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RESEARCH ARTICLE

Factors Influencing Use and Frequency of Rotational Grazing for Beef Cattle in Tennessee

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Abstract

This study determines which factors are associated with the use of rotational grazing and the frequency with which Tennessee producers rotate cattle during the summer months. Survey data were used to estimate an ordered response model with sample selection. Most respondents used rotational grazing, and the most frequent rotational schedule was rotating cattle one to two times per month. Factors including labor, capital, knowledge, and water availability influenced the use of rotational grazing and the frequency of rotating cattle. The insights from this study can inform the development of incentives to promote more intensive use of rotational grazing.

Keywords: Beef cattle; farm management; grazing; pasture management

JEL classifications: Q12; Q25

Introduction

Tall fescue (TF) is a hardy cool-season grass (CSG) with two growing seasons (Spring and Fall) that can persist in adverse weather conditions (Wolf, Brown, and Blaser, 1979). Grazing management of TF during the summer months has important economic implications for a large share of the United States (US) beef cattle industry. TF is grown on over 35 million acres and is the primary pasture and hay grass on roughly 40% of US cow–calf operations (United States Department of Agricultural National Statistical Service [USDA NASS], 2018). However, TF growth slows during the warmer summer months and TF has physiological characteristics that can lower conception rates and reduce daily gains when cattle are grazed on summer TF pasture (Looper et al., 2010).

Producers can compensate low summer forage production by providing cattle with supplemental feed, lowering the number of cattle on pasture, or making more land available for grazing during the summer (Kallenbach, 2015). These practices are short-term responses to address limited summer forage. Diversifying planted forages to extend grazing days into the summer months is a possible long-term solution. Growing conditions in the Southeastern US are favorable to producing both perennial CSG and annual warm-season grasses (WSGs) (Kallenbach, 2015). WSGs grow from mid-May through late summer, with perennials going dormant and annuals dying in early October. Studies find positive weight gains and higher net returns for beef cattle grazed on WSGs in this region (Burns and Fisher, 2013; Lowe et al., 2015, 2016; Keyser et al., 2016; Boyer et al., 2020a). However, converting pasture to integrated CSG and WSG grazing systems requires long-term investment, and producers have been slow to plant these forages (Keyser et al., 2019; Ren et al., 2022).

Rotational grazing is another possible forage management system to address the issue of slow summer forage production in this region. Rotational grazing is where only one part of a pasture is grazed at any one time, while the remaining pasture is allowed to rest (Undersander et al., 2002). Use of rotational grazing brings with it increased labor and managerial costs, in addition to capital expenses on fencing, pumps, power, and water tanks (Undersander et al., 2002; Gillespie, Kim, and Paudel, 2007; Gillespie et al., 2008; Lambert et al., 2014). Wang et al. (2018) found that rotational grazing can increase profitability in the short and long run if managed well, but results from controlled experimental grazing studies are mixed regarding its profitability (Briske et al., 2008; Gillespie et al., 2008). Rotational grazing can also provide environmental benefits by reducing overgrazing and extending grazing days (Muir, Pitman, and Foster, 2011; Byrnes et al., 2018; Stanley et al., 2018). Reducing overgrazing can moderate soil erosion, improve water quality, and promote soil health (Muir, Pitman, and Foster, 2011; Byrnes et al., 2018). Extending grazing days could also offset greenhouse gas emissions caused by ruminant enteric fermentation by increasing the amount of carbon sequestered by forages (Stanley et al., 2018). Forage productivity and the environmental benefits from rotational grazing have been found to increase as the frequency at which cattle are rotated between paddocks increases (Teague and Barnes, 2017; Mosier et al., 2021). However, higher-frequency rotational grazing requires a greater investment in labor, capital, and management (Smith et al., 2011; Rayburn, 2014).[1]

