}$. Each sample of residue represented 1 toss of the sampling square. All residue within the forage square was collected, as stalk choppers on the harvesting equipment did not leave standing stalks still attached to the soil surface.

In yr 2, 3 samples per paddock, or 27 total samples were collected on 23 Oct. 2013 (10 d before the start of grazing) and on 15 Jan. 2014. Residue samples were not able to be collected directly after the completion of grazing due to snow accumulation. For each sample, the previous 1.8 m^2 forage square was randomly tossed 3 times within each third of each paddock. After each of the 3 tosses, residue within the square was collected and placed in a bag so that 3 collections equaled 1 sample of residue. All residue in the sampling square was collected except for the bottom portion of the corn stalk.

Residue samples were sorted by plant component, such that stalks, cobs, and leaves/husks were separated. Samples were weighed before a 400 g subsample was dried in a 55°C oven for 3 d. Subsample dry matter (DM) was then used to calculate total DM availability in the original sample in order to calculate residue availability and utilization within the paddock area. For both yr, dried residue was ground using a Wiley mill (2 mm screen, Arthur H. Thomas, Philadelphia, PA) and a 100 g subsample of each component was collected for analysis. Before residue nutrient composition was analyzed, components were recombined so that each sample represented the initial forage component composition in the sampling area.

Corn gluten feed and soybean hull supplement was also collected each yr (Table 2.1). In yr 1, the supplement sample was analyzed at the University of Illinois at Urbana-Champaign, where all forage analysis were also conducted. In yr 2 and 3, supplement samples were analyzed by a commercial lab (Alvey Laboratory INC., Belleville, IL) using NIR procedures. Laboratory procedures at the University of Illinois analyzed samples for crude protein (CP) (Leco TruMac, LECO Corporation, St. Joseph, MI), ADF, neutral detergent fiber (NDF) (using Ankom Technology method 5 and 6, respectively; Ankom^{200} Fiber Analyzer, Ankom Technology), and total ash (600° C for 2 h, Thermolyne muffle oven model: F30420C, Thermo Scientific, Waltham, MA).

Statistical Analysis

For cow performance (BW and BCS), the MIXED procedure of SAS (SAS Inst. Inc., Cary, NC) was used to compare the effects of grazing method (SG and CG). Treatment was included as a fixed effect and yr was included as a random effect. Paddock was the experimental unit and there were 3 replications per treatment in each yr.

In yr 1, forage quality (NDF, ADF, CP, and organic matter (OM)) of CG and SG were compared at d 14 and d 28, and all 3 treatments (SG, CG, and CT) were evaluated at d 42 using the MIXED procedure of SAS. At d14, main plot of CG was compared to the second subplot of SG. At d 28, main plot of CG was compared to the third subplot of SG. There were 3 replications for d 14 and d 28. At d 42, main plots for CG, SG and CT were compared with 9 replications.

In yr 2, forage quality (NDF, ADF, CP, and OM) and availability ($kg{\cdot}ha^{-1}$ and component percent of total sample) were compared between CG, SG, and CT before and after grazing using the MIXED procedure of SAS. Paddock was the experimental unit. For forage quality, there were 9 replications for each treatment at each sampling time point (before and after grazing). For forage availability, there were 9 replications for each treatment and each residue component at each sampling point.

In yr 2, forage quality (NDF, ADF, CP, and OM) and availability (kg·ha^{-1} and component percent of total sample) were compared between grazing order (1, 2, and 3) within the SG treatment before and after grazing using the MIXED procedure of SAS. Grazing strip was the experimental unit. For forage quality, there were 3 replications for each strip at each sampling time point (before and after grazing). For forage availability, there were 3 replications for each subplot and each residue component at each sampling point.

For subsequent crop yield (Tons·ha^{-1}), the MIXED procedure of SAS was used to compare the effects of treatment (CG, SG, and CT). Treatment was included as a fixed effect and yr was included as a random effect. There were 3 replications per treatment per yr. Within the SG treatment, subsequent crop yield was compared within grazing order (1, 2, and 3). There were 3 replications for each grazing order each yr.

RESULTS

Cow Performance

Cow BW was not different (P = 0.63) before grazing (Table 2.2). However, cows within the SG treatment were heavier (P = 0.04) after grazing and had an increase (P = 0.04) in BW change compared to CG. No differences ($P \geq 0.31$) were detected in BCS before or after grazing.

Residue Utilization and Quality

Year 1

At d 14 of grazing, no differences ($P \geq 0.15$) were found for nutrient composition between CG and SG (Table 2.3). However, CG had increased (P < 0.01) ADF and tended to have decreased (P = 0.08) OM compared to SG at d 28, but all other variables were not different ($P \geq 0.18$). At the conclusion of grazing (d 42), SG had decreased (P = 0.02) NDF compared to

CG and CT, and CT had increased (*P* < 0.01) CP and OM compared to both CG and SG. There were no differences (*P* = 0.78) in ADF at d 42.

Year 2

No differences (*P* ≥ 0.21) were detected in forage availability between treatments before grazing began (Table 2.4). However, CT had increased (*P* = 0.03) CP and decreased (*P* = 0.02) ADF compared to SG and decreased (*P* = 0.02) NDF compared to CG. There were no differences (*P* = 0.32) between treatments for OM before grazing. There were also no differences (*P* ≥ 0.49) between SG strips before grazing for forage availability and quality (Table 2.5).

There was an increase (*P* < 0.01) in total residue, cobs, and leaves/husks for CT post-grazing compared to CG and SG, but no differences (*P* = 0.54) were detected in total stalk availability (Table 2.4). Control had increased (*P* < 0.01) leaves/husks and decreased (*P* < 0.01) stalks when comparing individual component percentages to total residue availability. The percentage of cobs available was not different (*P* = 0.11) between treatments. After grazing, CT had increased (*P* ≤ 0.03) CP and OM, decreased (*P* < 0.01) ADF, and tended (*P* = 0.06) to have decreased NDF compared to both CG and SG.

Within SG, strip 3 tended (*P* = 0.10) to have increased total residue available compared to strips 1 and 2 after grazing (Table 2.5). Strip 3 also had increased (*P* = 0.02) total cobs compared to strips 1 and 2 and tended (*P* = 0.07) to have an increase in percentage of cobs relative to total residue. There were no differences (*P* ≥ 0.32) between strips for leaves/husks and stalks. After grazing, strip 1 had increased (*P* = 0.02) ADF and tended (*P* = 0.09) to have decreased CP compared to strips 2 and 3. There were no differences (*P* ≥ 0.28) in NDF or OM between strips.

Subsequent Crop Yield

No differences (*P* = 0.19) were detected between treatments for subsequent corn yield following two grazing seasons (Table 2.6). However, within the SG treatment, the first strip tended (*P* = 0.10) to have reduced yields compared to the second strip, with the third strip being intermediate (Table 2.7).

DISCUSSION

Cows that strip grazed corn crop residues had increased BW gains and were heavier after grazing compared to cows that continuously grazed. Previous research has shown that strip grazing dormant forages can lengthen the grazing season, providing additional grazing days (Jones et al., 1998; Gerrish, 1996). Although improved animal performance has been minimally documented, we believe that utilizing strip grazing can lengthen the grazing season, or provide increased animal performance during a pre-determined grazing period. Since we strip and continuously grazed at the same stocking rate for a set period, our results support our hypothesis that strip grazing can also be used to increase cow performance. However, Russell et al. (1993) reported mixed results. The authors strip grazed or continuously grazed for 2 yr at a stocking rate of 0.41 $ha \cdot cow^{-1}$. Russell et al. (1993) reported that in yr 1, cows grazing in the strip stocking system tended to have increased BW gains compared to the continuous stocking system (0.30 vs. 0.15 $kg \cdot d^{-1}$). The authors noted that inclement weather conditions took place in yr 2 resulting in no animal performance differences, thus concluding that the benefits of strip grazing were weather dependent. For our study, precipitation accumulations of 66.5, 37.3, and 62.5 mm were recorded for yr 1, 2, and 3, respectively, over the 42 d grazing period, all of which were under the 30-yr average for the state of Illinois. Average temperatures during the grazing periods were 9.9, 1.4, and 8.7°C for yr 1, 2, and 3, respectively. Temperatures were colder in yr 2 because abnormally late corn harvest pushed back residue grazing. Our research suggests that strip grazing can be an effective grazing strategy under most climatic conditions. Our increased gain of 9.8 kg (0.23 $kg \cdot d^{-1}$) during a 42 d grazing season was similar to gains reported by Russell et al. (1993). Although strip grazing requires increased labor and fencing expenses, increased cow weight gains or increased stocking rates could potentially offset these additional costs.

