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Practice cost and size differences in invasive plant management strategies: An empirical analysis of US Great Plains states

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ABSTRACT

Grassland conservation of the Conservation Stewardship Program in the United States (US) is one of the largest cost-sharing initiatives for protecting grazing land from invasive and woody plants. The practice cost and unit size of various invasive and woody plant management strategies, such as mulching, brush management, and prescribed burning, are different from state to state. We aimed to compare and examine the association between practice cost ($/acre[ac]) and standard unit size of practice (acre) of mulching, brush management, and prescribed burning strategies in nine US Great Plains states, including Kansas, Montana, Nebraska, New Mexico, North Dakota, Oklahoma, South Dakota, Texas, and Wyoming. We estimated state-level average practice cost and unit size of mulching, brush management, and prescribed burning strategies using the conservation payment data of the Natural Resources Conservation Service (NRCS) to determine a cost-minimizing management strategy. A linear regression model was used to understand the association between practice cost and unit size of different management strategies and states. Practice cost and unit size differ by invasive and woody plant management strategy and Great Plains state. In the nine US Great Plains states, prescribed burning costs less on average ($29/ac) than mulching ($222/ac) and brush management ($152/ac) but covers a larger area on average (239 acres/unit) than mulching (3.19 acres/unit) and brush management (132 acres/unit). From the regression results, we also find a significantly negative association between practice cost and unit size (Coef. = -0.18, $p<0.05$). For prescribed burning, the practice cost is significantly lower (Coef. = -148.70, $p<0.00$) than the reference category of mulching. Our findings imply a policy idea that prescribed burning could be a cost-minimizing and high-coverage strategy than brush management in managing woody invasion under existing cost-unit size framework. Alternatively, expanding the typical unit sizes of a small covering strategy such as mulching could be another policy option for further assessment.

1. Introduction

Invasive and woody plant encroachment in the United States (US) is a major management and conservation concern in grasslands (Archer et al., 2017; Sala and Maestre, 2014). In the US, woody cover increases by <0.10%–2.30% of the total cover area (827 million acres) per year (Barger et al., 2011). Great Plains states are experiencing similar trends in woody tree cover expansion. In Oklahoma, for example, tree cover increased from 14.10% in 1990 to 25% in 2020 (Jones et al., 2018). The unexpected consequences of this encroachment process include decreased water availability, plant diversity, forage, and livestock production (Anadón et al., 2014; Lett and Knapp, 2005; Ratajczak et al., 2012). Several woody plant removal approaches, such as brush management, prescribed burning, and mulching play critical roles in managing and conserving grasslands and protecting them against woody invasion (Archer et al., 2011). The Natural Resources Conservation Service (NRCS) has a cost-sharing program to manage the process of woody encroachment (Liew et al., 2012; Tanaka et al., 2011) and has contributed at least 50% of the expected conservation expenditure.

As significant parts of the Great Plains transition from grassland to woodland (Barger et al., 2011), the need for conservation management strategies also increases simultaneously, which will cause a double burden of woody plant invasion. First, landowners will lose their grazing areas and—accordingly—their earning from cattle farming, forage production, and grazing land renting. Second, the NRCS will have to spend more money to control woody invasive plants, which will not be feasible owing to the increasing demand for financial allocation for conservation. From both economic and policy priority perspectives, this poses a decision-making dilemma for conservation managers and landowners.

To resolve this dilemma, it is necessary to determine a less costly conservation management strategy that covers and controls more woody-encroached areas so as to select appropriate management strategies within the budgetary allocation. We hypothesized that (i) practice cost and unit sizes vary substantially by management strategy and state; (ii)