Researchers have investigated cattle producer use of rotational grazing across various regions of the US (Kim, Gillespie, and Paudel, 2008; Mooney, Bolinson, and Barham, 2019; Lambert et al., 2014, 2020; Wang et al., 2020). Kim, Gillespie, and Paudel (2008) found that 48% of Louisiana beef cattle producers adopted rotational grazing. Lambert et al. (2014) reported that 61% of cattle producers in a Southeastern US watershed rotated cattle. Wang et al. (2020) found that while 83% of the cattle operators in the Great Plains practiced rotational grazing, the start-up and managerial costs of the practice where key reasons why remaining producers had not adopted it. The next three largest impedances to rotational grazing adoption were increased labor requirements, producer unfamiliarity with rotational grazing systems, and limited access to water. Thus, studies have commonly shown a USDA National Resource Conservation Service (NRCS) cost-share payment to cover these expenses associated with rotational grazing such as fencing and waterers to be necessary to encourage adoption (Kim, Gillespie, and Paudel, 2008; Lambert et al., 2020). While rotational grazing is being used, there is a lack of knowledge on what factors impact the use of higher-frequency rotational grazing. Additionally, to our knowledge, no study has specifically looked at the frequency of rotational grazing in this region. This type of grazing management could benefit this region, given the lack of TF forage growth in the summer.

The objective of this research is to identify factors affecting the use of rotational grazing and determine which farm and operator characteristics are associated with the frequency at which producers rotate cattle during the summer months. The data used in the analysis are from a 2018 survey of Tennessee beef cattle producers. We estimate an ordered response model with sample selection because some producers in the sample did not use rotational grazing. The response variable—the frequency at which a producer rotates cattle among paddocks—is ordinal. We regress use and rotational grazing frequency on operator characteristics, farm business attributes, and pasture management practices used by producers to determine which of these factors correlate with these outcomes.

Findings from this research give insight into the frequency with which producers rotate cattle and factors that might encourage or hinder use of higher-frequency rotational grazing. Implication can stretch beyond Tennessee to the Southeastern US, which also relies on TF as the primary forage for pasture and hay production. These results are also particularly relevant given the recent policy discussion of using practices like rotational grazing to increase carbon sequestration as well as potential increased funding to USDA NRCS cost-share programs to fund

[1]A common formula used by Extension to determine the number of paddocks is number of rest days divided by number of grazing days plus 1. Therefore, short duration of grazing days means the need for more paddocks (Smith et al., 2011; Rayburn, 2014).

the adoption of practices like rotational grazing. These results could inform policy-makers on how to target producers most likely to adopt rotational grazing.

Economic Framework

Rotational grazing requires producers to subdivide pastures into smaller management areas, commonly called paddocks, and move livestock from one paddock to the other depending on the state of forage health and productivity (Undersander et al., 2002). A producer implementing rotational grazing first designs a paddock layout, which determines the location, shape, number, and size of paddocks to establish (Undersander et al., 2002). Paddock designs consider the availability and quality of farm resources including water, soil type, forage species, access to natural shade, and topography. Capital investments include fencing, lanes, shade structures, and water systems. The number of paddocks is a function of the grazing duration of each paddock as driven by its productivity. Shorter grazing durations or higher-frequency rotation of cattle requires additional paddocks (Smith et al., 2011; Rayburn, 2014). The producer's decision to rotate livestock is based on forage growth and availability and prescribed by an established schedule (Undersander et al., 2002). Generally, more paddocks mean more livestock per land unit and higher levels of management (Teague and Barnes, 2017) and higher labor, capital, and management costs (Smith et al., 2011; Rayburn, 2014).

Some expenses are long-term investments depending on the type of fencing and water systems purchased. If water availability restricts the number of paddocks a producer could install, then the producer has the option to invest in a new well, pump, and water tank. Managing this type of system typically requires higher investment in management and labor (Gillespie, Kim, and Paudel, 2007; Gillespie et al., 2008). Adopters of rotational grazing should expect annual costs of production to increase by \$30 to \$70 per acre due to increased infrastructure (Undersander et al., 2002) and labor costs (Gillespie, Kim, and Paudel, 2007; Gillespie et al., 2008). Producer unfamiliarity with rotational grazing systems is a nonpecuniary barrier to its adoption (Wang et al., 2020).