One possible explanation for improved cow performance in SG management is greater nutritive quality residue at the end of the grazing season. In yr 1, SG residue had decreased ADF and tended to have decreased ash at d 28. At the conclusion of grazing, SG residue had decreased NDF. Within SG, strip 3 tended to have increased total residue available for grazing compared to strips 1 and 2 after grazing in yr 2. Strip 3 also had an increase in total cobs and an increase in percentage of cobs compared to strips 1 and 2. However, there were no differences between strips for leaves/husks and stalks. Therefore, we believe that the 14 d grazing period in strip 3 was enough time to allow cattle to consume all of the plant portions with greater digestibility, such as the leaves and husks. It is also important to note that the increase in cobs is believed to be from less animal trampling. Although it is unlikely that cattle consumed the cobs in strips 1 and 2, there were less cobs available for sampling because cattle trafficking may have pressed this residue component into the soil surface. After grazing, strip 1 had increased ADF and tended to have decreased CP compared to strips 2 and 3. Therefore, forage quality was affected by the increase in cattle trampling from cattle returning to the stationary water source and feed bunks, as well as increased stocking rates for the first 14 and 28 d of grazing in SG. There was an increase in total residue availability for CT compared to CG and SG because cattle were not removing residue from CT. However, there was also an increase in cobs and leaves/husks for CT compared to both grazing treatments, but no difference in stalk availability. It is well documented that after residual grain is consumed, cattle select the leaf and husk portions of crop residue first when grazing (Fernandez-Rivera and Klopfenstein, 1989; Gutierrez-Ornelas and Klopfenstein, 1991), leading to the decrease in these components in CG and SG. In our experiment, minimal, if any, grain was available for cattle consumption. In yr 1, warm temperatures and abundant rainfall between grain harvest and cattle grazing allowed residual corn to sprout and grow. After the first 14 d of grazing, cooler temperatures and frost were observed, killing residual corn plants. It is also important to note that increased harvesting efficiencies and modern corn plant hybrids were observed to leave minimal residual corn in our experiments. We believe that the 6148 Stone Seed Corn Smartstax hybrid and S680 JD combine utilized in our experiment left minimal residual corn from cornstalk lodging or harvesting loss for cattle to consume following harvest. These differences in harvesting efficiencies between previous experiments and our experiment may warrant updated recommendations on corn residue grazing.

The increase in total cobs within CT is believed to be from the previously mentioned hypothesis that cattle trafficking led to cobs being pressed into the soil profile, thus not being collected during forage sampling in CG and SG. Similar stalk availability across treatments agrees with previous research noted above, suggesting that it is unlikely that cattle will consume a measureable amount of stalk components. Due to the larger particle size of corn stalks compared to cobs, it is also unlikely that unconsumed stalks were trampled into the soil surface. After grazing, CT had increased CP and OM (yr 1 and 2), decreased ADF (yr 2), and tended to have decreased NDF (yr 1). Previous literature has outlined the decline in residue quality as it is selectively grazed (Fernandez-Rivera and Klopfenstein, 1989; Lamm and Ward, 1981). However, increased CT residue quality found in our experiment signifies grazing opportunity with a SG system. If the grazing period were to be expanded, we would predict that residue in a previously ungrazed strip would have similar nutrient quality as CT in our experiment. The increase in quality of CT residue shows the benefits of strip grazing in a more intensive corn residue grazing system beyond 42 d. It is worth noting that cattle in the strip grazing system may have decreased time spent traveling during the first part of grazing, due to a smaller pen size. Continuously grazed cattle were observed to have more movement in the first 14 d grazing period as they continued to select husks and look for minimal residual corn in the entire grazing paddock. During this time, it is hypothesized that the trampling of husks and leaves were increased across the entire paddock, with precipitation magnifying the loss of these components with greater nutritive quality. When the first strip fence was removed on d 14, SG cattle were observed as being less selective in their grazing behavior, and readily consuming leaves and husks instead of searching for residual corn, making these components more available for consumption due to decreased selectivity and losses from trampling. The decrease in movement early in the grazing period should also result in less energy expenditures of the cow that is associated with walking, potentially allowing for reallocation of this energy toward BW gain. Previous literature has also shown that younger cattle or cows that have not previously grazed corn residue need an acclimation period to ensure desirable performance (Fernandez-Rivera and Klopfenstein, 1989). We believe that strip grazing during a residue adjustment period may allow cattle to become less selective early on and decrease residue losses from trampling.

No differences were detected in subsequent corn yields following two grazing seasons, supporting our hypothesis. This agrees with previous research reporting that grazing corn residue should not decrease subsequent crop yield of soybeans and corn (Clark et al., 2004; Drewnoski et al., 2015).

Although treatment yields were similar, we saw a trend for yield decline in the first strip in SG. Previous research has not been reported on the effects that strip grazing may have on subsequent crop yield within comparative strips. In our study, supplement and mineral feeders, along with water troughs, were permanently located within the initial strip of SG. We hypothesize that this area of the field had the most animal trafficking, due to the continued reoccurrence of cattle to these areas, suggesting that increased trafficking and heavier grazing densities earlier in the grazing season may lower yields. Cattle were continually observed returning to the stationary water source and observed at the feed bunks during the time of supplementation. Therefore, the movement of water and feeder location may be necessary to ensure that these areas are not over trafficked. For the first 14 d, stocking rates were 9.1 $hd \cdot ha^{-1}$ (yr 1 and 2) and 10.7 $hd \cdot ha^{-1}$ (yr 3) in SG. Clark et al. (2004) grazed mature cows at a stocking density of 3.7 $hd \cdot ha^{-1}$ in 4 week intervals. The authors noted that in yr 3 there was an 8% soybean yield decline when grazed in the second of five grazing intervals compared to an ungrazed control, although yields averaged over the 3-yr experiment were not different. The yield decline was attributed to residue grazing during above freezing temperatures and increased precipitation. If strip grazing is utilized, early movement of strip fences may be necessary to decrease stocking rates in paddocks when heavy precipitation occurs. Moving feeder and water location as strip fences are moved may also be a management strategy to decrease the concentration of cattle in a specific area.

In conclusion, strip grazing of corn residue by beef cattle increased animal performance due to increased forage quality later in the grazing season. Subsequent crop yields were not affected by the grazing of corn residue. However, yields tended to be decreased in the initial strips of SG treatments, likely due to heavier trafficking from increased stocking rates. These results support the need for implementation of alternative management approaches when strip grazing corn residues in Illinois.

LITERATURE CITED

Betteridge, K., A. Mackay, T. Shepherd, D. Barker, P. Budding, B. Devantier et al. 1999. Effect of cattle and sheep treading on surface configuration of a sedimentary hill soil. Soil Research. 37(4): 743-760.

Clark, J. T., J. R. Russell, D. L. Karlen, P. L. Singleton, W. D. Busby, and B. C. Perterson. 2004. Soil surface property and soybean yield response to corn stover grazing. Agron. J. 96: 1364-1371.

Drewnoski, M. E., L. A. Stalker, J. C. MacDonald, G. E. Erickson, K. J. Hanford, and T. J. Klopfenstein. 2015. Effect of corn residue removal on subsequent crop yields. Nebraska Beef Report. : 53-55.

