

Research Article

Soil Hydrological Attributes of an Integrated Crop-Livestock Agroecosystem: Increased Adaptation through Resistance to Soil Change

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Integrated crop-livestock systems have been purported to have significant agronomic and environmental benefits compared to specialized, single-enterprise production systems. However, concerns exist regarding the effect of livestock in integrated systems to cause soil compaction, thereby decreasing infiltration of water into soil. Such concerns are compounded by projections of more frequent high-intensity rainfall events from anticipated climate change, which would act to increase surface runoff and soil erosion. A study was conducted to evaluate the effects of residue management, frequency of hoof traffic, season, and production system (e.g., integrated annual cropping versus perennial grass) on infiltration rates from 2001 through 2008 in central North Dakota, USA. Imposed treatments had no effect on infiltration rate at three, six, and nine years after study establishment, implying that agricultural producers should not be concerned with inhibited infiltration in integrated annual cropping systems, where winter grazing is used. The use of no-till management, coupled with annual freeze/thaw and wet/dry cycles, likely conferred an inherent resistance to change in near-surface soil properties affecting soil hydrological attributes. Accordingly, caution should be exercised in applying these results to other regions or management systems.

1. Introduction

The sustainability of agricultural production in the northern Great Plains of North America is inextricably linked to the amount and frequency of precipitation. Effective use of precipitation by plants requires the retention and movement of water into the soil, which is affected by vegetative cover and soil structure [1]. Management practices that either remove vegetative cover or deteriorate near-surface soil structure slow infiltration rates [2, 3]. Consequences of slower infiltration rates include greater surface runoff, increased erosion, and decreased on-site productivity. Such outcomes may be exacerbated by projected changes in climate, where a more vigorous hydrological cycle is expected to lead to more frequent high-intensity rainfall events [4]. Accordingly, understanding management effects on infiltration rates is important to ascertain potential off-site environmental impacts as well as long-term consequences to agricultural production.

Integrated crop-livestock systems have been purported to improve agricultural productivity, environmental quality, operational efficiency, and economic performance relative to specialized, single-enterprise production systems [5]. Benefits from crop-livestock integration emanate from production synergies brought about by using crops and crop residues for livestock feed while capturing nutrients from livestock wastes for crop production. While many attributes of integrated crop-livestock systems are positive, there are concerns regarding the role of hoof traffic from livestock in these systems to adversely affect near-surface soil conditions, with concomitant impacts on soil hydrological characteristics [6].

In 1999, a team of researchers at the USDA-ARS Northern Great Plains Research Laboratory initiated an integrated crop-livestock study aimed at evaluating production, nutritional, and environmental aspects of overwintering dry bred cows on swathed annual crops [7, 8]. From 2001 through 2008, infiltration rates were measured in the spring and fall

of each year at select locations in the established treatments, with the overarching purpose of quantifying treatment effects on near-surface soil hydrological attributes. Specifically, objectives of the research effort were to evaluate effects of residue management, frequency of hoof traffic, season, and production system (e.g., integrated annual cropping versus perennial grass) on infiltration rates for an integrated crop-livestock study located in central North Dakota, USA. As a guiding hypothesis for this research effort, we postulated that perennial grass pastures could be converted to a winter-grazed annual cropping system without adversely affecting soil hydrological attributes.

2. Materials and Methods

2.1. Site and Treatment Description. The research site was located at the USDA-ARS Northern Great Plains Research Laboratory southern research station approximately 5 km south of Mandan, North Dakota, USA (lat. 46°46'35", long. 100°54'20"). Soils at the site were Temvik-Wilton silt loams (FAO: Calcic Siltic Chernozems; USDA: Fine-silty, mixed, superactive, frigid Typic and Pachic Haplustolls) on a gently rolling upland (approximately 2% slope). Both Temvik and Wilton soils are considered well drained based on USDA-NRCS drainage class characterizations [9].

