Rangeland Ecology & Management 70 (2017) 448–455

Contents lists available at ScienceDirect

Rangeland Ecology & Management

journal homepage: http://www.elsevier.com/locate/rama

Original Research

# Whole-Ranch Unit Analysis of Multipaddock Grazing on Rangeland Sustainability in North Central Texas☆

Wayne Becker [a,*], Urs Kreuter [b], Sam Atkinson [c], Richard Teague [b,d]

[a] Graduate Student, Environmental Science, University North Texas, Denton, TX 76201, USA
[b] Professor, Ecosystem Science and Management, Texas A&M University, College Station, TX 77843, USA
[c] Professor, Environmental Science, University North Texas, Denton, TX 76201, USA
[d] Professor, Texas A&M AgriLife Research Center, Vernon, TX 76385-1658, USA

ARTICLE INFO

*Article history:*
Received 17 February 2016
Received in revised form 16 November 2016
Accepted 20 December 2016

*Key Words:*
multipaddock grazing
rangeland health
rangeland sustainability
whole-ranch assessment

ABSTRACT

The relevance of broad-spectrum advocacy of rotational grazing is often questioned because many research data do not support the practice, yet it is supported by on-ranch level indicators, ranch-level research, and government agencies that provide technical assistance to private landowners and managers. It is theorized that whole-ranch systems differ from experimental plots because of the use of adaptive management. The purpose of our study was to understand the perceptions of ranchers on impacts of ranch-scale multipaddock grazing, especially as it relates to rangeland sustainability in six North Central Texas counties. Sustainability was identified by three indices: land health sustainability, economic sustainability, and social sustainability. Four categories of grazing systems were identified: continuous, 2 − 4 paddocks, 4 − 8 paddocks, and 8 or more paddocks. Data were collected using a self-assessment mail survey. Analysis of respondent data indicated that increasing the number of paddocks may improve land health sustainability indicators on commercial ranches in North Central Texas, especially when respondents use eight or more paddocks.


## Introduction

Lands designated as “grazing land” encompass 25.9% of all land in the United States (Lubowiski et al., 2006). Rangeland ecologists generally accept that grazing by ungulates, together with fire, was instrumental in the evolutionary history of grassland ecosystems (Michunas et al., 1988; Frank and McNaughton, 2002). Accordingly, it has been postulated that grazing of rangelands dominated by native plants is potentially one of the most sustainable forms of agriculture, especially in areas with limited potential for crop production (Frank and McNaughton, 2002; Heitschmidt et al., 2004). At the same time, many studies implicate livestock grazing as a leading cause of rangeland degradation (Belsky et al., 1999; Centeri et al., 2009).

Grazing management systems were developed in an attempt to manage grazing stock and grazing lands in a manner that maintains or improves ecosystem structure and function while simultaneously achieving social and economic goals (Heitschmidt and Taylor, 1991). However, the efficacy of these systems as a means of ensuring the ecological health and agricultural sustainability of rangelands has been questioned (Klipple and Costello, 1960; Holechek et al., 1994; Ward, 1999; Briske et al., 2008). The complex interactions between livestock and the ecosystems they inhabit have resulted in divergent conclusions among grazing management researchers. For example, in a review of studies that compare rotational grazing strategies with continuous grazing, Briske et al. (2008, p. 3) conclude, “continued advocacy for rotational grazing as a superior strategy of grazing on rangelands is founded on perception and anecdotal interpretations.” In contrast, rotational grazing is deemed preferable by others who point out that overgrazing occurs on individual plants as a result of multiple, severe defoliations without sufficient physiological recovery between defoliations (Earl and Jones, 1996; Teague et al., 2013).

Reducing livestock numbers on rangeland has been suggested as the key to long-term sustainability. However, others recognize that matching stocking rate to available forage is an important first step in sustainable management, but it must be applied in conjunction with other management practices like postgrazing recovery to mitigate the effects of selective grazing (O'Reagain et al., 2003). Warren et al. (1986) indicated that having postgrazing recovery periods for rangeland is the key to avoiding changes in vegetation composition toward dominance by lower seral plants that are generally associated with lower soil hydrologic stability. In order to avoid long-term progressive vegetation shifts and soil degradation, rest periods between defoliations must be sufficiently long for the regrowth of grazed plants (Teague et al., 2013; Teague et al., 2015).

Numerous ranchers worldwide have successfully managed their land, some for more than 30 yr, using multipaddock grazing (Earl and

☆ The Grazing Lands Conservation Initiative, Texas and the Advanced Environmental Research Institute at the University of North Texas funded this project.
* Correspondence and permanent address: Wayne Becker, 4202 CR 308, Gainesville, TX, 76240-4202, USA. Tel.: +1 940 736 7080.
*E-mail address:* wbecker35@live.com (W. Becker).

http://dx.doi.org/10.1016/j.rama.2016.12.002
1550-7424/

Jones, 1996; Jacobo et al., 2006; Teague et al., 2011). In North Texas, Teague et al. (2011, 2013) reported better long-term maintenance of soil and plant resources, as well as economic viability on ranches where managers combine adaptive management with multipaddock grazing compared with those who practice continuous season-long stocking. Teague et al. (2013) go on to state that many ranchers who have practiced multipaddock grazing for decades have reported a high degree of satisfaction with the economic and ecological results, as well as improvements in management lifestyle and the social environment of their ranch businesses.

Recently there has been a call for monitoring and research of rangeland condition at the whole-ranch scale to investigate the interaction between adaptive management and various grazing strategies at relevant operational scales (Archibald et al., 2005; Brunson and Burritt, 2009; Briske et al., 2011). Briske et al. (2011) noted that variability of rangeland ecosystems has caused confusion over the effects of generic grazing recommendations because rangeland recoveries based on fixed grazing schedules do not address environmental variability. Often, variations in precipitation and plant growth appear to override the potential benefits derived from spatial and temporal redistribution of grazing pressure in rotational grazing strategies (Ash and Stafford-Smith, 1996). Plant growth and improvement in species composition are promoted primarily when grazing deferment coincides with favorable environmental conditions for the recovery of preferentially grazed plants. Other researchers have indicated that in logistically and financially constrained small-scale and short-term research trials, it is impossible to capture the complexity of rangeland resources in operational-scale grazing strategies (Laca, 2009; Teague et al., 2013).

These observations further point the need identified by Maczko et al. (2004) for investigations aimed at addressing the efficacy and sustainability of grazing strategies to be conducted at the whole-ranch scale and account for as many environmental, economic, and social factors pertaining to ranch management as possible. Whole-ranch grazing strategies unarguably use adaptive management, whereby pastures are rotated on the basis of many factors including weather, biomass removal, time, and seasonality. Elements of agricultural sustainability that influence the efficacy of any grazing strategy have been identified as fitting within one of three categories: environmental, economic, and social (Calker, 2005; Sydorovych and Wossink, 2008).