Federation of Animal Science Societies. 2010. Beef Cattle. Pages 61 in Guide for the Care and use of Agricultural Animals in Research and Teaching. 3rd ed. Federation of Animal Science Societies.

Fernandez-Rivera, S., and T. J. Klopfenstein. 1989. Yield and quality components of corn crop residues and Utilization of these residues by grazing cattle. J. Anim. Sci. 67(2): 597-605.

Gerrish, J. R. 1996. Extending the grazing season. Missouri Grazing Manual. Univ. Missouri Ext. Publ. M157. Univ. Missouri Ext., Columbia.: 113.

Gutierrez-Ornelas, E., and T. Klopfenstein. 1991. Changes in availability and nutritive value of different corn residue parts as affected by early and late grazing seasons. J. Anim. Sci. 69(4): 1741-1750.

Jones, E. R., S. Swain, R. A. Peiffer, and S. Jacobsen. 1998. Year-round grazing on the delmarva peninsula. Bull. A-111. : Delaware State Univ., Dover.

Klopfenstein, T., L. Roth, S. Fernandez-Rivera, and M. Lewis. 1987. Corn residues in beef production systems. J. Anim. Sci. 65(4): 1139-1148.

Krenzer, E., C. F. Chee, and J. Stone. 1989. Effects of animal traffic on soil compaction in wheat pastures. J. Prod. Agric. 2(3): 246-249.

Lamm, W. D., and J. K. Ward. 1981. Compositional changes in corn crop residues grazed by gestating beef cows. J. Anim. Sci. 52(5): 954-958.

Mapfumo, E., D. Chanasyk, M. Naeth, and V. Baron. 1999. Soil compaction under grazing of annual and perennial forages. Can. J. Soil Sci. 79(1): 191-199.

Miller, A. J., R. K. Faulkner, R. K. Knipe, D. R. Strohbehn, D. F. Parrett, and L. L. Berger. 2001. Critical control points for profitability in the cow-calf enterprise. Prof. Anim. Sci. 17: 295-302.

Oltjen, J. W., and J. L. Beckett. 1996. Role of ruminant livestock in sustainable agricultural systems. J. Anim. Sci. 74(6): 1406-1409.

Poore, M., G. Benson, M. Scott, and J. Green. 2000. Production and use of stockpiled tall fescue to reduce beef production costs. Proceedings of the American Society of Animal Science.

Rayburn, E., and B. Abaye. Tracey, and MA Sanderson. 2007. Assessing species composition and forage quality. Forage Utilization for Pasture-Based Livestock Production, NRAES-173.Natural Resource, Agriculture and Engineering Service, Ithaca NY.

Russell, J. R., M. R. Brasche, and A. M. Cowen. 1993. Effects of grazing allowance and system on the use of corn-crop residues by gestating beef cows. J. Anim. Sci. 71(5): 1256-1265.

TABLES AND FIGURES

Table 2.1. Composition (DM basis) of CGF/SBH supplement.

Item	Year		
Analyzed Nutrient Content	2012	2013	2014
CP	19.0	19.6	17.0
NDF	45.1	43.6	60.6
ADF	27.2	21.2	31.3

Table 2.2. Effect of grazing method on cow performance.

	Grazing System[1]			
Item	CG	SG	SEM	*P*-value
Initial BW, kg	640.8	641.5	0.99	0.63
Final BW, kg	644.4[b]	654.6[a]	3.34	0.04
Change in BW, kg	3.4[b]	13.2[a]	2.95	0.04
Initial BCS	5.9	6.0	0.08	0.46
Final BCS	5.8	5.9	0.09	0.77
Change in BCS	-0.1	-0.1	0.47	0.31

[1]CG = continuous grazing, SG = strip grazing

[a,b]Within a row, means without common superscripts differ ($P < 0.05$)

Table 2.3. Nutrient composition of forage at various time points (yr 1).

	Treatment[1]				
Analysis (% DM)	CG	SG	CT	SEM	*P*-value
d 14			.		
NDF	77.5	75.0	.	1.4	0.15
ADF	54.2	56.0	.	1.5	0.34
CP	3.80	3.99	.	0.23	0.48
OM	88	89	.	2	0.75
d 28					
NDF	69.3	72.1	.	2.2	0.28
ADF	59.8^{a}	54.4^{b}	.	1.2	<0.01
CP	3.87	4.36	.	0.29	0.18
OM	77	82	.	2	0.08
d 42					
NDF	77.0^{a}	71.7^{b}	76.9^{a}	1.4	0.02
ADF	54.6	55.0	56.0	1.4	0.78
CP	3.28^{b}	3.11^{b}	4.31^{a}	0.13	<0.01
OM	71^{b}	73^{b}	83^{a}	2	<0.01

[1]CG = continuous grazing, SG = strip grazing, CT = control

[a,b]Within a row, means without common superscripts differ ($P < 0.05$)

Table 2.4. Forage availability and nutrient composition (yr 2)

Item	Treatment[1]				
	CG	SG	CT	SEM	*P*-value
Pre Grazing					
Residue Availability					
Total, kg/ha	8420	9212	8552	327	0.21
Cobs, kg/ha	1112	1268	1137	95	0.47
Cobs, % of total	13.0	13.9	13.3	1.0	0.80
Leaves/husks, kg/ha	3581	3934	3635	177	0.33
Leaves/husks, % of total	42.9	42.5	42.4	1.3	0.96
Stalks, kg/ha	3727	4010	3780	177	0.49
Stalks, % of total	44.1	43.6	44.3	1.2	0.91
Nutrient Composition (% DM)					
NDF	73.3^{a}	72.3^{ab}	71.0^{b}	0.5	0.02
ADF	47.5^{ab}	48.6^{a}	46.6^{b}	0.5	0.02
CP	3.96^{ab}	3.53^{b}	4.39^{a}	0.21	0.03
OM	93	93	93	<1	0.32
Post Grazing					
Residue Availability					
Total, kg/ha	3979^{b}	4535^{b}	6668^{a}	271	<0.01
Cobs, kg/ha	354^{b}	418^{b}	829^{a}	64	<0.01
Cobs, % of total	9.1	9.0	12.6	1.3	0.11
Leaves/husks, kg/ha	911^{b}	1226^{b}	2839^{a}	150	<0.01
Leaves/husks, % of total	23.4^{b}	26.9^{b}	42.2^{a}	2.1	<0.01
Stalks, kg/ha	2714	2891	3000	182	0.54
Stalks, % of total	67.5^{a}	64.2^{a}	45.2^{b}	2.1	<0.01
Nutrient Composition (% DM)					
NDF	79.5	79.2	77.7	0.5	0.06
ADF	57.9^{a}	56.7^{a}	53.8^{b}	0.6	<0.01
CP	3.10^{b}	3.12^{b}	3.68^{a}	0.14	<0.01
OM	89^{b}	89^{b}	92^{a}	1	0.03

[1]CG = continuous grazing, SG = strip grazing, CT = control

[a,b]Within a row, means without common superscripts differ ($P < 0.05$)

Table 2.5. Effects of grazing order on forage availability and nutrient composition (yr 2).