The economic benefits from rotational grazing result from improved forage productivity, increases in average daily gain, reduced pasture fertilizer costs from distributed manure, and lower weed control costs resulting from a reduction in overgrazing (Gillespie et al., 2008; Wang et al., 2018). Rotational grazing can also decrease the risk of financial loss during droughts (Wang et al., 2020). Nonpecuniary benefits associated with rotational grazing are reducing soil erosion, improving water quality, and sequestering carbon on pasture (Muir, Pitman, and Foster, 2011; Teague and Barnes, 2017; Byrnes et al., 2018; Stanley et al., 2018). Short-duration grazing or higher-frequency rotations have been noted to increase forage productivity, since pastures have more time to rest (Teague and Barnes, 2017). However, nonpecuniary benefits have been the primary focus of studies examining higher-frequency rotational grazing with impacts such as retaining more nitrogen in the system and carbon in the soil (Teague and Barnes, 2017; Mosier et al., 2021). These financial and nonfinancial benefits vary across operations and regions. Still, they will be the driver of a producer's adoption of rotational grazing and the frequency with which they rotate cattle.

Data

Data were collected from a 2018 survey of Tennessee beef cattle producers. A list frame of 7513 beef cattle producers who had participated in the Tennessee Agricultural Enhancement Program (TEAP) was obtained from the Tennessee Department of Agriculture. A total of 5831 producers were identified and included in the email survey list frame. The survey was administered following Dillman's (2007) method using Qualtrics. Individuals identified with an email address received the survey on March 2, 2018. A reminder email was sent 2 weeks following initial delivery. The response rate was 24% with 1405 responses.

The survey instrument was divided into five sections. The first section included questions on livestock numbers, farm size, grazing management, and the use of CSGs and WSGs. Producers with cattle grazing WSGs completed the second section, which included questions on the WSG species used, the perceived effects of WSGs on their beef cattle operation, and their concerns about planting and managing WSGs. Producers who did not graze cattle on WSGs completed section three, which contained questions on participant willingness to establish WSGs. The fourth section included questions on supplemental cattle feeding practices and the impacts of drought on their operation. The final section focused on producer demographics. Producers were asked to state if they rotated cattle across pastures or paddocks during the summer months. If they did practice rotational grazing, they were subsequently asked the frequency of rotation. Respondents could indicate less than once per month, one to two times per month, three to four times per month, and more than once a week.[2] Descriptions of dependent and independent variables used in this analysis are shown in Table 1.

Empirical Model

Producers self-select into users and nonusers of rotational grazing. As a result, analysis of the frequency at which adopters rotate cattle is based on a nonrandom sample. Rotation frequency is observed only for the subgroup of producers who adopted the practice. When a sample depends on the outcome of a dependent variable, estimates may be biased and inconsistent (Cameron and Trivedi, 2005). To attend to this issue, we model rotation frequency as an ordered response model with sample selection.

The probability (Pr) a producer i adopts rotational grazing is

$$\Pr\left[\text{adopt}_i = 1|\mathbf{x}_i\right] \Rightarrow y^*_{Ai} = \alpha_0 + \mathbf{x}_i\alpha + u_i^A \tag{1}$$

where $\boldsymbol{x}_i$ includes farm operator and business characteristics hypothesized to affect the producer's decision to adopt rotational grazing, $\boldsymbol{\alpha}$ is a conformable vector of coefficients, α_0 is the intercept, and $y_{Ai}{}^*$ is a latent response variable observed as "1" for rotational grazing adopters, and 0 otherwise. The random error $u_i{}^A$ has an expected value of 0 and a variance of 1.

The ordered model for rotation frequency is

$$y^*_{Fi} = \begin{cases} 1 = & < 1 \text{ time per month if } y^*_{Fi} \le \kappa_1 \text{ and } y^*_{Fi} > 0|y^*_{Ai} > 0 \\ 2 = & 2 \text{ to } 3 \text{ times per month if } \kappa_1 \le y^*_{Fi} \le \kappa_2 \text{ and } y^*_{Fi} > 0|y^*_{Ai} > 0 \\ 3 = & 4 \text{ to } 5 \text{ times per month if } \kappa_2 \le y^*_{Fi} \le \kappa_3 \text{ and } y^*_{Fi} > 0|y^*_{Ai} > 0 \\ 4 = & > 5 \text{ times per month if } \kappa_3 \le y^*_{Fi} \text{ and } y^*_{Fi} > 0|y^*_{Ai} > 0 \end{cases} \tag{2}$$

where $y_{Fi}{}^*$ is a latent response variable that equals "1" if the argument is true and $y_{Ai}{}^* > 0$, and κ_j is a threshold cutoff to be estimated for the jth frequency. The probability a respondent rotates cattle at frequency j is