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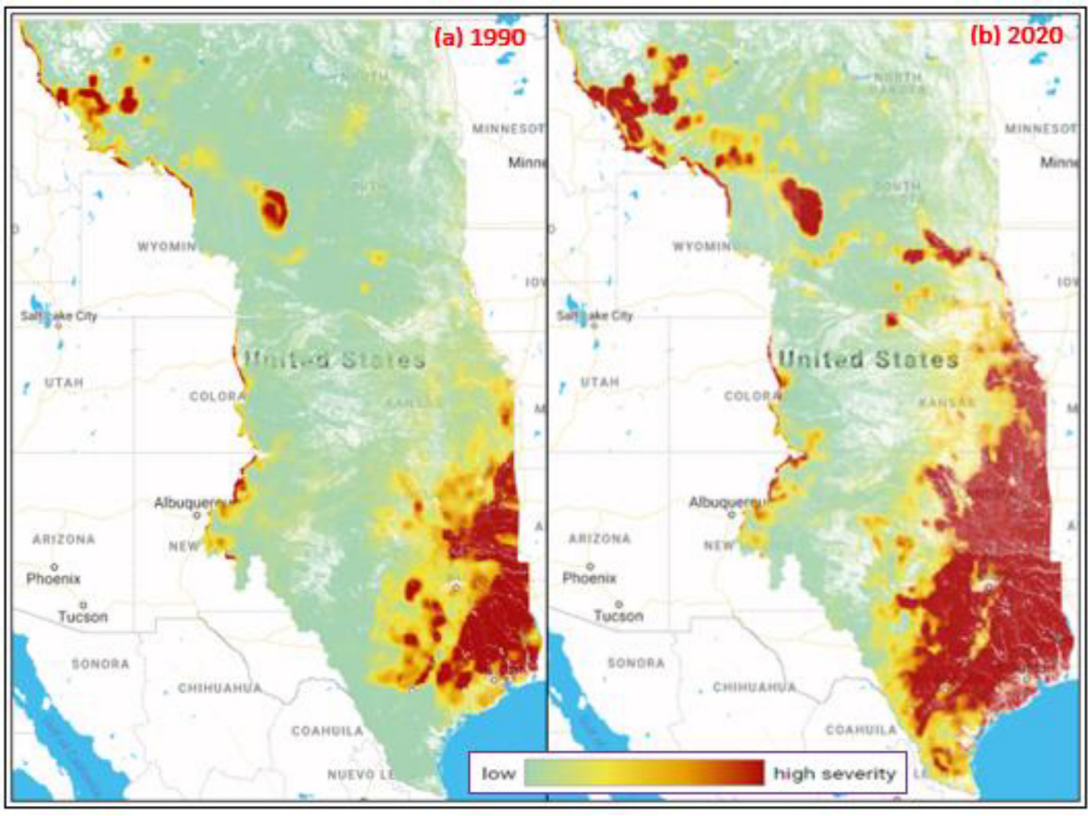

Fig. 1. Woody transition in US Great Plains states (1990–2020). Generated from the rangeland analysis platform (Jones et al., 2018).

mulching and brush management strategies have different (e.g., comparatively lower) practice costs than does prescribed burning, with state-level differences; and (iii) practice unit size is negatively related to practice cost, with state-level differences. To test these hypotheses, we compared and estimated the associations between practice cost and unit size of three management strategies (i.e., mulching, brush management, and prescribed burning) in nine Great Plains states.

2. Materials and methods

2.1. Study area and data

In this study, nine Great Plains states were considered for descriptive and statistical analyses, including Kansas (KS), Montana (MT), Nebraska (NE), New Mexico (NM), North Dakota (ND), Oklahoma (OK), South Dakota (SD), Texas (TX), and Wyoming (WY) (Fig. 1). We obtained practice cost and unit size data from the 2021 conservation payment schedules of the NRCS (2021a). Finally, we gathered 164 practice cost- and unit size-related observations regarding three management strategies, namely, mulching, brush management, and prescribed burning, regarding these nine states. Extreme-value outlier data were trimmed out due to the possibility of biased estimates.

2.2. Statistical analysis

We estimated state-level and overall mean (M), standard deviation (SD), and coefficient of variation (CV) of practice cost and unit size of the three management strategies using data obtained from the NRCS (2021a) for inter-strategy and inter-state comparisons of differences and variations. CV is a measure of relative variability in percent form and indicates the size of a standard deviation in relation to its mean. A higher CV value indicates a greater level of dispersion around the mean (i.e., higher variability). To supplement the inter-strategy comparison, we performed a weighted sum-based multi-criteria decision-making analysis (Hwang and Yoon, 1981; Zavadskas et al., 2012) to identify the preferred management strategy from mulching, brush management, and prescribed burning based on practice cost and unit size criteria.