**Figure 1.** Location of Study Area, in relation to Texas and the West Cross Timbers.

While investment in grazing systems research has been substantial, few detailed studies have been conducted to derive a broad understanding of the ranchers' perspectives regarding the efficacy of alternative grazing systems. To address this knowledge gap, we conducted a survey of ranch managers to determine their perceptions of key ecological, economic, and social indicators of sustainability according to the grazing system that each manager used. The use of multiple paddocks for managing grazing resources may enhance the vigor of preferred rangeland plants, profitability, and quality of life. Therefore, the central hypothesis of our study is that rancher perceptions of each of the three elements of rangeland sustainability are positively associated with the number of paddocks used in a grazing system. Paddock number has been identified as a fundamental factor for understanding the impacts of multipaddock grazing. In North Texas, bare ground was reduced with increased paddock numbers whereby eight-paddock management was superior to four-paddock management, which was superior to continuous grazing (Teague et al., 2010). Increasing paddock numbers is linked to less impact to preferred grass due to shorter grazing duration (Teague et al., 2013), and modeling multipaddock grazing confirms more paddocks shorten grazing periods and increase ecological conditions and profitability (Teague et al., 2015).

## Method

### *Study Area and Mail Survey*

This exploratory study used six counties in North Central Texas in the Cross Timbers and Rolling Prairies Ecological Regions, including Cooke, Jack, Montague, Wise, Parker, and Clay (Fig. 1). These six counties have similar characteristics. They are the same ecological region, are experiencing influence from urbanization, and have similar ranch sizes, yet extensive open grasslands and brushy rangelands still occur in the six-county area. Further, cattle ranching is the predominant land use. Projected gross receipts from livestock between 2007 and 2010 exceeded income from all other forms of agriculture by a factor of 10 or more (Texas AgriLife Extension Service, 2010).

Agricultural-use property tax evaluation databases were used in each county to identify prospective survey participants with a minimum of 200 ha of native grassland. Information from smaller ranches may have been of value, but 200 ha was chosen because it was greater than average for county farm size and was likely to be large enough to use multiple paddocks and use livestock for economic benefit. Using this minimum-size property criterion, a total of 550 commercial ranch enterprises were identified in the six counties and included in the study. The study was submitted for approval to the University of North Texas Institutional Review Board (IRB) for approval (Human Subjects Application No.10-235). It was determined to qualify for an exemption from further review.

Data were collected, using a self-assessment mail survey following the Dillman (2000) multicontact method. The survey was a 10-page questionnaire that was conducted over a 3-month period, beginning in June 2010, and consisting of five mailings: a presurvey letter about the study was mailed to all selected landowners on June 10; survey questionnaire with cover letter on June 14; reminder/thank you card on July 14; replacement questionnaire with cover letter to nonrespondents on August 11; and last reminder/thank you card to nonrespondents on Sept 16. Survey responses received up to 2 mo after the final mailing were included in the study. The survey questionnaire was developed from literature review and a rancher focus group. A pilot study was then conducted to ensure the questionnaire was written with clarity. Key issues included in the final questionnaire focused on management philosophy, management practices, land health indicators, economic indicators, quality of life and cultural experiences, and personal characteristics. Landowners receiving the survey were instructed "We are asking that this questionnaire be completed by the person who is currently most involved in making decisions about land management on the property." Potential respondents were also informed of the goals of the study: "This survey may help to establish key sustainability issues regarding livestock and rangeland from the ranch manager's perspective. Information gained is expected to: Help determine future direction of educational efforts for ranchers and general public; Provide input to decisions makers concerning producer needs; Provide insight to grazing system management from real ranch units to improve understanding of small 'scientific' studies."

### *Evaluation Indices*

Information requested about land health, economic indicators, and quality of life was asked in separate sections of the questionnaire. Respondent answers were solely dependent on individual understanding of the question. The questions in each section were used to create three indices (latent variables) of sustainability to investigate the ecological, economic, and social elements of rangeland management. Such latent variables are frequently used to reduce the number of variables in a complex data set by combining multiple related response items into an amalgamated index (Garson, 2011a). The three indices provided metrics to estimate the degree of perceived ecological, economic, and social sustainability of each respondent's ranch. Measurement of initial state of ranch sustainability, prior to the current landowners' initial perception, is beyond the scope of this study.

Using a procedure similar to that developed by Doll and Jackson (2009) to understand farmer attitudes toward grazing systems, related variables were identified that maximized the internal consistency as measured by Cronbach's alpha coefficient—α (Cronbach, 1951; Bland and Altman, 1997). This process indicates whether items are sufficiently interrelated to justify combining them into an index (Starkweather, 2011). The land-health sustainability (LS), economic sustainability (ES), and social sustainability (SS) indices were developed separately. Each index was developed by including response data for all questions (variables) related to the specific category of sustainability and then consecutively reducing the number of variables according to their contribution to the correlation coefficient (with the least contributing variable being removed first) until an $\alpha$ value ≥ 0.7 was reached or until the highest attainable $\alpha$ was achieved. Traditionally $\alpha \geq 0.7$ is considered the threshold value for combining individual variables into an index (Nunnaly and Bernstein, 1994; Starkweather, 2011; Garson, 2011b). Still, other sources have indicated instances exist where a "moderate" value for Cronbach's alpha ($\alpha = 0.6$ or lower) can be used for creation of a meaningful index (Winter et al., 2005; Leontitsis and Pagge, 2007; Karahoca et al., 2010).

LS scores were derived using 12 responses from the "land health indicators" section of the survey. Respondents were informed that, "Change in the environment is certain" and were then asked, "In relation to your property, please indicate your perception of the change noticed for each issue over the past 10 years." The response options were increased, remained constant, decreased, or unknown. Change toward greater sustainability was given a score of 1, remaining constant was assigned a value of "0," and lesser sustainability was assigned (−1). In instances where "unknown" was selected (2.5% of all responses), a value of "0" (no change) was assigned to provide a consistent cumulative score range for all respondents while not biasing mean scores in either direction. Increases in "Juniper," "Other Brush," "Bare Ground," "Invasive Weeds," "Livestock Trails," "Gullies," "Soil Compaction," "Small Pedestals," "Evidence of Plant Litter," and "Other Evidence of Water Flow" were determined to be consistent with less sustainability and a decrease consistent with greater sustainability, while increases of "Tall Grass" and "Deer" were determined to be consistent with greater sustainability and a decrease consistent with less sustainability. ES and SS scores were derived from items where survey participants were asked to respond to each using a 7-point response scale, in which 1 = strongly agree, 4 = neutral, and 7 = strongly disagree. For the purpose of consistency and to simplify representation of the results, the data used to calculate index scores were standardized so that a value of 1 corresponded to the maximum possible response score and −1 corresponded to the minimum possible response score (e.g., maximum and minimum possible scores for respondent perceptions of LS, ES, and SS).