$$\Pr\left[y^*_{Fi} = 1|\mathbf{z}_i\right] = F(\kappa_1 - \mathbf{z}_i\boldsymbol{\beta}, \alpha_0 + \mathbf{x}_i\boldsymbol{\alpha}, \rho) \tag{3}$$

$$\Pr\left[y^*_{Fi} = 2|\mathbf{z}_i\right] = F(\kappa_2 - \mathbf{z}_i\boldsymbol{\beta}, \alpha_0 + \mathbf{x}_i\boldsymbol{\alpha}, \rho) - F(\kappa_1 - \mathbf{z}_i\boldsymbol{\beta}, \alpha_0 + \mathbf{x}_i\boldsymbol{\alpha}, \rho)$$

$$\Pr\left[y^*_{Fi} = 3|\mathbf{z}_i\right] = F(\kappa_3 - \mathbf{z}_i\boldsymbol{\beta}, \alpha_0 + \mathbf{x}_i\boldsymbol{\alpha}, \rho) - F(\kappa_2 - \mathbf{z}_i\boldsymbol{\beta}, \alpha_0 + \mathbf{x}_i\boldsymbol{\alpha}, \rho)$$

$$\Pr\left[y^*_{Fi} = 4|\mathbf{z}_i\right] = 1 - F(\kappa_3 - \mathbf{z}_i\boldsymbol{\beta}, \alpha_0 + \mathbf{x}_i\boldsymbol{\alpha}, \rho),$$

[2]The specific question did not reference a year, but summer 2017 would be the most recent summer grazing period to reference. In the supplemental information, we provide data on weather condition in Tennessee during the summer of 2017.

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Table 1. Variable names and definitions

Variables	Definition
Dependent variables	
ROTATE	=1 if a producer rotates cattle between pastures and paddocks during the summer; 0 otherwise
ROTSFR	Frequency of rotating cattle in the summer =1 if less than once a month, =2 if one or two times a month, =3 if three or four times per month, and =4 if more than once a week
Independent variables	
STOCK	Annual average of animal units divided by total acres grazed
ACRE	Total acres of the operation
DIVR	=1 if a producer has intentionally diversified their cool-season perennial grass with other grass; 0 otherwise
FERT	=1 if a producer applied fertilizer and/or lime in 2017; 0 otherwise
WEED	=1 if a producer sprayed to control weeds in 2017; 0 otherwise
TEST	=1 if a producer tested soil in 2017; 0 otherwise
REDO	=1 if a producer has renovated or converted pasture in the last 10 years; 0 otherwise
CUT	=1 if the producer cut hay in 2017; 0 otherwise
WELL	Percentage of the farm's water source that come from a groundwater well
SURFACE	Percentage of the farm's water source that comes from rainfed surface water
PASSON	=1 if the producer indicated they plan on passing on their farming operation after retiring; 0 otherwise
EXT1	Number of Extension publications and websites accessed in 2017
EXT2	Number of Extension field days or workshop attended in 2017
AGE	Producer age in years
TOTINC	Total taxable farm and nonfarm income for 2017 scale 1–7 that is =1 if <\$25,000, =2 if ≥\$25,001 and ≤\$50,000, = 3 if ≥\$50,001 and ≤\$70,000, = 4 if ≥\$75,001 and ≤\$100,000, =5 if ≥\$100,001 and ≤\$140,000, =6 if ≥\$140,001 and ≤\$200,000; =7 if ≥\$200,001
PERINC	Percentage of 2017 income from farming scale 1–5 that =1 if <20%, =2 if ≥20% and ≤40%, =3 if ≥41% and ≤60%, =4 if ≥61% and ≤80%, =5 if ≥81%

where $F(\cdot)$ is the bivariate standard normal cumulative density function, z_i is the farm operator and business attributes, ρ is the correlation coefficient (discussed below), and $\boldsymbol{\beta}$ is the conformable vector of slope coefficients. The propensity a producer rotates cattle at frequency j is

$$y^*_{Fi} = \kappa_j - \mathbf{z}_i\boldsymbol{\beta} + u_i^F \tag{4}$$

where u_i^F has an expected value of 0 and a variance of 1. The error terms of equations (1) and (4) are assumed to be distributed as multivariate normal (MVN) random variables:

$$\begin{bmatrix} u_i^A \\ u_i^F \end{bmatrix} \sim \mathrm{MVN}\left(\begin{bmatrix} 0 \\ 0 \end{bmatrix}, \begin{bmatrix} 1\rho \\ \rho 1 \end{bmatrix}\right). \tag{5}$$