To assess the relationship between practice cost and unit size of three invasive plant management strategies used in nine US Great Plains states, we employed the following regression model with two categorical variables (Wooldridge, 2010).

$$pc_l = \beta_0 + \beta_1 pus_l + \beta_2 msC_{1l} + \beta_3 sC_{2l} + \mu_l$$

In this equation, pc_l is the practice cost ($/acre[ac]) of a given location l as a dependent variable, and pus_l is the practice unit size (acre) of l as an independent variable. The second independent variable captures the categories of management strategy (msC_{1l}), which indicates mulching (reference category and denoted as 0), brush management (denoted as 1), and prescribe burning (denoted as 2). We also included the state (sC_{2l}) as another categorical variable to find the effect of KS (denoted as 1), MT (denoted as 2), NM (denoted as 3), ND (denoted as 4), OK (denoted as 5), SD (denoted as 6), TX (denoted as 7), and WY (denoted as 8) compared to NE (reference category and denoted as 0). Along with the main regression model (Model 1), we estimated two additional regression models separately, namely, practice unit size and state (Model 2) and management strategy and state (Model 3), as a part of the robustness check of the main model (Model 1). We used Stata version 17 for statistical analyses (StataCorp, 2021), and the level of statistical significance was specified as $p \leq 0.05$.

3. Results

Mulching and brush management cost an average of $222/ac and $152/ac, respectively, but prescribed burning costs only $29/ac (Table 1). Mulching is costlier in Kansas ($401/ac), Nebraska ($353/ac), and South Dakota ($382/ac) than in other states, such as Montana

Table 1
Practice cost and unit size of three woody plant management strategies by state.

State	Practice cost ($/acre)									Practice unit size (acre)								
	ML			BM			PB			ML			BM			PB		
	M	SD	CV	M	SD	CV	M	SD	CV	M	SD	CV	M	SD	CV	M	SD	CV
KS	401	428	1.07	131	171	1.3	15	4	0.29	0.70	0.51	0.72	144	134	0.93	320	0	0.00
MT	115	153	1.33	272	260	0.96	43	52	1.22	0.51	0.69	1.36	95	61	0.64	88	41	0.47
NE	353	341	0.96	116	117	1.01	22	17	0.77	5.53	9.66	1.75	45	37	0.82	288	230	0.80
NM	147	163	1.11	170	131	0.77	55	107	1.96	3.03	4.67	1.54	203	169	0.83	283	98	0.35
ND	129	180	1.39	143	133	0.93	17	11	0.65	10.06	14.06	1.4	76	47	0.62	200	170	0.85
OK	115	121	1.05	116	109	0.94	26	12	0.48	3.70	5.47	1.48	78	49	0.63	242	116	0.48
SD	382	407	1.07	173	146	0.84	13	5	0.39	0.70	0.51	0.72	33	36	1.08	320	0	0.00
TX	119	125	1.05	128	123	0.97	24	12	0.52	3.70	5.47	1.48	78	49	0.63	264	102	0.39
WY	115	153	1.33	175	229	1.3	29	22	0.75	0.51	0.69	1.36	293	377	1.29	83	39	0.47
Avg.	222	258	1.16	152	156	1.02	29	47	1.60	3.19	5.82	1.83	132	171	1.29	239	130	0.54

Note: Coefficient of variation (CV) is a unitless measure.
M = Mulching; BM = Brush management; PB = Prescribed burning; M = Mean; SD = Standard deviation; CV = Coefficient of variation; Avg. = Average

Table 2
Practice cost-unit size criteria-based decision-making analysis for determining preferred management strategy.

Management strategy	Criteria		Normalized matrix		Weighted sum (ws)	Rank	Preference
	Cost (C)	Unit size (S)	Cost (nc)	Unit size (ns)			
Mulching	$222	3.19 acres	0.13 (= 29/222)	0.01 (= 3.19/239)	0.07	3	Least preferred
Brush management	$152	132 acres	0.19 (= 29/152)	0.55 (= 132/239)	0.37	2	Less preferred
Prescribed burning	$29	239 acres	1.00 (= 29/29)	1.00 (= 239/239)	1.00	1	Preferred

Notes: On the basis of linear normalization technique, we used non-beneficial method $[X = Min\ x/x]$ for practice cost and beneficial method $[X = x/Max\ x]$ for unit size to estimate the respective normalized decision matrix. We assumed equal weight (0.5) for both cost and unit size criteria. Ranking was performed by applying the weighted sum method (Hwang and Yoon, 1981; Zavadskas et al., 2012) on the normalized matrix (ws = 0.5*nc + 0.5*ns), which represents the preferred strategy.