Item	Grazing order within SG 1	2	3	SEM	*P*-value
Pre Grazing					
Residue Availability					
Total, kg/ha	9090	8897	9668	496	0.54
Cobs, kg/ha	1281	1183	1343	154	0.76
Cobs, % of total	14.2	13.3	14.3	2.1	0.94
Leaves/husks, kg/ha	3821	3817	4167	403	0.79
Leaves/husks, % of total	41.8	42.9	42.8	2.2	0.92
Stalks, kg/ha	3988	3897	4158	245	0.74
Stalks, % of total	44.0	43.8	42.9	1.6	0.86
Nutrient Composition (% DM)					
NDF	72.4	71.4	73.0	0.9	0.49
ADF	48.7	48.6	48.5	0.8	0.98
CP	3.32	3.74	3.53	0.29	0.62
OM	94	93	93	<1	0.64
Post Grazing					
Residue Availability					
Total, kg/ha	4219	4314	5071	251	0.10
Cobs, kg/ha	235^{b}	331^{b}	687^{a}	82	0.02
Cobs, % of total	5.7	7.5	13.7	2.0	0.07
Leaves/husks, kg/ha	1102	1145	1430	243	0.61
Leaves/husks, % of total	25.9	26.5	28.2	5.0	0.94
Stalks, kg/ha	2881	2838	2954	244	0.94
Stalks, % of total	68.4	66.0	58.1	4.6	0.32
Nutrient Composition (% DM)					
NDF	78.9	80.2	78.5	1.0	0.46
ADF	58.9^{a}	56.1^{b}	55.1^{b}	0.7	0.02
CP	2.80	3.24	3.33	0.15	0.09
OM	86	88	92	2	0.28

^{a,b}Within a row, means without common superscripts differ ($P < 0.05$)

Table 2.6. Effect of grazing method on subsequent corn yield.

	Treatment[1]				
Item	CG	SG	CT	SEM	*P*-value
Yield, Tons/ha[2]	12.44	12.97	12.96	0.49	0.19

[1]CG = continuous grazing, SG = strip grazing, CT = control

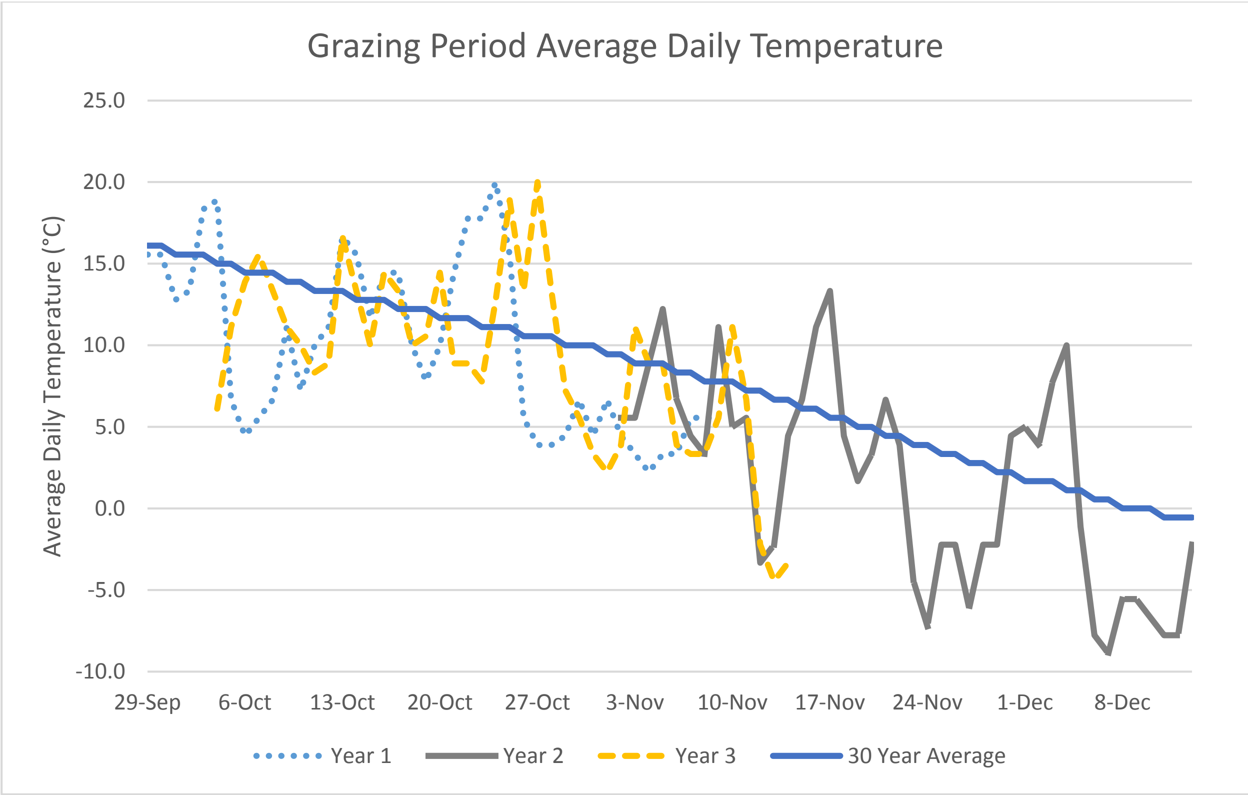
[2]2013 and 2014 combined corn yield

Table 2.7. Effect of grazing order on subsequent corn yield.

	Grazing Order[1]				
Item	1	2	3	SEM	*P*-value
Yield, Tons/ha[2]	12.48	13.41	13.00	0.28	0.10

[1]Within strip grazing treatment
[2]2013 and 2014 combined corn yield

Figure 2.1. Average daily temperature during the 42 d grazing period.



CHAPTER 3

AGRONOMIC ASSESSMENT OF GRAZING METHOD OF CORN RESIDUES ON SOIL PROPERTIES

ABSTRACT

The objectives were to evaluate the effects of beef cows grazing corn residues on soil physical and chemical properties. Two grazing methods (strip grazing, **(SG)** and continuous grazing, **(CG)**) and a control (ungrazed, **(CT)**) were arranged in a randomized complete block design with 3 replications for 2 yr. Within SG, subplots were assigned with a grazing order **(1, 2, 3)**, with 3 replications each yr to determine the effects that grazing duration and stocking densities in a strip grazing system have on soil properties. In SG, cattle grazed subplot 1 for 14 d, subplot 1 and 2 for 14 d, and subplots 1, 2, and 3 for 14 d. Thirty-six spring-calving, multiparous Angus cows were utilized in years 1 (BW = 648 ± 41 kg) and 2 (BW = 710 ± 71 kg) at a stocking density of 3.0 $hd \cdot ha^{-1}$ in CG, and 9.1, 4.6, and 3.0 $hd \cdot ha^{-1}$ for subplots 1, 1 and 2, and 1, 2, and 3 in SG, respectively. Cattle grazed for 42 d beginning on 29 Sept. 2012 (Year 1) and 2 Nov. 2013 (Year 2). Soil samples were collected before and after cattle grazing each yr. Paddock dimensions were marked during yr 1 with GPS coordinates so that the same treatment was applied to the same paddock area and location each year. Bulk density was increased ($P < 0.01$) in both grazing treatments compared to CT, but penetration resistance was not affected ($P = 0.56$) by treatment. Water aggregate stability was decreased ($P = 0.01$) in CG and SG compared to CT. Soil pH was increased ($P < 0.01$) in SG. Soil nitrate ($N\text{-}NO_3$) was increased ($P = 0.03$) in CG compared to SG, with CT being intermediate. Soil ammonium ($N\text{-}NH_4$) was not affected ($P = 0.14$) by grazing treatment. Grazing order in SG did not affect ($P \geq 0.25$) soil physical or chemical properties. Although livestock grazing increased soil compaction, root restricting levels

of compaction were not reached. Results indicate that cattle and crops can be integrated with the grazing of corn residue, resulting in minimal effects on soil properties.

INTRODUCTION

Feed costs are the greatest expense for beef cattle producers (Miller et al., 2001). Grazing corn (*Zea mays* L.) residue is an effective way of reducing feed costs in the winter months for Midwestern cow/calf operations (Klopfenstein, 1987). However, there is potential for negative changes in soil properties caused by animal trampling when grazing.

Cattle can exert as much or more surface pressure to the soil as farming equipment (Greenwood et al., 1997). However, compaction from livestock is typically limited to the soil surface (Ferrero and Lepiec, 2000). The destruction of soil structure by animal trampling typically only occurs in wet, frequently visited areas (Shealth and Carlson, 1998). Limiting grazing to temperature periods below freezing may also negate negative soil physical properties associated with grazing (Clark et al., 2004).