### *Model Specification*

The survey data were used to determine respondents' grazing system (GS) contributions to the LS, ES, and SS indices. Statistical analysis used the generalized linear model and multivariate analysis of covariance (MANCOVA) in SPSS 18.0. In this model, the LS, ES, and SS indices were designated as dependent variables; a categorical variable that indicated the number of paddocks used for grazing purposes (GS) by the respondent was designated the independent variable. A covariate indicating the number of hectares managed by the respondent was added as a control for the number of paddocks used to reduce the error of the model.

The independent variable, grazing system (GS) category, was qualified by asking ranch managers to select the category that best described their system. The categories were 1) continuous stocking, 2) two to four paddocks, 3) four to eight paddocks, 4) more than eight paddocks, or 5) other systems. These categories were assigned values of 1, 2, 3, 4, or 5, respectively. Two respondents selected the category of "other" (Beetz and Rinehart, 2010), one specifying "double stocking of yearling cattle from January through July" and the other "rotation by observation." These were eliminated from the analysis because no set category was identifiable from the response, and they were unrepresentative of the majority of survey respondents.

### *Statistical Analyses*

Normality was assessed as skewness being within the +2 to −2 range and kurtosis within +3 to −3 range (Garson, 2011b). Multiple analysis of variance (MANOVA) with type IV sum of squares was used to test the relationship between sustainability indices and grazing system category. Data passed the assumption of Bartlett's test of sphericity ($P = 0.005$), which indicates the dependent variables were significantly intercorrelated to justify the use of MANOVA. Univariate post hoc comparisons were then made, comparing each group within the GS variable to each sustainability index. In addition to the sections within the survey used for index creation, a poll was also taken of management practices and rancher philosophy. Specifically, the variables were stocking rate (SR), land area managed (LAM), animal units per ha (AU), rate of return (RR), and philosophical orientation toward "land rest." To better understand results from the MANOVA and to investigate rancher actions and motivations, these additional variables were analyzed for nonparametric association with grazing system groups and other key variables within the study using Spearman's rho correlation coefficient, chi-square test for independence, or contingency tables.

## Results

### *Survey Response*

Of the 550 ranch respondents included in the study, 188 (34.2%) responded. Of these, 124 indicated that they managed livestock on native rangeland and they completed all or most of the questionnaire. The remaining 64 respondents indicated that they did not own native rangeland, did not manage livestock on their land, or simply lacked the knowledge to complete the questionnaire. An additional 18 were removed from the study due to > 10% missing responses. To investigate outliers in our data we used Mahalanobis distances. Three respondents with distances > 15 were removed from consideration. Therefore, the effective survey sample consisted of 486 rangeland-based cattle ranchers who owned at least 200 ha of land. With 103 qualified respondents, the effective response rate was 21.1%, which is in line with or better than other published studies aimed at seeking the opinion of agricultural producers (Greiner et al., 2008; Sydorovych and Wossink, 2008).

A nonresponse bias analysis was conducted by mailing a second one-page questionnaire to 177 (50%) randomly selected survey participants who did not respond to the initial survey. Of these, 21 (11.9%) completed and returned the second questionnaire. The original respondent population and the nonrespondents' data for two demographic parameters were compared. The mean age of respondents (62.0 yr) was significantly greater than that of nonrespondents (45.8 yr) (Mann-Whitney U; $P =$ 0.000). Reasons for nonresponse were given: 23% claimed that the survey did not pertain to them, with 14% adding that the land was leased out. Additionally, 47% of nonrespondents cited the length of the survey or their time as the reason for nonresponse. However, there was no statistical difference for years managing rangeland between respondents (33.2 yr) and nonrespondents (37.6 yr) (Mann-Whitney U; $P = 0.653$).

On the basis of the acceptable but relatively low response rate and the statistically significant differences between the ages of the respondent and nonrespondent groups, the research results cannot be unequivocally extrapolated to the survey sample as a whole. Furthermore, due to the nonrandomized selection of six counties in North Central Texas for the study, the survey results cannot be extrapolated to grazing lands across Texas. Accordingly, the research results are presented and discussed strictly with respect to the survey respondents.

### *Respondent Characteristics*

When analyzing only the survey respondents used for this analysis, 87.5% were male. On average, they were 62 (standard deviation [SD] = 11.7) yr of age, they had 34.7 (SD = 19.2) years of ranching experience, and the land that they were managing had been in their family 49.4 (SD = 41.01) yr; 60% were not first-generation landowners. Respondents reported the size of the property they managed was, on average, 2 787 ha (SD = 3 347). Even though ranches with > 200 ha of rangeland were targeted, respondents reporting native rangeland management ranged in size from 32 to 7290 ha. The area represented by the properties that the respondents manage is approximately 11.8% of the total land area in pasture and rangeland within the six counties included in the study.

### *Index Creation*

Cronbach's alpha was used for creation of the sustainability indices. The LS index consisted of 12 variables ($\alpha = 0.707$), the ES index consisted of 6 items ($\alpha = 0.709$), and the SS index consisted of 8 items ($\alpha = 0.667$). Descriptive statistics are reported in Table 1. A list of the items included in each index is reported in Table 2. When the indices were finally created, the ES identified a belief that grazing management and profitability are linked and that a ranch run as a business will endure over time; the SS determined the contribution of ranch management to individual satisfaction with aspects of personal, family, and community life; and the LS indicated the perception that ecological indicators of land health are improving.

### *Grazing System Contribution to Land Health, Economic, and Social Sustainability Indices*

MANCOVA was used to test the influence of GS category, and property size as a covariate, on the three sustainability indices (LH, ES, and SS). The Wilks' lambda test is used to test for differences between the means of groups on a combination of dependent variables. The Wilks' lambda multivariate test of overall differences among groups was statistically significant for the independent variable, GS (F = 2.042; $P = 0.036$). Likewise, the Wilks' lambda multivariate test of overall differences among groups was statistically significant for the covariate, land area managed (F = 3.145; $P = 0.029$). Univariate between-subject tests showed that GS was significantly and moderately related to LS ($P = 0.33$; partial eta-squared = 0.095) but not ES ($P = 0.064$; partial eta-squared = 0.080) or SS ($P = 0.512$; partial eta-squared = 0.026).