We use a flexible semiparametric approach to estimate the ordered response model with sample selection, which relaxes assumptions of error normality typically maintained for maximum likelihood estimation of probit and ordered probit regressions. Parametric estimators of discrete models can be sensitive to distributional assumptions of error terms (Chen and Khan, 2003; Stewart, 2004, 2005). The estimator used here follows the approach of Gallant and Nychka

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(1987), Stewart (2004), and De Luca and Perotti (2011). The procedure makes no assumption about the densities of the error terms. De Luca and Perotti approach the problem of recovering the unobserved error densities using two-dimensional Cartesian products of Hermite polynomial expansions. The expansion approximations are used to derive a pseudo-maximum likelihood objective function for estimating the model parameters. The optimal number of polynomial terms for dimensions 1 and 2 are found by performing a grid search ranging from $p = 1, \ldots, 8$ along both dimensions. Optimal polynomial orders are those minimizing the Bayesian information criterion. De Luca and Perotti (2011)'s *snpopsel* procedure in STATA 16 (StataCorp, 2020) was used in the analysis.

Explanatory Variables

Variables included in the outcome and rotation frequency equations and their hypothesized signs were identified through a literature review. These variables are generally categorized as "pasture and grazing management practices" and "constraints or barriers to using rotational grazing." Independent variables and the hypothesized signs of the parameters in both the selection and outcome equations were the variables categorized as various "constraints or barriers" to using rotational grazing. These variables were identified by Wang et al. (2020).

Adoption Equation

Lambert et al. (2020) found that willingness to adopt rotational grazing was inversely correlated with stocking density. Gillespie et al. (2008) reported higher stocking rates with rotational grazing would decrease net returns relative to higher stocking rates with continuous grazing. Following the findings form Lambert et al. (2020), we anticipate the stocking rate parameter estimate to be negative. An increase in the total acres operated is expected to positively influence the likelihood of producers using rotational grazing (Kim, Gillespie, and Paudel, 2008; Lambert et al., 2020). Operating on more land is anticipated to have more flexibility to make land use changes and adopt best management practices. Pasture improvement practices such as soil testing, fertilizing pastures, weed control, and renovating pastures are hypothesized to have a positive parameter estimate (Lambert et al., 2014, 2020).

We also hypothesize a negative parameter estimate for a farm that cuts its own hay. This assumption is based on Boyer et al.'s (2020b) finding that rotational grazing decreased the number of days a producer feeds hay, thus, reducing their hay demand. The final independent variable specific to the selection equation is a dummy variable indicating whether the producer expected to pass on their farm to family after retirement. Lambert et al. (2020) and Kim, Gillespie, and Paudel (2008) found that producers who planned on passing the farm on to family were more likely to adopt rotational grazing. We also anticipate a similar relationship with this variable and the likelihood of using rotational grazing.

Rotation Frequency Equation

Having more acres to operate is expected to increase producers' flexibility to rotate cattle more frequently; thus, we expected larger farms to be more likely to rotate more often. Kim, Gillespie, and Paudel (2008) reported a stream or river running through a field or pasture impedes the adoption of rotational grazing. They speculated that having surface water that cattle could access for watering decreased the likelihood a producer would install a water trough or tank. Wang et al. (2020) found that water source constraints were the primary reason producers did not adopt rotational grazing. Respondents commented that the lack of groundwater, cost of drilling, and government regulations prevented them from using rotational grazing. We hypothesize that a higher