Documentation of soil structure changes have primarily focused on equipment wheel trafficking, in which compaction has caused increased bulk density (BD) and decreased total pore space (Lal, 1996), and poor water infiltration (Wallatt and Pullar, 1983). Although animal trampling negatively affects soil physical properties similarly, yield reductions have not occurred when grazing on soils used for row crop production (Drewnoski et al., 2015; Clark et al., 2004).

The introduction of livestock into cropping systems may provide improved nutrient cycling (Entz et al., 2005) and biodiversity. Total C and N stocks can increase with cattle integration (Tracy and Zhang, 2008) because of the positive influence on carbon cycling (Wardle et al., 2004).

Forage utilization can be increased by strip grazing dormant forages with livestock. However, strip grazing corn residue has shown to decrease subsequent crop yields in the initial grazing strip (Lehman et al., 2015). Increased grazing densities have shown to increase surface BD and penetration resistance (PR) compared to lower grazing densities (Mapfumo et al., 1999).

Minimal documentation has been completed on the effects of cattle integration and alternative grazing methods on soils used for row crop production. Our objectives were to evaluate the effects of corn residue grazing and grazing method on soil physical and chemical properties. We hypothesized that soil compaction would be limited to the soil surface, but that greater grazing densities with strip grazing would result in increased compaction. We also hypothesized that available N would be increased with cattle grazing treatments, and that increased stocking rates in the initial strip of SG would concentrate compaction and available N compared to strips 2 and 3.

MATERIALS AND METHODS

Experimental Design

A 2-yr field experiment was initiated in 2012 to investigate the effects of beef cows grazing (continuous or strip-grazing) corn residues on soil physical and chemical properties at the University of Illinois Dudley Smith Farm near Pana, Illinois (39°39’ N, 89°08’ W). Thirty-six Angus cows were grazed in yr 1 (BW = 648 ± 41 kg) and 2 (BW = 710 ± 71 kg). Cattle grazing began on 29 Sept. 2012 (yr 1) and 2 Nov. 2013 (yr 2). Two grazing methods (strip grazing, **(SG)** and continuous grazing, **(CG)**) and a control (ungrazed, **(CT)**) were arranged in a randomized complete block design with 3 replications, allowing for 9 grazing paddocks. Within SG, subplots were assigned with a grazing order **(1, 2, 3)**, with 3 replications each yr to determine the effects that grazing duration and stocking densities in a strip grazing system have on soil properties. Cattle were grazed at a stocking density of 3.0 cows·ha^{-1} in CG, and 9.1, 4.6, and 3.0 cows·ha^{-1} for subplots 1, 1 and 2, and 1, 2, and 3 in SG, respectively. In SG, cattle grazed subplot 1 for 14 d, subplot 1 and 2 for 14 d, and subplots 1, 2, and 3 for 14 d. Each paddock was 1.97 ± 0.03 ha. The same field was utilized in both yr. Paddock dimensions were marked during yr 1 with GPS coordinates (GARMIN eTrex personal navigator, 12 channel, GARMIN International, Inc, Kansas, USA), so that the same treatment was applied to the same paddock area and location each yr. Cows grazed corn residue fields for 6 weeks (42 d). Continuous treatments were allowed access to the entire paddock throughout the entire duration of grazing. In the strip treatments, paddocks were divided into 3 strips using one strand of temporary electric fence, allowing access to a new strip every 14 d. The first 14 d period cows were grazing on the first third of the paddock. They were then allowed access to the first and second strip for the next 14 d. The last 14 d of the experiment allowed strip treatments to have access to the entire paddock (first, second, and third strip). In SG, strips were not back fenced, so that cattle could travel back to the initial strip for access to a stationary water and mineral source, and when supplemental feed was offered.

Soil Measurements

Two yr (2012 and 2013) of soil analysis were conducted. Soils at this farm site are of the Virden series, consisting of silty, clay loams classified as fine, smectitic, mesic Vertic Argiaquolls (Tracy and Zhang, 2008). Soil sampling was conducted four times over the course of the first two yr. Soils were sampled before and after the 6 week period of residue grazing, on 6 Sept and 20 Nov 2012 (yr 1) and 23 Oct and 19 Dec 2013 (yr 2). Two soil samples (yr 1) and 3 soil samples (yr 2) were collected from random locations within each 1/3 of CG and CT and within SG subplots to reduce geographical variation within treatment areas. Six total samples (yr 1) and 9 total samples (yr 2) were collected from each treatment paddock during each sampling.

Soils were sampled with a light weight automated soil sampler (Amity Tech, Fargo, ND) to depths of 50 cm. Cores were taken back to the Agroecology lab at University of Illinois Urbana-Champaign and cut into increments of 10 cm. Soil core samples were analyzed for bulk density (BD, Mg/m^3) and water aggregate stability (WAS, %) and chemical properties of soil N-nitrate ($N\text{-}NO_3$, mg/kg), N-ammonium ($N\text{-}NH_4$, mg/kg), and soil pH. After measuring gravimetric water content at each depth, BD was determined using the core method (Blake and Hartge, 1986) at each depth increment. Field wet soil was analyzed for $N\text{-}NO_3$ and $N\text{-}NH_4$ using KCL extraction followed by flow injection analysis with a Lachat automated analyzer (Lachat Intruments, Loveland, CO). Samples were then air dried and sieved by 2 mm. Soil aggregates of the soil fraction between 1-2 mm from the top two depths were run for WAS with an Eijkelkamp wet sieving apparatus (Eijkelkamp, Giesbeek, The Netherlands) following Kemper and Rosenau (1986). Soil pH (1:1 soil:water) was determined via potentiometry with a Mettler Toledo AG SevenEasy pH Meter (Schwerzenbach, Switzerland).

Penetration resistance (PR, kPa) was recorded with a Field Scout SC 900 Soil Compaction Meter (Spectrum Technologies, Plainfield, IL) with a cone basal area of 1.28 cm^2 and a cone angle of 30°. Thirty measurements were taken per paddock and were averaged to the depths of 0-5, 5-10, 10-20, 20-30, 30-40, and 40-50cm. To characterize our experimental plots at the beginning of the study, a sample was taken with a shovel from the center of each subplot representative of the A horizon to determine the maximum bulk density (BDmax, Mg/m^3) and the particle size distribution by the hydrometer method (American Society for Testing and Materials, 1982; Gee and Bauder, 1986).

Statistical Analysis

Year was considered a random effect in the statistical analyses. Table 3.7 reflects the weather conditions for both years relative to the 30-yr average for Pana, IL. In addition, statistical analyses were conducted on the differences between the recorded variables before and after the 6 week grazing period to more clearly separate the animal grazing effect on the soil properties in both yr. Data were analyzed using the GLIMMIX procedure of SAS software version 9.4 (SAS Institute Inc., 2013). Grazing and depth were considered fixed effects, while blocks and yr were considered random effects. Dependent variables measured at successive depths were analyzed using a repeated measures approach selecting AR(1) as the variance-covariance matrix of the residuals based on the Akaike's Information Criterion (Gbur et al., 2012). Probability values associated with the analysis of variance of soil physical and biochemical parameters are presented in table 3.1. When appropriate, least square means were separated using the PDIFF option of LSMEANS in SAS PROC GLIMMIX; least significant differences (LSD) values are reported at alpha level (α)=0.05. A similar statistical approach was used to further investigate the SG strategy, where we studied the soil properties within each of the areas sequentially accessible to livestock, creating an artificial factor "grazing order" (levels, 1, 2, 3) where the livestock grazed for a period of 2 weeks at a time with no back fencing. Grazing order and depth were considered fixed effects, while blocks and years were considered random effects. Statistical model and SAS codes are available upon request from the authors.

RESULTS

Table 3.1 shows the exact probability values (*p*-values) associated with the different sources of treatment variation in the analysis for PR, BD, WAS, available N, and soil pH across the two yr of the experiment. Table 3.2 shows the *p*-values associated with the different sources of grazing order variation in the analysis for PR, BD, WAS, available N, and soil pH across the two years of the experiment.