Because of significant interaction of LS with GS, univariate post hoc comparisons between groups were also made (Table 3). Data for all indices passed the assumption of equal group error variance, as tested by Levene's test, and for ES (LS $P = 0.970$, ES $P = 0.140$, and SS $P = 0.350$). Since homogeneity of variances could be assumed, Dunnett's test was used to compare single-paddock grazers, those using two to four paddocks, and those using four to eight to the group observed to have the highest sustainability scores within LS—those using eight or more paddocks.

### *Nonparametric Variable Associations*

Since the utilization of multipaddock systems was being investigated, and because it is difficult to separate the number of paddocks

**Table 2**
Variables included in indices.

| | |
|---|---|
| Economic (ES) | 1. Financial risk can be reduced by implementation of proper grazing practices. |
| | 2. Proper grazing management of rangeland will positively influence the long-term profitability of a ranch. |
| | 3. Deterioration of range conditions will cause long-term economic difficulties. |
| | 4. When compared to other ranches, I perceive the rate of return that I receive from grazing rangeland as being above average. |
| | 5. I consciously plan for long-term economic sustainability (5 or more years). |
| | 6. I know my cost of production. |
| Land health (LS) | 1. Juniper |
| | 2. Other brush |
| | 3. Bare ground |
| | 4. Invasive weed species (thistle, cacti, greenbriar, etc.) |
| | 5. Livestock trails |
| | 6. Gullies |
| | 7. Soil compaction |
| | 8. Small pedestals (rocks or plants that appear elevated. |
| | 9. Evidence of plant litter around obstructions like grass clumps and stones |
| | 10. Other evidence of nongully water flow patterns |
| | 11. Tall grasses |
| | 12. Deer |
| Social (SS) | 1. Livestock management on my ranch does not infringe on my free time or ability to enjoy occasional recreation activities. |
| | 2. Livestock management on my ranch does not interfere with family involvement. |
| | 3. I derive a great deal of satisfaction from my work on the ranch. |
| | 4. I am actively involved with my community. |
| | 5. I have the time to learn about subjects that are of interest to me. |
| | 6. I have a good relationship with neighboring ranches. |
| | 7. All decision makers (ranch owners or family) are involved in long-range planning and goal making. |
| | 8. Livestock management on my ranch does not infringe on my free time or ability to enjoy occasional recreation activities. |

**Table 1**
Descriptive statistics for dependent variables.

| | *N* | Minimum | Maximum | Sum | Mean | Std. Deviation | Skewness | Kurtosis |
|---|---|---|---|---|---|---|---|---|
| Land health (LS) | 103 | −.55 | .92 | 16.05 | .16 | .30 | .38 | −.59 |
| Economic (ES) | 103 | −.33 | 1.00 | 58.06 | .56 | .24 | −1.11 | 2.82 |
| Social (SS) | 103 | .14 | 1.00 | 35.57 | .35 | .17 | 1.38 | 2.55 |
| Valid *N* | 103 | | | | | | | |

**Table 3**
Multiple comparisons and mean differences in number of paddocks used controlling for acres managed.

| Dependent variable | Comparison No. of paddocks | | Mean difference | Std. error | 95% confidence interval | |
|---|---|---|---|---|---|---|
| | | | | | Lower bound | Upper bound |
| Land health sustainability (LS) | 1 | ≥ 8 | −.25[1] | .10 | −.48 | −.019 |
| | 2-4 | ≤ 8 | −.21 | .10 | −.44 | .03 |
| | 4-8 | ≥ 8 | −.10 | .10 | −.34 | .14 |
| Economic sustainability (ES) | 1 | ≥ 8 | −.06 | .08 | −.13 | −.25 |
| | 2-4 | ≤ 8 | −.10 | .08 | −.29 | .09 |
| | 4-8 | ≥ 8 | −.02 | .08 | −.18 | .21 |
| Social sustainability (SS) | 1 | ≥ 8 | −.01 | .06 | −.15 | .12 |
| | 2-4 | ≤ 8 | −.04 | .06 | −.09 | .19 |
| | 4-8 | ≥ 8 | −.01 | .06 | −.16 | .12 |

*Note*. Comparisons based upon observed means. MSE = 0.0280.
[1] $P < .05$, where $P$ values are adjusted using the Dunnett (2-sided).

utilized by a ranch from the assumption that longer periods of land rest are occurring, a chi-square test of goodness of fit was performed to determine if utilization of additional paddocks did, in fact, relate to resting land. Using additional paddocks was related to resting land as an integral part of grazing management $X^2$ (12, $N = 98$) = 33.615; $P < 0.01$.

With "Land Rest" being identified as a motivator for respondents, Spearman's rho correlational analysis was used to evaluate this motivator with respect to respondent's choice of GS, as well as respondent's perception of rate of return (RR), self-characterization of stocking rate (SR), and animals per 2.5 ha (AU). GS, SR, and AU were significantly correlated with RR; Land Rest was correlated with GS; and AU was correlated with SR (Table 4). RR was initially one of the questions determined to be part of the ES. It was the only question in the survey that directly inquired about perception of profitability. SR was derived by asking respondents their perception of categories for stocking rate (in relation to NRCS recommendations). Choices were high, moderate, conservative, and light. AU reflects responses whereby respondents were asked to quantify hectares allocated per AU by categorizing them as "< 8," "8 − 12," "13 − 18," "19 − 24," and "> 24 per 2.5 ha."

Even though post hoc testing identified no significant GS effects for SS and ES, there is still a need for further understanding of the overall model. Figure 2 depicts the mean indices scores grouped by respondents' selection of GS. When comparing, one notices an inverse relationship between SS and ES; therefore, further investigation between the variables within both indices were warranted. These variables were evaluated for correlation with the independent variable, GS, and with the covariate, LAM. The only finding of significance discovered for LAM was "I have a good relationship with neighboring ranches" $r_s$ (98) = −.215, $P = .034$. Further, the only variable resulting in a significant correlation with GS was "RR" $r_s$ (96) = −.204, $P = 0.047$.

## Discussion

For rangeland in the mid to tall grasslands of North Central Texas and the Texas Cross Timbers and Prairies Ecological Region, our data corroborated the hypothesis that the number of separate paddocks used is positively related to LS, one of the three rangeland sustainability indices. However, ES and SS were not found to be related to GS, specifically, increasing with number of paddocks. These findings were controlled for hectares managed by whole-ranch units with a mean size of 1050 ha, which is representative of viable commercial ranches within the study area.