In 1999, two 6.0 ha crested wheatgrass (*Agropyron desertorum* (Fisch. ex. Link) Schult.) pastures were sprayed twice with glyphosate (*N*-(phosphonomethyl) glycine) in mid-May at 0.7 kg a.i. ha⁻¹ and converted to an annual crop sequence of oat/pea (*Avena sativa* L./*Pisum sativum* L.), triticale/sweet clover (*Triticum aestivum* × *Secale cereale*/ *Melilotus officinalis* L.), and corn (*Zea mays* L.) using no-till planting techniques. Beginning in 2007, the crop sequence was amended to oat/alfalfa (*Medicago* spp.)/hairy vetch (*Vicia villosa* Roth)/red clover (*Trifolium pratense* L.), Brown midrib sorghum-sudangrass (*Sorghum bicolor* L. Moench)/sweet clover/red clover, and corn. Each phase of the crop sequence was present each year in both pastures, which served as replicates. Oat and triticale/sorghum crop mixtures were planted in mid- to late May, while corn was planted in early June. All crops were planted with a John Deere 750 no-till drill in 19 cm rows (John Deere, Moline, Ill). Fertilizer was applied during planting every year in all crop phases as urea (70 kg N ha⁻¹ for all crops from 1999 to 2006, 35 kg N ha⁻¹ for oat and sorghum crop mixtures, and 70 kg N ha⁻¹ for corn in 2007 and 2008) and monoammonium phosphate (6 kg N ha⁻¹ and 11 kg P ha⁻¹ for all crops every year). Weeds were managed using preemergent herbicides following recommended practices by local farmers.

The oat and triticale/sorghum crop mixtures were harvested for grain between mid-August and early September with the straw spreader removed from the combine, which created a swath of straw and chaff for winter grazing. The corn was swathed for forage in mid- to late September. Crop swaths were oriented parallel to the direction of each crop or crop mixture (e.g., oat, triticale/sorghum, corn). Each crop or crop mixture was split into three residue management treatments including no residue removal (CONTROL), residue removal with a baler (HAYED), and residue

removal by grazing with livestock (GRAZED) (Figure 1). The CONTROL and HAYED treatments were randomly assigned within each crop or crop mixture at one end of the plot area, whereas the GRAZED treatment extended across the majority of the plot area and could not be randomly assigned due to logistical considerations associated with field operations and livestock management. Plot area within a crop or crop mixture was 0.05 ha for the CONTROL and HAYED treatments and 1.69 ha for the GRAZED treatment.

The swathed crop residues from the cropping sequence in the GRAZED treatment represented winter forage for ten 4–6-year-old dry bred Hereford cows, due to calve in late March. Grazing commenced in mid-November and ended in mid-February, with the oat crop mixture grazed first, triticale/sorghum crop mixture second, and corn last. Access to crop swaths was controlled by an electric fence and portable fence posts, which allowed for grazing on one crop or crop mixture at a time. Portable fences were oriented at right angles to the swaths within a crop or crop mixture and were moved daily to provide fresh forage for livestock. A shelter and water fountain was located on the end of each pasture within the GRAZED treatment. For each crop or crop mixture, grazing was initiated closest to the shelter and water fountain and extended toward CONTROL and HAYED treatments over time. Accordingly, the direction of grazing within a crop or crop mixture contributed to greater livestock traffic closer to the shelter and water fountain (Clay Erickson, personal communication).

Two 6.0 ha western wheatgrass (*Pascopyrum smithii* (Rydb.) Love) pastures were used as a perennial grass treatment for comparison of infiltration results with the annually cropped treatments. Swathed grass from the pastures was used as winter forage from 1999 through 2002 for the same number of cows managed similarly as outlined above. Due to a lack of adequate forage due to drought in 2002 and 2003, the perennial grass treatment was hayed but not grazed in 2003. From 2004 through 2008, the perennial grass treatment was lightly grazed with ten Hereford or Angus cows from mid-October to mid-January. Readers are encouraged to review previous reports for additional details regarding crop and livestock management related to the study [7, 8].