Soil Physical Properties

Penetration resistance was not significantly influenced ($P = 0.56$) by cattle grazing, but was influenced ($P < 0.01$) by depth. Bulk density was significantly influenced by grazing ($P < 0.01$) and depth ($P < 0.01$). Bulk density was increased for both CG and SG compared to CT, and BD increased through the soil profile to 20 cm and then remained similar as it approached 50 cm (Table 3.3). Water aggregate stability was significantly influenced by grazing ($P = 0.01$) and tended to be influenced by depth ($P = 0.10$). Continuous grazed and SG had decreased WAS compared to CT, and WAS tended to have a greater decline from 0-10 compared to 10-20 (Table 3.3).

Grazing order within SG did not influence soil physical properties ($P \geq 0.42$) (Table 3.5). Penetration resistance was influenced by depth ($P < 0.01$) and BD tended ($P = 0.08$) to be influenced by depth within SG.

Soil Chemical Properties

For nutrient characterization, concentrations of soil ammonium ($N\text{-}NH_4$) were not influenced ($P = 0.14$) by grazing. However, concentrations of soil nitrate ($N\text{-}NO_3$) were influenced ($P = 0.03$) by grazing. Continuous grazing increased soil nitrate compared to SG, with CT being intermediate (Table 3.4). Available nitrogen was also influenced ($P < 0.01$) by depth, reflecting nutrient stratification. Soil pH was significantly influenced ($P < 0.01$) by grazing, as SG had greater soil pH compared to CG and CT. Soil pH was not influenced ($P = 0.32$) by soil depth.

Grazing order did not influence available N or soil pH ($P \geq 0.25$). However, depth influenced soil available N ($P \leq 0.03$) (Table 3.6).

DISCUSSION

Increased BD values for grazed treatments suggest that compaction occurred with the grazing of corn residue by cattle, supporting our hypothesis. However, our BD values of 1.36 g/cm^3 were less than the theoretical plant root restricting BD value of 1.50 g/cm^3 for silty clay loams (Kaufmann et al., 2010). Soils in this experiment have shrink-swell potential and high organic matter levels, which are typical of resilient soils found in Illinois (Web Soil Survey, 2015). Following a disturbance, such as mechanical tillage or compaction from machinery or livestock trafficking, resilience allows soil to return to its previous state. In addition, compaction from hoof traffic may have been alleviated from freezing and thawing processes, as well as shrinking and swelling processes occurring between the time of grazing and crop growth the following growing season. However, soil samples were not collected in the spring following fall grazing of corn residue, so reduction in BD from natural soil processes and spring tillage in our study site cannot be confirmed. Previous experiments have shown increased soil disturbance and compaction from grazing corn residue by beef cattle, although authors noted that the shallow compaction following grazing was likely removed after tillage (Tracy and Zhang, 2008; Clark et al., 2004). Clark et al. (2004) reported that grazing did not affect BD, yet PR was increased as much as 44% in the top 10 cm when grazed in October and November. These results confirm our finding of increased soil compaction post-grazing, although our experiment and Clark et al. (2004) found the increase in soil compaction with alternative compaction measurements. The results of the experiment conducted by Clark et al. (2004) suggest that soil compaction will be minimalized if grazing occurs on frozen soils. However, residue nutrient quality declines later in the grazing season (Gutierrez-Ornelas and Klopfenstein, 1991), so cattle producers will often graze before soils are frozen. We also reported increased compaction after grazing, but in the form of increased BD instead of PR. Up to 75% of variation in PR can be attributed to soil moisture at the time of sampling (Silva et al., 2003). Soil moisture did not differ between treatments at the time of soil sampling for our experiment; however, variations in soil moisture between our experiment and Clark et al. (2004) may exist.

Although increased BD was present after grazing in our experiment, it was not severe or root limiting, and PR values were insignificant. Ungar and Kasper (1994) suggested that PR of 2000 kPa in a dry soil inhibits root growth. Average PR values post-grazing in our experiment were 1307, 1271, and 1238 kPa for CG, SG, and CT, respectively, well below the critical value of 2000 kPa. Thus, subsequent crop growth and yield should not be hindered. As expected, BD below 10 cm were increased relative to the upper 10 cm of the soil profile. The increase in BD with depth is likely related to greater additions of corn residues and increased activity of micro and macro fauna and roots in the topsoil (Hamza and Anderson, 2005).

Cattle grazing also decreased WAS when compared to CT. Animal hoof traffic likely contributed forces on the soil surface in CG and SG, which disrupted existing aggregates. Coulter et al. (2009) reported that water stable aggregation is increased in the response to greater residue production in a continuous corn system relative to a corn-soybean rotation. Corn residue has a greater resistance to decomposition due to its increased C/N ratio and lignin content, resulting in increased humic acid precursors in the soil following corn production. The decrease in WAS in our grazed treatments suggest that the removal and consumption of corn residue by cattle could negatively impact the aggregation processes benefiting from large amounts of corn residue production. The consumption of residues in grazed treatments may have resulted in decreased C additions to the soil. Greater C additions from increased crop residues have been reported to increase the formation of soil aggregates (Martens, 2000).

The increase in N-NO_3 with CG relative to SG is more complex. We had hypothesized that grazing may increase available N, primarily due to nutrient additions to the system in the form of a high protein cattle feed supplement (corn gluten feed and soybean hull pellets). However, soil nitrate was not increased in SG. Due to the differences in grazing method and animal location, CG cattle may have more evenly returned nutrients to the entire treatment area via manure and urine. Strip grazed cattle, unlike CG, did not have access to the entire grazing paddock for the full 42 d grazing period by design. Due to the design of the strip grazing system, 6 head were grazed in strip 1 from d 1-14 (9.1 $hd \cdot ha^{-1}$). Cows grazed strips 1 and 2 from d 15-28 (4.6 $hd \cdot ha^{-1}$), and strips 1, 2, and 3 from d 29-42 (3.0 $hd \cdot ha^{-1}$). This change in grazing method may have led to differences in manure dispersion between the two grazing treatments, creating limitations with sampling technique and sensitivity. Differences in residue utilization may also cause differences in soil available N. Over time, we believe that nutrient additions to the soil from cattle grazing may be more detectible, as continued grazing and tillage may disperse nutrients more uniformly within both CG and SG treatment areas. Increased residue utilization and consumption in SG may have removed residue and N from the SG system, whereas increased animal trafficking in CG may have led to increased residue decomposition and nutrient return to the soil. Tracy and Zhang (2008) saw increased total soil N when residue and cool season annual fields were grazed by beef cattle, compared to a continuous corn system. Welch et al. (2015) also noted that compacted soils had increased total carbon and P compared to non-compacted soils due to the densification of the soil creating more nutrients per unit area. Acuna and Villamil (2014) reported increased N-NO_3 under compacted soil surfaces compared to soils with decreased BD. Differences in previous experiments were attributed to densification of the topsoil. The consumption of high C/N ratio residue by grazing cattle may require less N additions to the cropping system, since less residue is being decomposed via soil activity. Since all treatments were fertilized equally, N additions to the soil that were not used during the growing season may still have been present in CG after the corn crop was harvested.

This study also set out to investigate the effects of grazing order within SG. The lack of significant effects on either soil physical or chemical properties by grazing order indicate that grazing affected soil properties similarly, regardless of grazing order. We hypothesized that that the first strip in SG would have increased PR and BD compared to strips 2 and 3, as well as increased available N. Cattle in SG grazed at greater stocking densities for the first 28 d of the experiment because the same number of cattle were grazed in a smaller area relative to CG. However, compaction differences were not significant with these increased stocking densities, so grazing at a high stocking density for an initial short duration, like in SG, should not result in increased compaction. Cattle were also observed returning to strip 1 throughout the grazing experiment due to the location of feed bunks and water sources. Although differences were not detected, further research with improved sampling sensitivity is needed to test the alternative effects that a SG system may have on both soil compaction and nutrient concentrations.