The results reported here are producers' perceptions, not physically measured improvement in rangeland health or producer profitability. The study provides interesting points for further study, but definitive conclusions that would represent a broader group of ranchers than those who participated in the study cannot be drawn. These approaches allowed us to access producer knowledge and experience at the local level and thereby use social research methods to assess rangeland sustainability elements to take into account many complex issues. As such, using respondent self-assessment results helps separate solid producer evidence from activist-based testimonials and speculation, a process supported by Knapp and Fernandez-Gimenez (2009). This method of data collection allows for greater integration and information exchange among researchers and managers, creating mutually beneficial opportunities for the profession by facilitating development of evidence-based conservation practices, as called for by Briske et al. (2011). It is important to remember that GS measured paddock numbers. Ultimately, that was the variable being investigated, not whether respondents used multipaddock grazing. Clearly, confusion does exist between the two. With multipaddock systems, strict rotation is not suggested; grazing sequence may skip certain paddocks that have need of additional rest. Rangeland educational institutions may not clearly distinguish between the two. This is evident even in educational pamphlets, such as those presented by the National Sustainable Agriculture Information Service, which describes management intensive grazing as another term for rotational grazing and explains that subdividing pastures is an easy way to begin the system (Beetz and Rinehart, 2010).

**Table 4**
Spearman's rho correlation between four variables and land rest.

| Measure | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| Rate of return | — | | | |
| Grazing system | −.204[1] | — | | |
| Stocking rate | 0.315[2] | −0.125 | — | |
| Animal units per 2.5 ha | 0.285[2] | −0.032 | 0.406[2] | — |
| Land rest | 0.080 | −0.465[2] | 0.039 | −0.099 |

[1] Significant at the 0.05 probability level.
[2] Significant at the 0.01 probability level.

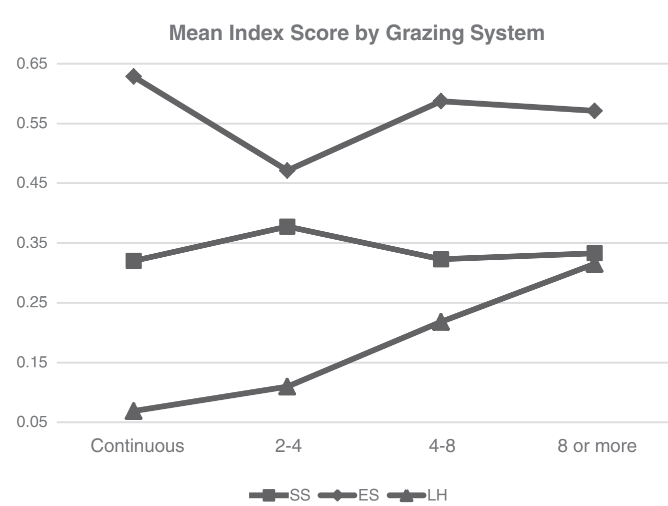


**Figure 2.** Comparative Means of Sustainability Indices Score by Grazing System.

This study indicates that North Central Texas ranchers who responded to our survey and who used eight or more paddocks perceived that the ecological status of their land was improving compared with those ranchers who grazed their livestock continuously in a single paddock. Findings of significant differences were only noted when comparing continuous grazing with those using eight or more paddocks. However, the trend showed an increase in sustainability scores with an increase in the number of paddocks used per ranch (Fig. 2). Therefore, ranchers whose land was rested for longer periods of time were observing greater land health improvement. Since this study used questions that examined integrity of the biotic community, soil/site stability, and hydrologic function as outlined by NRCS (2000), ranch level use of more than eight paddocks is deemed superior to continuous grazing for obtaining these three objectives in the North Texas area. It is also noteworthy that the fewer the paddocks being used for the rotation, the less likely the respondents were to be aligned with ecological sustainability as identified in ES. Identifying a linkage between respondents' philosophical belief that land rest is important and the use of eight or more paddocks for rotation leads us to believe that increasing length of land rest is deemed the critical factor leading to improvement in land health.

These findings are consistent with the postdefoliation rest-from-grazing paradigm, which supports the benefits of multipaddock use for livestock production, identified by Teague et al. (2011, 2013) and the simulation modeling results reported by Teague et al. (2015). It is understood that grazing under enclosed conditions does not occur uniformly over landscapes or over time (Ash and Stafford-Smith, 1996; Bailey et al., 1996; Witten et al., 2005). Repeated selective defoliation of landscape components, as well as certain species and individual plants within those areas under continuous grazing, can cause a gradually widening area of degradation, even at light to moderate stocking rates (Ash and Stafford-Smith, 1996). Thus, palatable and actively growing plants located in preferred areas are at a disadvantage (Earl and Jones, 1996). The process of patch-selective grazing results in the effective stocking rate on heavily used patches being much higher than that intended for the area as a whole. Therefore, while conservative stocking is an important first step in sustainable management, it must be applied in conjunction with other management practices like short grazing periods at high stock density (O'Connor, 1992) and periodic deferment to mitigate the effects of selective grazing (O'Reagain et al., 2003). Doing so will increase the proportion of desired plant species and increase plant vigor following growing season deferment (Smith, 1895; Merrill, 1954; Hormay and Evanko, 1958; Teague et al., 2004; Müller et al., 2007). As managing for grassland dominated by high seral plants improves hydrological function (Warren et al., 1986), land rest to allow recovery of plants after grazing is the key to integrity of the biotic community, soil/site stability, and soil hydrologic stability. Thus, the finding of improved land health being noted with land management using eight or more paddocks per herd is corroborated by additional range management research in this geographic area and other grazing ecosystems.

Other factors such as stocking rate and number of AU per hectare are commonly asserted as being influential to rangeland economic performance. Research indicates that when stocking rate increases, production per animal decreases, and at the same time production per land area increases to a maximum point and then declines (Pieper et al., 1978; Heitschmidt et al., 1990). When we examined stocking rate and AU per 2.5 ha with perception of economic performance, findings confirmed that these variables were significant. In fact, the contingency table investigating the AU per 2.5 ha suggests that an increase in density improves economic performance to a point and then declines. Meanwhile, the variable investigating stocking rate by categorizing respondents into groups found those considering their stocking rate to be high perceived their profitability to be greater. However, number of paddocks being used by respondents had no bearing on stocking rate or animals per 2.5 ha as identified by no significant parametric associations of GS and SR and GS and AU.

ES is primarily a mix of believing that grazing management and profitability are linked and a ranch run with certain business practices will endure over time. Poor economic sustainability by respondents in this study using two to four paddocks could be a result of grazing distribution, which may result in less desirable forage quality and thus animal performance. Grazing distribution is critical because herbivores express diet selectivity and thus patchy grazing to greater or lesser degrees when managed under rotational grazing (Hunt et al., 2007). It is known that grazing distribution is more even with management when using a greater number of paddocks (Barnes et al., 2008). They contribute their findings to improvements in timing and frequency of grazing.