2.2. Infiltration Measurements. Infiltration measurements were made using single-ring infiltrometers [10]. Briefly, measurements were made by inserting an aluminum ring (i.e., a 15 cm i.d. irrigation pipe cut to a 15 cm length) into the soil to a 7.5 cm depth and applying two separate applications of water within the enclosed space of the ring. The volume of water for each application was equivalent to a 2.54 cm depth (1 inch) within the ring. The time necessary for each application of water to infiltrate into the soil was recorded using a stopwatch. To adjust for potential differences in antecedent water content among treatments, only data from the second water application were used.

Infiltration measurements were made during the spring (April) and fall (October) of 2001/2002, 2004/2005, and 2007/2008. The timing of measurements corresponded to the time after crops had been swathed but not grazed and

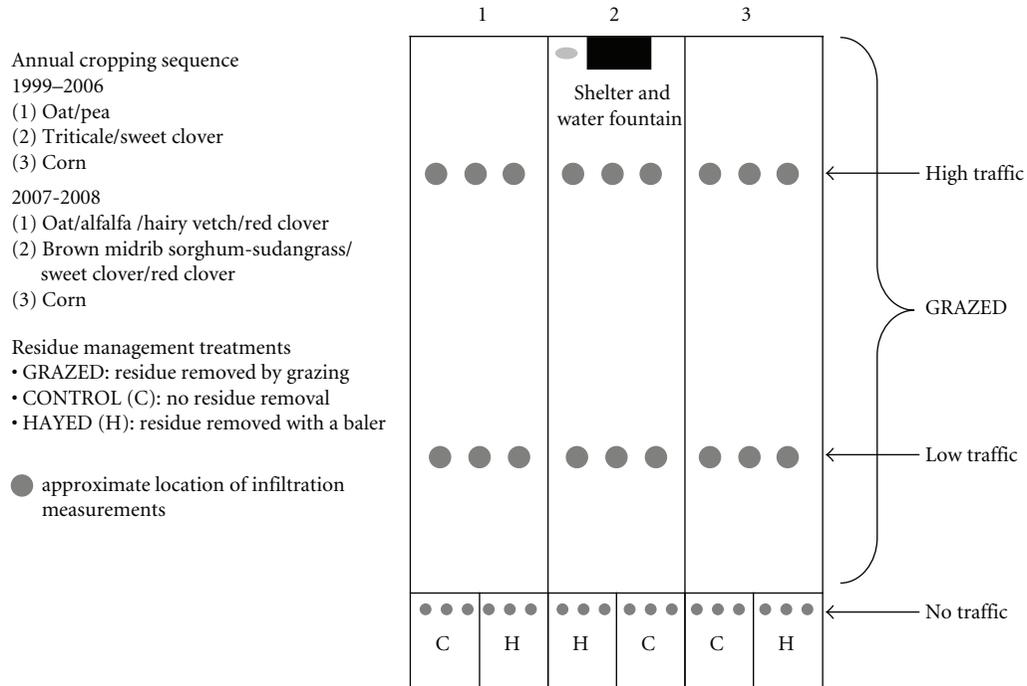


FIGURE 1: Diagram of cropping sequence, residue management treatments, and hoof-traffic zones within an integrated annual cropping pasture near Mandan, ND.

after the swathed crops had been grazed but not replanted. Measurements in the CONTROL and HAYED treatments were made using nine infiltrometers, oriented randomly in each treatment but between crop rows. Measurements in the GRAZED treatment were made in two transects differing in frequency of hoof traffic and also between crop rows. Nine infiltrometers (three per crop strip) were placed in a transect perpendicular to the swaths approximately 100 m from the shelter and water fountain (representing high-traffic (HT)). A similar transect was established approximately 200 m from the shelter and water fountain (representing low-traffic (LT)). Measurements in the western wheatgrass pastures mirrored that in the annual crop treatments, but with fewer infiltrometers (three in the CONTROL, HAYED, and GRAZED hoof traffic transects).