LITERATURE CITED

American society for testing and materials. Standard test methods for moisture-density relations of soils and soil-aggregated mixtures using 5.5-lb (2.49-kg) hammer and 12-in (305-mm) drop.1982. American Society for Testing and Materials, Standards in Building Codes.

Acuña, J., and M. B. Villamil. 2014. Short-term effects of cover crops and compaction on soil properties and soybean production in Illinois. Agron. J. 106(3): 860-870.

Blake, G. R., and K. H. Hartge. 1986. Bulk density. Methods of soil analysis, part 1. Madison (WI). Soil Science Society of America.

Clark, J. T., J. R. Russell, D. L. Karlen, P. L. Singleton, W. D. Busby, and B. C. Perterson. 2004. Soil surface property and soybean yield response to corn stover grazing. Agron. J. 96: 1364-1371.

Coulter, J. A., E. D. Nafziger, and M. M. Wander. 2009. Soil organic matter response to cropping system and nitrogen fertilization. Agron. J. 101(3): 592-599.

Drewnoski, M. E., L. A. Stalker, J. C. MacDonald, G. E. Erickson, K. J. Hanford, and T. J. Klopfenstein. 2015. Effect of corn residue removal on subsequent crop yields. Nebraska Beef Report. : 53-55.

Entz, M., W. Bellotti, J. Powell, S. Angadi, W. Chen, K. Ominski et al. 2005. Evolution of integrated crop-livestock production systems. Grassland: A Global Resource. Wageningen Academic Publ., Wageningen, the Netherlands. : 137-148.

Ferrero, A., and J. Lipiec. 2000. Determining the effect of trampling on soils in hillslope-woodlands. International Agrophysics. 14(1): 9-16. Retrieved 15 May 2015, from the SCOPUS database.

Gbur, E.E., W.W. Stroup, K.S. McCarter, S. Durham, L.J. Young, M. Christman, M. West, and M. Kramer (eds.). 2012. Analysis of generalized linear mixed models in the agricultural and natural resources sciences American Society of Agronomy, Crop Science Society of America, Soil Science Society of America, Madison, WI.

Gee, G. W., and J. W. Bauder. 1986. Particle-size analysis. Methods of soil analysis, part 1: Physical and mineralogical methods. Madison (WI). Soil Science Society of America Journal.

Greenwood, K. L., D. A. Macleod, and K. J. Hutchinson. 1997. Long-term stocking rate effects of soil physical properties. Aust. J. Exp. Agric. 37: 413-419.

Gutierrez-Ornelas, E., and T. Klopfenstein. 1991. Changes in availability and nutritive value of different corn residue parts as affected by early and late grazing seasons. J. Anim. Sci. 69(4): 1741-1750.

Hamza, M., and W. Anderson. 2005. Soil compaction in cropping systems: A review of the nature, causes and possible solutions. Soil Tillage Res. 82(2): 121-145.

Kaufmann, M., S. Tobias, and R. Schulin. 2010. Comparison of critical limits for crop plant growth based on different indicators for the state of soil compaction. Journal of Plant Nutrition and Soil Science. 173(4): 573-583.

Klopfenstein, T., L. Roth, S. Fernandez-Rivera, and M. Lewis. 1987. Corn residues in beef production systems. J. Anim. Sci. 65(4): 1139-1148.

Lal, R. 1996. Axle load and tillage effects on crop yields on a mollic ochraqualf in northwest ohio. Soil Tillage Res. 37(2-3): 143-160. Retrieved 15 May 2015, from the SCOPUS database.

Lehman, B. E., A. R. Green, L. F. Rodrigez, M. B. Villamil, T. Liu, and D. W. Shike. 2015. Agronomic assessment of grazing method of corn residues on cow performance, residue utilization, and crop yield. M.S. Thesis.

Mapfumo, E., D. Chanasyk, M. Naeth, and V. Baron. 1999. Soil compaction under grazing of annual and perennial forages. Can. J. Soil Sci. 79(1): 191-199.

Martens, D. A. 2000. Plant residue biochemistry regulates soil carbon cycling and carbon sequestration. Soil Biol. Biochem. 32(3): 361-369.

Miller, A. J., R. K. Faulkner, R. K. Knipe, D. R. Strohbehn, D. F. Parrett, and L. L. Berger. 2001. Critical control points for profitability in the cow-calf enterprise. Prof. Anim. Sci. 17: 295-302.

Sheath, G., and W. Carlson. 1998. Impact of cattle treading on hill land: 1. Soil damage patterns and pasture status. N. Z. J. Agric. Res. 41(2): 271-278.

Silva, A. P., S. Imhoff, and M. Corsi. 2003. Evaluation of soil compaction in an irrigated short-duration grazing system. Soil Tillage Res. 70(1): 83-90.

Soil Survey Staff. Web soil survey. NRCS-USDA; 2012.2015(May) from the http://websoilsurvey.nrcs.usda.gov/ database.

Tracy, B. F., and Y. Zhang. 2008. Soil compaction, corn yield response, and soil nutrient pool dynamics within an integrated crop-livestock system in Illinois. Crop Sci. 48(3): 1211-1218.

Unger, P. W., and T. C. Kaspar. 1994. Soil compaction and root growth: A review. Agron. J. 86(5): 759-766.

Wardle, D. A., R. D. Bardgett, J. N. Klironomos, H. Setala, W. H. van der Putten, and D. H. Wall. 2004. Ecological linkages between aboveground and belowground biota. Science. 304(5677): 1629-1633.

Welch, R. Y., and Nafziger,E., Villamil,M. B. 2015. Using cover crops to alleviate compaction in organic grain farms. M.S. Thesis.

Willatt, S., and D. Pullar. 1984. Changes in soil physical properties under grazed pastures. Soil Research. 22(3): 343-348.

TABLES

Table 3.1. Probability values associated with the analysis of the effects of grazing and depth, and their interactions on the studied soil variables.

Source	PR	BD	WAS	NH4	NO3	pH
			Probability values			
Grazing	0.56	<0.01	0.01	0.14	0.03	<0.01
Depth	<0.01	<0.01	0.10	<0.01	<0.01	0.32
Grazing*D	0.32	0.98	0.60	0.92	0.97	0.99

Table 3.2. Probability values associated with the analysis of the effects of grazing order and depth, and their interactions on the studied soil variables.

Source	PR	BD	WAS	NH4	NO3	pH
			Probability values			
Order	0.42	0.75	0.50	0.53	0.25	0.39
Depth	<0.01	0.08	0.13	0.03	<0.01	0.59
Order*D	0.89	0.88	0.40	0.92	1.00	0.87

Table 3.3. Effects of cattle grazing on soil physical properties.

		Treatment[1]								
			CG			SG			CT	
Item	Depth	Pre	Post	D	Pre	Post	D	Pre	Post	D
PR, kPa	0-5	497	1169	672	552	947	395	445	858	413
	5-10	1226	1703	477	1273	1435	162	1156	1479	323
	10-20	1704	1307	-397	1735	1478	-257	1661	1345	-274
	20-30	1478	1185	-244	1528	1313	-103	1347	1351	252
	30-40	965	1023	708	610	1103	841	870	1126	849
Main Effect	0-40	1189	1307	197	1184	1271	143	1112	1238	260
BD, g/cm^3	0-10	1.32	1.36	0.05	1.29	1.36	0.07	1.26	1.27	0.01
	10-20	1.42	1.43	0.01	1.39	1.40	0.01	1.40	1.36	-0.04
	20-30	1.43	1.43	0.01	1.45	1.43	-0.02	1.41	1.36	-0.06
	30-40	1.42	1.40	-0.01	1.44	1.41	-0.03	1.41	1.37	-0.04
	40-50	1.40	1.38	-0.03	1.43	1.38	-0.05	1.43	1.35	-0.07
Main Effect	0-50	1.40	1.40	0.00[a]	1.40	1.40	0.00[a]	1.38	1.34	-0.04[b]
WAS, %	0-10	79.50	64.48	-15.02	81.21	60.16	-19.81	74.34	69.84	-4.50
	10-20	77.19	67.01	-10.19	81.7	69.93	-10.07	76.39	73.51	-2.88
Main Effect	0-20	78.35	65.74	-12.60[b]	81.45	65.04	-15.09[b]	75.37	71.68	-3.69[a]

[ab]Different superscripts within a row differ ($P < 0.05$)

[1]CG = continuous grazed; SG = strip grazed; CT = ungrazed control

Table 3.4. Effects of cattle grazing on soil chemical properties.