Many studies have identified rotational management issues to be governed by plant physiological processes. It is understood that rangeland provided with a long rest period or low grazing pressure decreases in forage quality because of increased plant maturity (McNaughton, 1979). There are circumstances where rotational grazing performance lags behind that of continuously grazed animals as herbivores better learn which plants to consume (Provenza, 2003). However, if grazing periods are kept short enough, animals can maintain sufficient diet quality to meet performance goals (Teague et al., 2008, 2013). Research has also shown that a greater number of paddocks used per herd facilitates longer post-grazing recovery periods because grazing animals are more highly concentrated on smaller portions of the total grazing area, thereby allowing longer periods without defoliation before the next grazing event (Teague et al., 2013, 2015).

It could be speculated that use of more than one and fewer than eight paddocks actually reduces economic sustainability compared with other systems. Economic sustainability would obviously be intertwined with forage productivity and animal performance, and some studies have shown advantages for better animal performance with continuous grazing management (McIlvain and Savage, 1951; Reece, 1986; Holechek et al., 1987). However, studies where management has specifically aimed at providing for plant needs and animal performance and the accumulative effects of improved management over sufficient years has shown multipaddock grazing provides superior outcomes (Teague et al., 2013). It is suggested that future research carefully consider the number of paddocks and the paddock rest period, as these parameters may be crucial factors that affect overall ranch performance. Allowing respondents the ability to write in the number of paddocks used would be best to capture the thresholds where multipaddock benefits are recognized.

SS is composed of variables identifying ranch management's contribution to individual satisfaction with aspects of community life. Significant findings of "I have a good relationship with neighboring ranches" and LAM may have further implications. The negative correlation between "I have a good relationship with neighboring ranches" and LAM would indicate improvement in relationships among neighbors with decreasing size of property managed. This may be indicative of the smaller operations relying on, or interacting with each other, on a regular basis. It is possible that smaller ranches would be less likely to have high numbers of paddocks and therefore those using only two to four paddocks would have greater sustainability scores.

Social systems are the least studied component of rangeland science and management (Vavra, 1996), and few range-specific measures of social and economic attributes exist (Tanaka and Torell, 2002). Social processes include management and social regulation, reflecting social policies pertaining to natural resource use and management (Maczko and Hidinger, 2008). These processes can be internal or external in nature such that internal factors are specific to the individual or family and external are specific to society as a whole (Calker, 2005; Sydorovych and Wossink, 2008). Direct interviews from ranches in the United States that use holistic resource management give an indication of quality of life indicators. Stinner et al. (1997) describe quality of life goals for one ranch as "long-term business that is prosperous and stable and can provide for two families without anyone having to work away from the business, closer family ties, time for leisure, time for working in a strong community, school and church, and a good education for the children."

Attempts to identify an index that had a significant contribution to social sustainability for North Texas ranches failed. In the SS index, more than half of the statements were related to having free time. The index may have been better suited if it had investigated factors such as management and social regulation, as well as cultural resources, education, governance structures, markets, legal system, social interaction, and family. These are social processes identified by Maczko and Hidinger (2008). These social processes are more in line with social concern of those treating their ranch as a business rather than a source of leisure. In particular, future attempts to identify the social parameters that contribute to ranch sustainability need to evaluate factors in line with business objectives. Additionally, internal factors need to be evaluated separately from external. Such an attempt could reduce variability in producer response.

Lastly, it has been noted that effective adaptive management of rangeland is largely undocumented, but it is widely acknowledged. This fact requires much greater emphasis than it has received (Stuth, 1991; Brunson and Burritt, 2009; Hanselka et al., 2009; Teague et al., 2011). The research presented here provides the framework to investigate whole-ranch units, dissecting the decision-making process and the management practices that lead to an understanding of sustainable practices, especially on a regional scale.

## Implications

Respondents' observations of targeted ranch level indicators were used to compare 103 whole-ranch units. While this is a substantial number of ranching units in the context of physical grazing studies, results are presented and discussed strictly with respect to the survey respondents and not extrapolated to a larger group. These results are purely producers' perceptions and are not based on quantifiable improvement in rangeland health or producer profitability. Because of the limited geographic scope of the research, the relatively small response sample, and the significant difference between respondents and nondependent age, this study must be treated as a pilot survey. In results and discussion sections we refer only to the survey respondents' response patterns and don't extrapolate these to a broader population of ranchers. The study provides interesting points for further study, but definitive conclusions that would represent a broader group of ranchers than those who participated in the study cannot be drawn.

The approach presented is an important synthesis exercise to identify and quantify main variables involved in the perception of ranchers regarding rangeland sustainability. The indexes of ecological, economic, and social sustainability were constructed on the basis of relevant variables, and their quantification is necessarily subjective. The primary benefit of the study is the unique technique for investigating perceptions of decision makers on how land is managed in real-world ranching units. The methodology used may be useful in analysis of other grazing areas to better understand what management choices are likely to provide the greatest sustainability benefits.

This study demonstrates the perception among ranchers about the differences among various multipaddock grazing systems when analyzing the system for sustainability attributes. It is hypothesized that the categories used to analyze the number of paddocks need not be precisely interpreted, but more generally, the greater the number of paddocks, the more likely land health benefits may be gained. On the basis of published research, these gains are likely attained due to increased periods of recovery after grazing and short periods of grazing. In most real-world situations the timing of land rest will vary because of weather, water availability, forage regrowth, proximity to cattle working facilities, etc. These varying factors dictate the need for adaptive management. Evidence suggests that any increase in the number of paddocks available for the cow herd will positively influence land health objectives with appropriate management. However, utilization of four or fewer paddocks may create conditions that are antagonistic to the parameters measured by the ES in this study. These setbacks may be overcome as land health benefits increase with availability of additional paddocks. Theoretically, these inequalities could help explain the divergent conclusions among grazing management researchers concerning continuous grazing benefits compared with multipaddock grazing systems. The perceptions of this group of ranchers warrant additional investigation to determine the linkage between land health and economic ranch performance with an increasing number of paddocks, with the benefits possibly being derived from additional duration of land rest and shorter periods of grazing.

## References


Ash, A.J., Stafford-Smith, D.M., 1996. Evaluating stocking rate impacts in rangelands: animals don't practice what we preach. Rangeland Journal 18 (2), 216–243.

Archibald, S., Bond, W.J., Stock, W.D., Fairbanks, D.H.K., 2005. Shaping the landscape: fire-grazer interactions in an African savanna. Ecological Applications 15, 96–109.

Bailey, D.W., Gross, J.E., Laca, E.A., Rittenhouse, L.R., Coughenour, M.B., Swift, D.M., Sims, P.L., 1996. Mechanisms that result in large herbivore grazing patterns. Journal of Range Management 49, 386–400.