Three data transformations were evaluated prior to use of untransformed data for statistical analyses. Distribution of log, square root, inverse, and untransformed data was evaluated in SAS using the Shapiro-Wilk test to assess normality given the limited number of observations ($n = 207$) [11]. All four sets of data yielded outcomes significant at $P \leq .001$, implying that the data were not normally distributed.

Effects of residue management, frequency of hoof traffic, season, and production system on infiltration rate were evaluated three, six, and nine years after study establishment with PROC mixed in SAS using a significant criterion of $P \leq .05$ [12]. Tested effects were considered fixed, while replicates and their interaction were considered random. Treatment means were calculated across crop phases. Given that the GRAZE residue management treatment was not randomly assigned in each replicate, caution was exercised when interpreting results.

To facilitate meaningful comparisons, only data from spring infiltration measurements were used unless stated otherwise. Additionally, for frequency of hoof traffic, data from the CONTROL and HAYED treatments were combined to represent a no-traffic treatment (NT). Similarly, only data from the GRAZED treatment were used to compare seasonal effects (i.e., Fall versus Spring) on infiltration rate.

3. Results and Discussion

Livestock integration of an annual crop sequence (GRAZED) did not significantly affect infiltration rate as compared to residue management not involving livestock (HAYED) or residue left in place (CONTROL) (Figure 2(a)). Numerically, however, infiltration rates within the GRAZED treatment were consistently lower among the three residue management treatments at three, six, and nine years after study establishment. Despite the numerically lower infiltration rates in the GRAZED treatment (e.g., approximately 5 cm hr^{-1} in 2002; Figure 2(a)), concerns with potential runoff were negligible at this site as the occurrence of a 5 cm rain over a 1 hr duration is expected to happen at a historical frequency from 10 to 25 yr [13]. Both low- and high-frequency hoof traffic zones (LT, HT) possessed numerically lower infiltration rates as compared to the zone where hoof traffic was excluded (NT) (Figure 2(b)); however, differences among hoof traffic zones were not significant in any year. Moreover, infiltration rates within the GRAZED treatment did not differ between fall and spring in 2001/2002, 2004/2005, or 2007/2008 (Figure 2(c)).

Infiltration rates did not differ between integrated annual cropping and perennial grass grazing systems during any of