		Treatment								
			CG			SG			CT	
Item	D	Pre	Post	D	Pre	Post	D	Pre	Post	D
NH_4, mg N/kg	0-10	4.88	2.13	-2.75	5.15	2.28	-2.87	5.74	2.2	-3.54
	10-20	3.45	1.60	-1.84	3.53	1.85	-1.68	3.37	1.58	-1.78
	20-30	2.22	1.23	-0.99	2.39	1.42	-0.97	3.04	1.38	-1.66
	30-40	1.89	1.29	-0.60	2.16	1.37	-0.79	2.37	1.15	-1.20
	40-50	1.80	1.35	-0.45	1.97	2.75	0.78	2.23	1.38	-0.82
Main Effect	0-50	2.85	1.52	-1.32	3.04	1.94	-1.10	3.37	1.54	-1.82
NO_3, mg N/kg	0-10	12.46	8.94	-3.52	16.39	9.73	-6.66	14.13	11.75	-2.38
	10-20	8.82	7.51	-1.31	13.85	8.54	-5.31	13.67	8.12	-5.55
	20-30	5.81	7.94	2.14	10.62	8.04	-2.58	10.36	7.18	-3.18
	30-40	4.46	8.85	4.39	7.45	7.82	0.38	6.38	7.37	0.98
	40-50	4.30	9.64	5.34	6.26	9.64	3.38	4.43	7.94	3.48
Main Effect	0-50	7.17	8.58	1.41[a]	10.91	8.76	-2.16[b]	9.89	8.47	-1.41[ab]
pH	0-10	5.97	6.04	0.07	5.76	5.97	0.21	5.77	5.79	0.03
	10-20	6.06	6.08	0.03	5.87	6.00	0.14	5.82	5.91	0.10
	20-30	6.31	6.26	-0.05	6.09	6.21	0.12	6.02	6.05	0.02
	30-40	6.42	6.39	-0.03	6.27	6.37	0.10	6.16	6.17	0.01
	40-50	6.47	6.41	-0.07	6.31	6.40	0.09	6.25	6.24	-0.01
Main Effect	0-50	6.25	6.24	-0.01[b]	6.06	6.19	0.13[a]	6.00	6.03	0.03[b]

[ab]Different superscripts within a row differ ($P < 0.05$)

[1]CG = continuous grazed; SG = strip grazed; CT = ungrazed control

Table 3.5. Effects of grazing order on soil physical properties.

		Grazing Order[1]								
			1			2			3	
Item	D	Pre	Post	D	Pre	Post	D	Pre	Post	D
PR, kPa	0-5[a]	553.10	1071.07	517.98	466.07	907.58	441.51	635.80	861.14	225.34
	5-10[a]	1220.21	1711.83	491.62	1102.61	1314.46	211.84	1495.53	1278.47	-217.07
	10-20[b]	1691.29	1529.70	-161.59	1632.24	1370.19	-262.04	1882.76	1534.4	-348.36
	20-30[ab]	1605.55	1380.56	-67.14	1365.96	1219.29	-146.67	1611.06	1356.63	-85.73
	30-40[a]	695.77	1195.64	968.92	798.62	933.70	616.95	243.58	1180.48	936.91
BD, g/cm^3	0-10	1.28	1.37	0.10	1.28	1.33	0.05	1.32	1.37	0.05
	10-20	1.40	1.41	0.01	1.38	1.40	0.03	1.40	1.39	0.00
	20-30	1.47	1.43	-0.04	1.44	1.42	-0.02	1.43	1.44	0.01
	30-40	1.48	1.46	-0.02	1.42	1.37	-0.05	1.41	1.41	-0.01
	40-50	1.46	1.40	-0.07	1.42	1.36	-0.06	1.40	1.39	-0.01
WAS, %	0-10	87.29	62.23	-20.41	76.92	65.40	-11.53	80.44	52.85	-27.59
	10-20	79.95	68.93	-8.68	83.17	70.80	-9.28	81.93	70.05	-11.88

[ab]Different superscripts within a column differ ($P < 0.05$)

[1]Within SG

Table 3.6. Effects of grazing order on soil chemical properties.

		Grazing Order[1]								
			1			2			3	
Item	D	Pre	Post	D	Pre	Post	D	Pre	Post	D
NH_4, mg N/kg	0-10[b]	4.94	2.90	-2.04	5.11	2.23	-2.88	5.41	1.73	-3.69
	10-20[ab]	3.64	2.13	-1.51	3.13	1.53	-1.6	3.83	1.89	-1.93
	20-30[a]	2.33	1.75	-0.58	2.46	1.40	-1.06	2.38	1.12	-1.26
	30-40[a]	1.95	1.36	-0.59	2.61	1.42	-1.19	1.92	1.33	-0.59
	40-50[a]	2.20	1.79	-0.41	1.91	5.19	3.28	1.81	1.29	-0.52
NO_3, mg N/kg	0-10[c]	16.91	8.09	-8.82	13.04	9.44	-3.59	19.23	11.67	-7.56
	10-20[c]	16.02	9.56	-6.46	12.51	7.98	-4.53	13.03	8.09	-4.93
	20-30[bc]	12.60	8.17	-4.43	7.26	7.03	-0.22	11.99	8.91	-3.08
	30-40[ab]	9.24	7.63	-1.61	5.18	7.37	2.19	7.92	8.48	0.56
	40-50[a]	7.19	9.50	2.31	5.09	10.16	5.07	6.49	9.26	2.77
pH	0-10	5.72	5.95	0.24	5.96	6.02	0.06	5.61	5.95	0.34
	10-20	5.82	6.01	0.20	6.00	6.06	0.06	5.78	5.94	0.16
	20-30	6.11	6.24	0.14	6.19	6.26	0.07	5.99	6.13	0.14
	30-40	6.33	6.40	0.07	6.30	6.40	0.10	6.18	6.31	0.13
	40-50	6.35	6.42	0.07	6.33	6.46	0.13	6.25	6.32	0.08

[abc]Different superscripts within a column differ ($P < 0.05$)

[1]Within SG

Table 3.7. Experiment weather conditions relative to 30-yr average.

Item	Year 1 (2012)	Year 2 (2013)	30 Year Average
Precipitation, cm	67.4	81.4	115.9
Temperature, °C	13.9	11.1	11.7

CHAPTER 4

CONCLUSIONS

Strip grazing corn residue showed to be a valuable management strategy for increasing cattle performance during a set grazing period compared to the traditional continuous grazing system. Increased forage availability and nutrient quality from decreased grazing selectivity with strip grazing may also allow for opportunities to extend the residue grazing season into the winter months, further reducing production costs in the cow/calf industry. Grazing residue caused soil compaction, but root restricting levels of compaction were not reached, and soil surface compaction was likely alleviated by natural soil processes or by spring tillage. Additional research is needed to further explore the effects that residue grazing may have on WAS and long term soil nutrient concentrations. Minimal effects on subsequent corn yield were quantified with both grazing systems relative to the ungrazed control. However, the slight yield decrease in initial strips of the strip grazing system warrant further investigation. Increased stocking densities with strip grazing may imply the necessity of moveable watering and supplementation areas when heavy precipitation occurs.