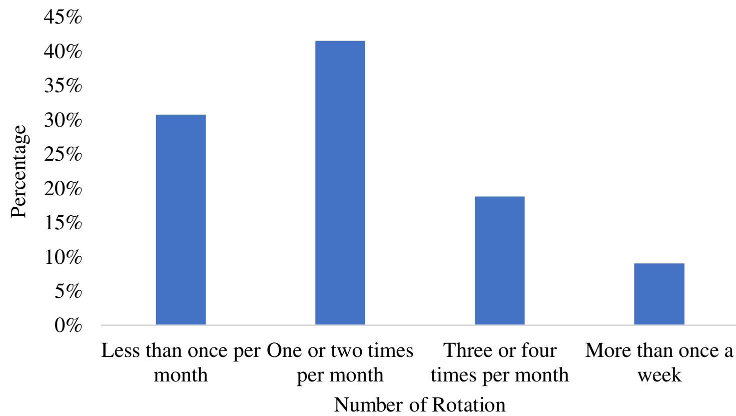

Figure 1. Percentage of producers' rotation frequency during the summer in Tennessee.

reliance on well water for watering cattle is correlated with the propensity to use multiple paddocks and therefore rotate cattle more frequently. On the other hand, surface water sources might be more difficult to pump to paddocks. Another possible explanation is water sources could be correlated with land quality. For example, more surface water might suggest higher land quality and less of a need to rotate cattle to increase the productivity. The more a farm relies on surface water, the less likely it would be to adopt rotational grazing and likely rotate cattle less often.

We hypothesize that producers who attend University Extension Service events and used Extension media, including publications and websites, are more likely to adopt rotational grazing and rotate more frequently. Presumably, producers interacting with Extension services are more informed about the benefits and costs of rotational grazing. Lambert et al. (2020) found that older producers were less likely to adopt rotational grazing. Older producers may not be willing or capable of the labor required to implement rotational grazing and to rotate cattle more frequently. Also, the payback period for rotational grazing might be longer than the producer expects to remain in operation. We hypothesize that producer age will be negatively correlated with the likelihood of adopting rotational grazing and rotate cattle less frequently.

Household income, including farm and nonfarm income, and the percentage of the household income from farming were included in the adoption and rotation frequency equations. Kim, Gillespie, and Paudel (2005) found that households with higher income were more likely to use rotational grazing, but the percentage of household income from farming was unassociated with use. Wang et al. (2020) concluded that financial constraints were a primary barrier to adoption of rotational grazing. Household income is a capital constraint to adopting rotational grazing. Households earning a higher share of their income from off-farm employment may face labor constraints in terms of the time available for farming. We expect household income and percent of income from farming will be positively associated with adoption and the frequency at which operators rotate cattle.

Results

Most respondents (77%) stated they rotated cattle in the summer and of those who rotated cattle, 31% rotated less than once per month, 41% rotated one to two times per month, 19% rotated three to four times per month, and 9% rotated more than once a week (Table 2, Figure 1). Previous studies in this region have not reported such a high use of rotational grazing (Kim, Gillespie, and Paudel, 2008; Lambert et al., 2014).

Table 2. Summary statistics of the independent and dependent variable

Variables	Observations	Average	Standard deviation	Minimum	Maximum
Dependent variables					
ROTATE	1570	0.773	0.419	0	1
ROTSFR	1213	2.060	0.923	1	4
Independent variables					
STOCK	1472	0.696	0.602	0.009	9.580
ACRE	1485	144.59	300.39	7	10,200
DIVR	1482	0.775	0.417	0	1
FERT	1341	0.746	0.435	0	1
WEED	1328	0.797	0.403	0	1
TEST	1257	0.621	0.485	0	1
REDO	1377	0.379	0.485	0	1
CUT	1398	0.866	0.341	0	1
WELL	1314	24.63	35.71	0	100
SURFACE	1302	58.25	38.90	0	100
PASSON	1362	0.759	0.427	0	1
EXT1	1339	2.22	1.14	1	5
EXT2	1342	2.97	1.40	1	5
AGE	1359	54.99	13.26	17	91
TOTINC	1253	3.77	1.82	1	7
PERINC	1310	1.76	1.17	1	5

Average annual stocking density was 0.70 animal units per acre, or one cow–calf pair per 1.5 acres. This stocking rate is close to University Extension recommendations. Most of the land respondents operated on was owned (78%). A majority (77%) of respondents stated they had diversified their perennial CSG with other grasses (77%). Majorities of respondents also indicated they had fertilized and/or limed pastures (75%) and sprayed to control weeds (80%) in the year of the survey. Sixty-two percent of respondents used soil testing to determine how much fertilizer to apply. More than a third (38%) of the respondents had either renovated or converted a pasture within the last 10 years. Most (87%) respondents cut hay in 2017. On average, well water made up about 25% of respondent's primary water supply, while 58% was from surface water. The remaining water (17%) was from municipal utilities or other sources. Municipal and other water sources were excluded from the regression to avoid collinearity issues.