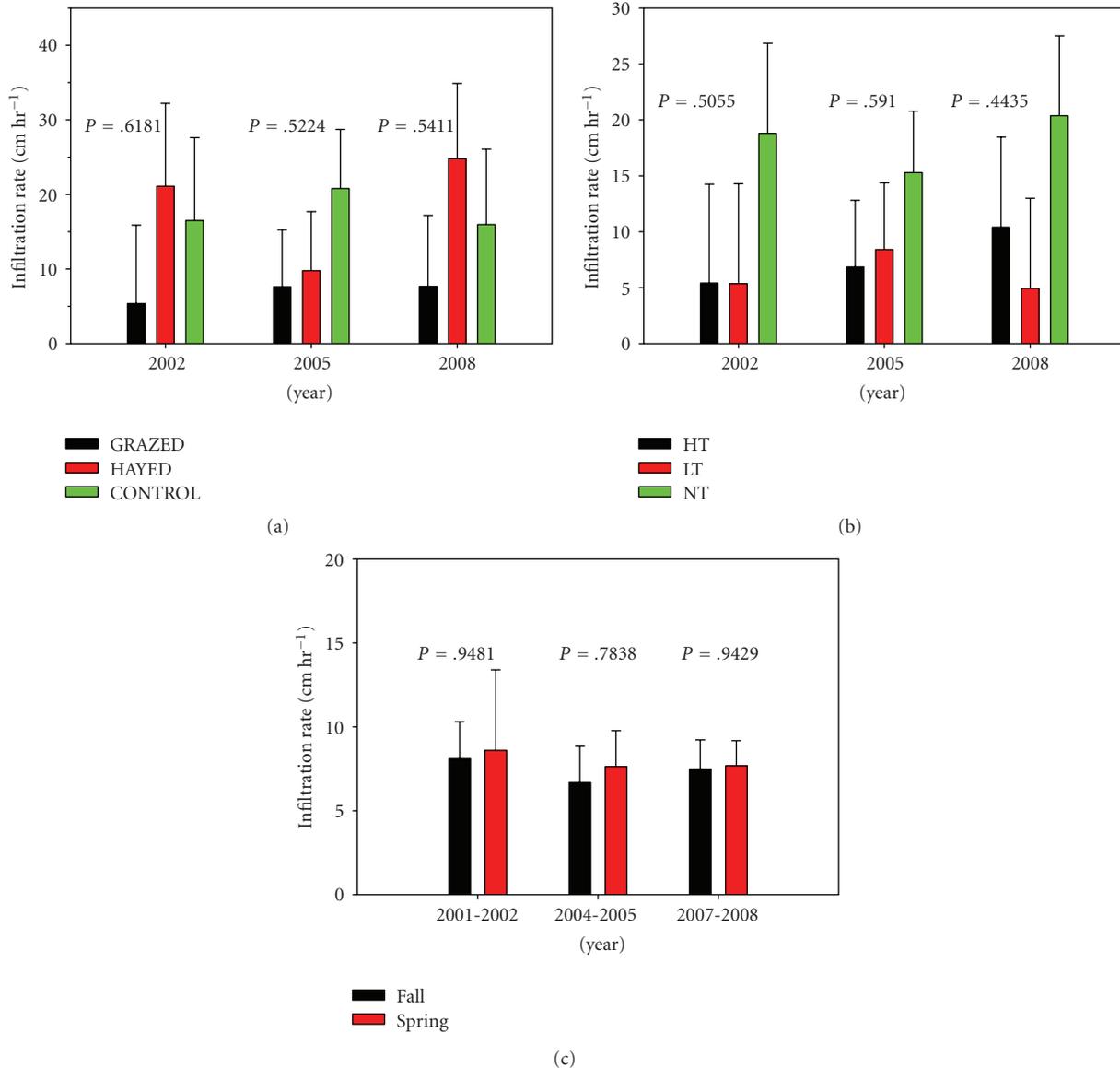


FIGURE 2: Effects of grazing and residue management (a), degree of hoof traffic (b) (HT: high traffic, LT: low traffic, and NT: no traffic), and season (c) on infiltration rate for an integrated crop-livestock system near Mandan, ND. Spring infiltration measurements were used in (a) and (b). Error bars represent ± 1 standard error.

the measurement times (Table 1). Accordingly, the guiding hypothesis for the study was not disproved, suggesting that perennial grass pastures may be converted to a winter-grazed annual cropping system without compromising infiltration of water into soil.

Maintenance of key hydrological functions in agroecosystems is an essential attribute affecting agricultural productivity and environmental quality. Climate-induced shifts toward more frequent high-intensity rainfall events pose significant challenges to the hydrological functions of agroecosystems and, in turn, agricultural sustainability [14]. As such, anticipated changes in climate may favor agroecosystems that can effectively capture and store significant amounts of water in soil following intense precipitation events. Findings from

TABLE 1: Mean infiltration rate in the spring of 2002, 2005, and 2008 for integrated annual cropping and perennial grass near Mandan, ND.