Barnes, M.K., Norton, B.E., Maeno, M., Malechek, J.C., 2008. Paddock size and stocking density affect spatial heterogeneity of grazing. Rangeland Ecology & Management 61, 380–388.

Beetz, A.E., Rinehart, L., 2010. Rotational Grazing. National Sustainable Agriculture Information Service Available at: https://attra.ncat.org/attra-pub/viewhtml.php?id=245 Accessed 15 May, 2016.

Bland, J.M., Altman, D.G., 1997. Statistics notes: Cronbach's alpha. British Medical Journal 314, 572.

Belsky, A.J., Matzke, A., Uselman, S., 1999. Survey of livestock influences on stream and riparian ecosystems in the western United States. Journal of Soil and Water Conservation 54 (1), 419–432.

Briske, D.D., Derner, J.D., Brown, J.R., Fuhlendorf, S.D., Teague, W.R., Havstad, K.M., Gillen, R.L., Ash, A.J., Willms, W.D., 2008. Rotational grazing on rangelands: reconciliation of perception and experimental evidence. Rangeland Ecology & Management 61, 3–17.

Briske, D.D., Sayre, N.F., Huntsinger, L., Fernandez-Gimenez, M., Budd, B., Derner, J.D., 2011. Origin, persistence, and resolution of the rotational grazing debate: integrating human dimensions into rangeland research. Rangeland Ecology & Management 64, 325–334.

Brunson, M.W., Burritt, E.A., 2009. Behavioral factors in rotational grazing systems. Rangelands 31 (5), 20–25.

Calker, K.J., 2005. Sustainability of Dutch dairy farming systems: a modeling approach [doctoral thesis]. Wageningen Universiteit, Wageningen, The Netherlands.

Centeri, C., Herczeg, E., Vona, M., Balazs, K., Penksza, K., 2009. The effects of land-use change on plant–soil–erosion relations. Nyereg Hill, Hungary. Journal of Plant Nutrition and Soil Science 172, 586–592.

Cronbach, L.J., 1951. Coefficient alpha and the internal structure of tests. Psychometrika 16 (3), 297–334.

Dillman, C.A., 2000. Mail and Internet surveys: the tailored design method. second ed. John Wiley and Sons, New York, NY, USA.

Doll, J.E., Jackson, R.D., 2009. Wisconsin farmer attitudes regarding native grass us in grazing systems. Journal of Soil and Water Conservation 64 (4), 276–285.

Earl, J.M., Jones, C.E., 1996. The need for a new approach to grazing management—is cell grazing the answer? The Rangeland Journal 18, 327–350.

Frank, D.A., McNaughton, S.J., 2002. The ecology of the earth's grazing ecosystems. BioScience 48, 513–521.

Garson, G., 2011a. Scales and standard measures. From Statnotes: topics in multivariate analysis Available at: http://facultychassncsuedu/garson/pa765/statnotehtm Accessed 12 May 2011.

Garson, G., 2011b. Testing of assumptions. From Statnotes: topics in multivariate analysis Available at: http://facultychassncsuedu/garson/pa765/statnotehtm Accessed 19 May 2011.

Greiner, R., Patterson, L., Miller, O., 2008. The role of grazier motivations and risk attitudes in the adoption of grazing best management practices. Proceedings from 52nd Annual Conference of the Australian Agricultural and Resource Economics Society; 5-8 February 2008; Canberra, Australia.

Hanselka, W., Lyons, R., Mosley, M., 2009. In: Winn, J. (Ed.), Grazing land stewardship. Texas AgriLife Extension Service Publication B-6221.

Heitschmidt, R.K., Taylor Jr., C.A., 1991. Livestock production. In: Heitschmidt, R.K., Stuth, J.W. (Eds.), Grazing management: an ecological perspective. Timber Press, Portland, OR, USA, pp. 161–177.

Heitschmidt, R.K., Conner, J.R., Canon, S.K., Pinchak, W.E., Walker, J.W., Dowhower, S.L., 1990. Cow/calf production and economic returns from yearlong continuous, deferred rotation and rotational grazing treatments. Journal of Production Agriculture 3, 92–99.

Heitschmidt, R.K., Vermeire, L.T., Grings, E.E., 2004. Is rangeland agriculture sustainable? Journal of Animal Science (82(Suppl)), 138–146.

Holechek, J.L., Berry, T.J., Vavra, M., 1987. Grazing system influences on cattle diet and performance on mountain range. Journal of Range Management 40, 55–60.

Holechek, J.L., Tembo, A., Daniel, A., Fusco, M., Cardenas, M., 1994. Long term grazing influences on Chihuahuan desert rangeland. Southwestern Naturalist 39, 342–349.