About 76% of the respondents intended to pass along their farm operation to family members. Average respondent age was 55 years, which is near the average Tennessee cattle producers' age reported in the 2017 Census of Agriculture (USDA NASS, 2018). Respondents, on average, attended two Extension workshops or events in 2017 and accessed three Extension publications. The mean of total household income (including farm and nonfarm income) was between $50,000 and $100,000 in 2017. These values are within the range of household income reported by USDA Economic Research Service (ERS) (2020). Between 20 and 40% of household income was from farming, indicating that many respondents relied on off-farm income in 2017, a finding typical of beef cattle producers (USDA ERS, 2020).

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Table 3. Heckman ordered probit regression estimates ($n = 982$)

Variable	Rotates grazing (ROTATE)	Rotation frequency (ROTSFR)
STOCK	−0.29532***	
ACRE	−0.00002	−0.0001
DIVR	0.10396	
FERT	0.12343	
WEED	−0.02719	
TEST	0.41261***	
REDO	0.49740***	
CUT	−0.16682	
WELL	0.00412*	0.0030**
SURFACE	−0.00876***	−0.0047***
PASSON	0.13051	
EXT1	0.08239*	−0.0263
EXT2	0.04451	0.0669**
AGE	−0.00262	−0.0002
TOTINC	−0.01720	0.0306
PERINC	−0.05519	0.0698**
Intercept	1.03254	
κ_1	–	−0.5716*
κ_2	–	0.6388***
κ_3	–	1.4361***
ϕ_{11}	1	
ϕ_{21}	1	
Log likelihood (LL)	−1365.93	
Wald chi-squared *P*-value	<0.0001	
Pseudo R squared	0.1	

*Significant at the 10%.
**Significant at the 5% level.
***Significant at the 1% level. ϕ_{11} and ϕ_{21} are polynomial expansion coefficients.
Notes: They have no substantive interpretation. κ_1, κ_2, and κ_3 are the ordered probit threshold parameters.

Ordered Probit with Sample Selection

Farms that stocked cattle at relatively higher rates on average for the year and used surface water for watering cattle were less likely to use rotational grazing (Table 3). This finding is consistent with the hypothesized relationship between stocking density and adoption. A one-unit change in stocking density reduced the likelihood of using rotational grazing by 0.07 (Table 4). While this finding corresponds with Lambert et al. (2020), the marginal effect is small. Producers who soil tested for fertilizer recommendations and had renovated a pasture in the last 10 years were 0.09 and 0.12 percentage points more likely to use rotational grazing, respectively. The probability of using rotational grazing increased 0.02 percentage points, the more a producer attended an Extension workshop or events ($P < 0.10$).

Table 4. Marginal effects for rotational grazing adoption and rotation frequency

Variable	Rotates grazing	=1 if less than once a month	=2 if one or two times a month	=3 if three or four time per month	=4 if more than once a week
STOCK	−0.0719***	–	–	–	–
ACRE	0.0000	0.00002	0.00002	0.00002	0.00002
DIVR	0.0253	–	–	–	–
FERT	0.0301	–	–	–	–
WEED	−0.0066	–	–	–	–
TEST	0.1005***	–	–	–	–
REDO	0.1211***	–	–	–	–
CUT	−0.0406	–	–	–	–
WELL	0.0010*	−0.0009**	−0.00012	0.0005**	0.0005**
SURFACE	−0.0021***	0.0014***	0.00019*	−0.0008***	−0.0008***
PASSON	0.0318	–	–	–	–
EXT1	0.0201*	0.0080	0.00105	−0.0044	−0.0047
EXT2	0.0108	−0.0203**	−0.00267	0.0112**	0.0118**
AGE	−0.0006	0.0001	0.00001	0.00001	0.00001
TOTINC	−0.0042	−0.0093	−0.00122	0.0051	0.0054
PERINC	−0.0134	−0.0212**	−0.00279	0.0117**	0.0124*

*Significant at the 10% level.
**Significant at the 5% level.
***Significant at the 1% level.