Year	Infiltration rate (cm hr ⁻¹)		P value
	Integrated annual cropping	Perennial grass	
2002	13.0 (5.8)*	7.1 (7.4)	.5984
2005	10.9 (5.6)	21.1 (7.1)	.3821
2008	14.0 (3.8)	5.1 (4.3)	.2649

* Values in parentheses represent standard error of the mean.

this study indicate that integrated annual cropping systems utilizing winter grazing may be suitably adapted to a more

vigorous hydrological cycle from the standpoint of water capture and storage. Such adaptation emanates from the capacity of the management system to withstand significant changes in near-surface soil physical properties known to affect water infiltration into soil during, and following, conversion from perennial grass. One example of resistance to change in soil physical condition was expressed through the magnitude of treatment effects on soil bulk density, a general indicator of soil compaction. Within the surface 7.5 cm of soil, soil bulk density never exceeded 1.20 Mg m^{-3} over the course of the study nor were soil bulk density values correlated with infiltration rates ($r = -0.07$; $P = .3033$; $n = 207$) (data not shown) [15].

Pragmatically, results from this study suggest that agricultural producers should not be concerned with infiltration problems in integrated annual cropping systems, where winter grazing is used. Had cattle caused serious soil compaction during winter grazing, it would have been expressed through significantly lower infiltration rates. A combination of management-, climatic-, and edaphic-related factors was likely responsible for the observed resistance in soil change to the treatment perturbations.

No-till conversion of the crested wheatgrass pastures to annual cropping in 1999 may have been critical in conferring an inherent resistance against changes in near-surface soil physical properties caused by subsequent perturbations from cropping and grazing. An absence of tillage during conversion allowed for soil physical properties (soil structure, pore continuity, and pore size) to remain unchanged. This consistency in soil physical condition during conversion was likely critical in buffering soil changes potentially caused by differences in plant type (annual crops versus perennial grass) or implementation of field activities (e.g., spraying, planting, and swathing) over the course of the study.

Utilization of winter grazing in this study likely mitigated potential soil compaction in the GRAZED treatments as the soil is typically frozen from November through March. In the absence of mid-winter thawing periods, soils remain frozen and less susceptible to compaction by hoof traffic. Moreover, soils in the northern Great Plains undergo annual freeze/thaw and wet/dry cycles, which act to fracture compacted soil zones through the expansion/contraction of soil minerals and water in soil pores. Such natural amelioration processes have been found to buffer effects of grazing on near-surface soil compaction in the northern Great Plains [16]. Significant contributions from earthworm tunneling, as observed in the integrated annual cropping system (Jason Gross, personal communication), can also limit effects of compaction on soil water properties through the creation of large biopores.

4. Conclusions

Infiltration of water into soil was found not to be significantly affected by management perturbations within an integrated annual cropping system, where winter grazing was used. The consistent freeze/thaw and wet/dry cycles characteristic of the northern Great Plains, coupled with the use of no-till

management, likely played an important role in the outcome of the results. Accordingly, caution should be exercised in applying results from this study to other regions or management systems. Outcomes from the study are nonetheless valuable from the standpoint highlighting the need of agroecosystem management to minimize changes in soil hydrological functions. Such an attribute may be critical in adapting to a more vigorous hydrological cycle from anticipated climate change.

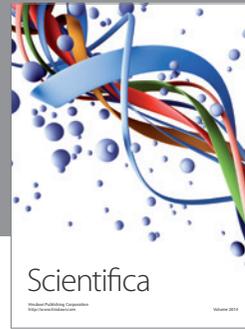
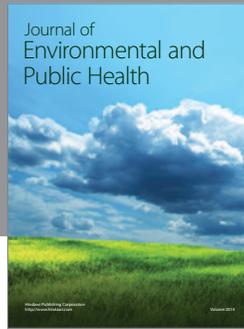
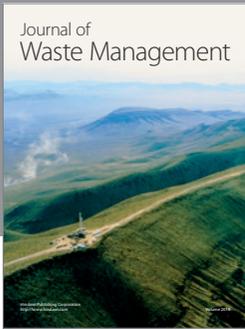
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References