Hormay, A.L., Evanko, A.B., 1958. Rest-rotation grazing … a management system for bunchgrass ranges. California Forest and Range Experiment Station Misc Paper 27. USDA Forest Service, Albany, CA, USA.
Hunt, L.P., Petty, S., Crowley, R., Fisher, A., Ash, A.J., MacDonald, N., 2007. Factors affecting management of cattle grazing distribution in northern Australia: preliminary observations on the effect of paddock size and water points. Rangeland Journal 29, 169–179.
Jacobo, E.J., Rodrı´Guez, A.M., Bartoloni, N., Deregibus, V.A., 2006. Rotational grazing effects on rangeland vegetation at a farm scale. Rangeland Ecology & Management 59, 249–257.
Karahoca, D., Karahoca, A., Karaoglu, A., Gulluoglu, B., Arifoglu, E., 2010. Evaluation of web based learning on student achievement in primary school computer courses. Procedia—Social and Behavioral Science 2 (2), 5813–5819.
Klipple, G.E., Costello, D.F., 1960. Vegetation and cattle responses to different intensities of grazing on shortgrass ranges of the central Great Plains. US Department of Agriculture, Washington, DC, USA Technical Bulletin 1216.
Knapp, N.C., Fernandez-Gimenez, M.E., 2009. Knowledge in practice: documenting rancher local knowledge in northwest Colorado. Rangeland Ecology & Management 62, 500–509.
Laca, E.A., 2009. New approaches and tools for grazing management. Rangeland Ecology & Management 62, 407–417.
Leontitsis, A., Pagge, J., 2007. A simulation approach on Cronbach's alpha statistical significance. Mathematics and Computers in Simulation 73, 336–340.
Lubowiski, R.N., Vesterby, M., Bucholtz, S., Baez, A., Roberts, M.J., 2006. Economic Information Bulletin No (EIB-14) USDA Economic Research Service Available at: http://wwwersusdagov/Publications/EIB14/ Accessed 17 July 2009.
Maczko, K.A., Bryant, L.D., Thompson, D.W., Borchard, S.J., 2004. Putting the pieces together: assessing social, ecological, and economic rangeland sustainability. Rangelands 26 (3), 3–14.
Maczko, K., Hidinger, L. (Eds.), 2008. Sustainable rangeland ecosystem goods and services. Sustainable Rangeland Roundtable. Available at: http://sustainablerangelandswarnercnrcolostateedu/. Accessed 12 June 2010.
McIlvain, E.H., Savage, D.A., 1951. Eight-year comparisons of continuous and rotational grazing on the southern plains range. Journal of Range Management 4, 42–47.
McNaughton, S.J., 1979. Grazing as an optimization process: grass-ungulate relationships in the Serengeti. The American Naturalist 113, 691–703.
Michunas, D.G., Sala, O.E., Lauenroth, W.K., 1988. A generalized model of the effects of grazing by large herbivores on grassland community structure. American Naturalist 132, 87–106.
Merrill, L.B., 1954. A variation of deferred rotation grazing for use under southwest range conditions. Journal of Range Management 7, 152–154.
Müller, B., Frank, K., Wissel, C., 2007. Relevance of rest periods in non-equilibrium rangeland systems—a modeling analysis. Agricultural Systems 92, 295–317.
NRCS, 2000. Interpreting indicators of rangeland health technical reference 1734-6. Version 3. pp. 3–9.
Nunnaly, J.C., Bernstein, I.H., 1994. Psychometric theory. third ed. McGraw-Hill, New York, NY, USA.
O'Connor, T.G., 1992. Patterns of plant selection by grazing cattle in two savanna grasslands: a plant's eye view. Journal of the Grassland Society of Southern Africa 9, 97–104.
O'Reagain, P., McKeon, G., Day, K., Ash, A., 2003. Managing for temporal variability in extensive rangelands—a perspective from Northern Australia. Proceedings of the VIIth International Rangeland; July 26-August 1, 2003; Congress Durban, South Africa, pp. 799–809.
Pieper, R.D., Donart, G.B., Parker, E.E., Wallace, J.D., 1978. Livestock and vegetational response to continuous and four-pasture one-herd grazing systems in New Mexico. Proceedings of the International Rangeland Congress 1, 560–562.
Provenza, F.D., 2003. Foraging behavior: managing to survive in a world of change. Utah Agricultural Experiment Station. Available at: http://behavenet/products/booklethtml. Accessed 18 July 2009. p. 63.
Reece, P.A., 1986. Short-duration grazing research and case studies in Nebraska. Proceedings of Short-Duration Grazing and Current Issues in Grazing Management Shortcourse Washington State University Cooperative Extension Service. WSU, Pullman, WA, USA.
Smith, J.G., 1895. Forage conditions of the prairie region. USDA Yearbook of Agriculture—1895. US Department of Agriculture, Washington, DC, USA, pp. 309–324.
Starkweather, J., 2011. Internal Consistency Analysis SPSS Shortcourse Research and Statistical Support, UNT. Available at: http://wwwuntedu/rss/class/Jon/SPSS_SC/ Accessed 19 April 2011.
Stinner, D.H., Stinner, B.R., Martsolf, E., 1997. Biodiversity as an organizing principle in agroecosystem management: case studies of holistic resource management practitioners in the USA. Agriculture, Ecosystems & Environment 62, 199–213.
Stuth, J.W., 1991. Foraging behavior. In: Heitschmidt, R., Stuth, J. (Eds.), Grazing management: an ecological perspective. Timber Press, Portland, Oregon, USA, pp. 65–83.
Sydorovych, O., Wossink, A., 2008. The meaning of agricultural sustainability: evidence from a conjoint choice survey. Agricultural Systems 98, 10–20.
Tanaka, J.A., Torell, L.A., 2002. Status of economic criteria and indicators for the sustainable rangelands roundtable. In: Bartlett, E.T., Mitchell, J.E. (Eds.), Sustainable rangeland management: status of a roundtable to determine criteria and indicators, a work in progressProceedings of the Sustainable Rangelands Roundtable symposium at the Society Range Management Annual Meeting, Kansas City, Feb 13-19. Colorado State University, Fort Collins, CO, USA, pp. 51–53.
Teague, R., Dowhower, S.L., Waggoner, J.A., 2004. Drought and grazing patch dynamics under different grazing management. Journal of Arid Environments 58, 97–117.
Teague, R., Provenza, F., Norton, B., Seffens, T., Barnes, M., Kothmann, M., Roath, R., 2008. Benefits of multi-paddock grazing management on rangelands: limitations of experimental grazing research and knowldege gaps. In: Schroder, H.G. (Ed.), Grasslands: ecology, management and restoration. Nova Science Publishers Inc., Hauppauge NY, USA, pp. 11788–13619.
Teague, W.R., Dowhower, S.L., Ansley, R.J., Pinchak, W.E., Waggoner, J.A., 2010. Integrated grazing and prescribed fire restoration strategies in a mesquite savanna: I. Vegetation response. Rangeland Ecology & Management 63, 275–285.
Teague, R., Dowhower, S.L., Baker, S.A., Haileb, N., DeLaunea, P.B., Conover, D.M., 2011. Grazing management impacts on vegetation, soil biota and soil chemical, physical and hydrological properties in tall grass prairie. Agriculture Ecosystem and Environment 141, 310–322.
Teague, R., Provenza, F., Kreuter, U., Steffens, T., Barnes, M., 2013. Multi-paddock grazing on rangelands: why the perceptual dichotomy between research results and rancher experience? Journal of Environmental Management 128, 699–717.
Teague, R., Grant, B., Wang, H., 2015. Assessing optimal configurations of multi-paddock grazing strategies in tallgrass prairie using a simulation model. Journal of Environmental Management 150, 262–273.
Texas AgriLife Extension Service, 2010. Texas County Agriculture Income Report. Texas A&M University, College Station, TX, USA.
Vavra, M., 1996. Sustainability of animal production systems: an ecological perspective. Journal of Animal Science 74, 1418–1423.
Ward, N., 1999. Ranchers need support for sustainable ranching: what government can do. Rangelands 21 (3), 13–17.
Warren, S.D., Thurow, T.L., Blackburn, W.H., Garza, N.E., 1986. The influence of livestock trampling under intensive rotation grazing on soil hydrologic characteristics. Journal of Range Management 39, 491–495.
Winter, S.J., Esler, K.J., Kidd, M., 2005. An index to measure the conservation attitudes of landowners towards Overberg Coastal Renosterveld, a critically endangered vegetation type in the Cape Floral Kingdom. South Africa Biological Conservation 126, 383–394.
Witten, G.Q., Richardson, F.D., Shenker, N., 2005. A spatial-temporal analysis on pattern formation around water points in a semi-arid rangeland system. Journal of Biological Systems 13, 1–23.