The more an operation relied on surface water for watering cattle, the less likely it was to use rotational grazing. A 1% increase in the operation's reliance on surface water was 0.0002 percentage points less likely to use rotational grazing. On the other hand, operations that relied more heavily on well water were more likely to use rotational grazing. A 1% increase in the farm's reliance on well water increased the likelihood of using rotational grazing by 0.001 percentage points at the 0.1 significance level. These results are like previous studies that found access to water sources was a barrier toward adopting rotational grazing (Kim, Gillespie, and Paudel, 2008; Wang et al., 2020). The directional effect of reliance on well and surface water flipped depending on the frequency level of rotations (Table 4). Using more well water decreased the likelihood of rotating less than once a month, but more reliance on surface water increased the likelihood of rotating at this frequency. However, when rotating three or four times a month or more than once a week, signs of marginal effects were as hypothesized.

One explanation of these results might be a producer who rotates at the lowest frequency (less than once a month) did not want to invest in the infrastructure and paddocks to move cattle more frequently. That is, they wanted to use rotational grazing but at a lower cost. Lower-frequency rotations would not require as many paddocks; thus, the cost of water and fencing infrastructure would be low. Investing in well water development and water tanks would be high for such infrequent rotations, requiring greater marginal benefits from long-duration grazing periods. More surface water might be a lower cost water source for this frequency of rotating, especially if the stream or river is used as a barrier of the paddocks. Conversely, if a producer invested in well water and perhaps strategically placed water systems, they would rotate cattle across paddocks more frequently. Cost-share programs aiding development of pasture access to water could encourage the use of rotational grazing.

We saw a similar effect with the knowledge and labor constraints. The more a producer reads Extension publications, and the higher percentage of farming provides of the household income, the less likely they would rotate less than once a month. However, the more a producer reads Extension publications, the more likely they would rotate cattle more than three times a month. Finally, if the farm provides a higher percentage of the producer's household income, they were more likely to rotate at least three times per month. The producers who seek more information and rely more on farming for their income would rotate at higher frequencies. This might suggest the investment into knowledge by the individual could lead to adoption of a complex paddock and grazing management system. Dependence on farming for household income further defines the person to rotate more frequently to be willing to devote more time and labor to a more complex paddock and grazing system. The marginal effects for all variables affecting rotating cattle one or two times a month were insignificant. This interesting finding might deserve more research. This was the preferred frequency of using rotational grazing by respondents.

Conclusion

The objective of this research was to determine which farm and business characteristics were associated with the use of rotational grazing in Tennessee beef cattle, and to determine which of these factors were associated with the frequency a producer rotated cattle during the summer months. Data from a 2018 survey of Tennessee beef cattle producers was analyzed with an ordered response model with sample selection.

Most of the respondents (77%) used rotational grazing in the summer. The most common rotational grazing schedule was moving cattle between paddocks one to two times per month. Higher stocking density and reliance on surface water was negatively associated with the adoption of rotational grazing, while producers who soil test and renovate pastures were more likely to rotate cattle. The use of Extension resources and greater reliance on well water for watering cattle were positively associated with the adoption of rotational grazing. Farms that used relatively more well water for cattle rotated livestock more frequently. The opposite effect was observed for surface water. High-income farms rotated cattle more frequently.

Of the producers who practiced rotational grazing, those who accessed Extension resources and relied more on farming for their income would rotate at higher frequencies. Producers who had access to, or invested in, well water rotated cattle more frequently. The costs of grazing cattle increase the more frequently cattle are moved between paddocks. However, these producers appear to have invested in knowledge capital and water sources to realize the added benefits from rotational grazing systems. The findings demonstrate that water source type and availability play an important role in producers' willingness to adopt rotational grazing and the frequency at which cattle are rotated. Incentivizing producers to use less surface water and well development might be a practical solution for USDA NRCS to encourage conservation practices like rotational grazing to be considered. This might also help improve water quality by reducing the number of cattle with access to surface water (Lambert et al., 2014; 2020). However, we note the marginal effects of the estimate are small and that these recommendations would not likely result in large-scale adoption.

Supplementary material. For supplementary material accompanying this paper visit https://doi.org/10.1017/aae.2022.16

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