- [1] N. C. Brady and R. R. Weil, *The Nature and Properties of Soils*, Prentice Hall, Upper Saddle River, NJ, USA, 12th edition, 1999.
- [2] J. L. Pikul and J. K. Aase, "Infiltration and soil properties as affected by annual cropping in the northern Great Plains," *Agronomy Journal*, vol. 87, no. 4, pp. 656–662, 1995.
- [3] S. D. Warren, T. L. Thurow, W. H. Blackburn, and N. E. Garza, "The influence of livestock trampling under intensive rotation grazing on soil hydrologic characteristics," *The Journal of Range Management*, vol. 39, no. 6, pp. 491–495, 1986.
- [4] M. A. Nearing, F. F. Pruski, and M. R. O'Neal, "Expected climate change impacts on soil erosion rates: a review," *Journal of Soil and Water Conservation*, vol. 59, no. 1, pp. 43–50, 2004.
- [5] M. P. Russelle, M. H. Entz, and A. J. Franzluebbers, "Reconsidering integrated crop-livestock systems in north America," *Agronomy Journal*, vol. 99, no. 2, pp. 325–334, 2007.
- [6] R. M. Sulc and B. F. Tracy, "Integrated crop-livestock systems in the U.S. corn belt," *Agronomy Journal*, vol. 99, no. 2, pp. 335–345, 2007.

- [7] D. L. Tanaka, J. F. Karn, M. A. Liebig, S. L. Kronberg, and J. D. Hanson, "An integrated approach to crop/livestock systems: forage and grain production for swath grazing," *Renewable Agriculture and Food Systems*, vol. 20, no. 4, pp. 223–231, 2005.
- [8] J. F. Karn, D. L. Tanaka, M. A. Liebig, R. E. Ries, S. L. Kronberg, and J. D. Hanson, "An integrated approach to crop/livestock systems: wintering beef cows on swathed crops," *Renewable Agriculture and Food Systems*, vol. 20, no. 4, pp. 232–242, 2005.
- [9] Soil Survey Staff, "Natural Resources Conservation Service, United States Department of Agriculture. Web Soil Survey," 2011, <http://websoilsurvey.nrcs.usda.gov>.
- [10] M. Sarrantonio, J. W. Doran, M. A. Liebig, and J. J. Halvorson, "On-farm assessment of soil quality and health," in *Methods for Assessing Soil Quality*, J. W. Doran and A. J. Jones, Eds., pp. 83–105, Soil Science Society of America, Madison, Wis, USA, 1996.
- [11] SAS Institute, *SAS/STAT User's Guide. Version 6.0*, vol. 2, SAS Institute, Cary, NC, USA, 4th edition, 1990.
- [12] R. C. Littell, G. A. Milliken, W. W. Stroup, and R. D. Wolfinger, *SAS System for Mixed Models*, SAS Institute, Cary, NC, USA, 1996.
- [13] D. M. Hershfield, "Rainfall frequency atlas of the United States," in *Weather Bureau technical Paper*, vol. 40, US Government Printing Office, Washington, DC, USA, 1961.
- [14] W. M. Edwards and L. B. Owens, "Large storm effects on total soil erosion," *Journal of Soil and Water Conservation*, vol. 46, no. 1, pp. 75–78, 1991.
- [15] M. A. Liebig, D. L. Tanaka, S. L. Kronberg, E. J. Scholljegerdes, and J. F. Karn, "Integrated crops and livestock in central North Dakota, USA: agroecosystem management to buffer soil change," *Renewable Agriculture and Food Systems*. In press.
- [16] E. Mapfumo, D. S. Chanasyk, M. A. Naeth, and V. S. Baron, "Soil compaction under grazing of annual and perennial forages," *Canadian Journal of Soil Science*, vol. 79, no. 1, pp. 191–199, 1999.



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