($115/ac), New Mexico ($147/ac), and Texas ($119/ac). However, brush management cost in Montana ($272/ac) is higher than in all eight remaining states. In New Mexico and Montana, the cost of prescribed burning is higher ($55/ac and $43/ac, respectively) than the lowest rate in South Dakota ($13/ac). Overall, the coefficient of variation (CV) of brush management (1.02) is lower than that of mulching (1.16) and prescribed burning (1.60). Seven states have low variance (CV<1) in prescribed burning, which is greater than brush management (6 states) and mulching (1 state) (Table 1).

Mulching, brush management, and prescribed burning each have an average management unit size of 3.19, 132, and 239 acres, respectively. In North Dakota, the average size of mulching is roughly 10 acres while the other states are close to the overall average (3.19 acres). Brush management unit sizes in Kansas, New Mexico, and Wyoming are larger than in other states, which average less than 100 acres. Except for Montana and Wyoming, the unit size of prescribed burning is 200 acres or higher. In general, the CV of prescribed burning (0.54) is lower than that of mulching (1.83) and brush management (1.29). All nine states present low variance (CV<1) in prescribed burning, which is greater than brush management (7 states) and mulching (2 states).

From the practice cost-unit size criteria-based decision-making analysis, we found that prescribed burning ranks first based on weighted sum score (1.00) while brush management (ws = 0.37) and mulching (ws = 0.07) ranked second and third, respectively (Table 2). Based on the ranking, alternatives are prioritized as follows: prescribed burning is preferred to brush management, which is likewise preferred to mulching. Therefore, prescribed burning as the preferred strategy with respect to the assessment performed considering the practice cost-unit size criteria.

Model 1 presents the main results from the regression analysis (Table 3). The relationship between practice cost and unit size is negative and statistically significant. An increase in 1 acre in practice (or management) unit size results in a decrease of $0.18 in practice cost (Coef. = -0.18, $p<0.05$). For prescribed burning, the practice cost is $148.70 ($p<0.00$) lower than that for mulching (reference category). Similarly, practice cost of brush management is $43.42 lower than that of mulching; but the estimate is not statistically significant ($p = 0.24$). Although different states indicate either positive or negative magnitudes compare to the reference category of Nebraska, we found no statistically significant coefficients. Models 2 and 3 further present the results for management unit size and management strategy, respectively, together with state. In Model 2, the coefficient of management unit size is different from that in Model 1; however, it indicates a negative and significant relationship between unit size and cost similar to Model 1 (Coef. = -0.33, $p<0.00$). In Model 3, we also found similar associations between management strategy and cost. For prescribed burning, the practice cost is $191.34 ($p<0.00$) lower than that for mulching. This sensitivity analysis show that the results from Model 2 are robust enough to draw conclusions on the estimated associations under the cost-unit size framework.

4. Discussion

Our analysis provides an empirical basis for evaluating practice cost and unit size of three different invasive and woody plant management strategies (i.e., mulching, brush management, and prescribed burning) in nine Great Plains states in the US. We found management strategy- and state-level differences in practice cost and unit size. Prescribed burning was observed to be less costly than mulching and brush management and to cover a larger management area. In addition, regression results indicate a negative association between practice cost and unit size as well as with management strategy. We by no means imply that prescribed burning is the only cost-minimizing (and, thus cost-effective) strategy. These results should be considered under the practice cost-unit size framework, which suggests that prescribed burning is less expensive and high-coverage strategy than mulching and brush management in the Great Plains states.

According to our first hypothesis, practice cost and unit size differ substantially by management strategy and state. On average, the man-

Table 3
Results from linear regression models on the association between practice cost and unit size in US Great Plains states.

Variable	Model 1		Model 2		Model 3	
	Coef.	*p*-value	Coef.	*p*-value	Coef.	*p*-value
Practice unit size	-0.18	0.04	-0.33	0.00		
Management strategy						
Mulching (Ref.)						
Brush management	-43.42	0.24			-65.09	0.07
Prescribed burning	-148.70	0.00			-191.34	0.00
State						
NE (Ref.)						
KS	-0.71	0.99	9.49	0.86	-10.05	0.85
MT	19.57	0.74	2.73	0.97	29.19	0.63
NM	5.77	0.91	21.93	0.67	-8.67	0.86
ND	-46.61	0.48	-41.68	0.54	-43.90	0.51
OK	-55.71	0.29	-53.24	0.33	-54.11	0.31
SD	29.91	0.62	34.34	0.59	31.15	0.61
TX	-44.28	0.39	-46.47	0.39	-44.39	0.40
WY	1.09	0.99	16.47	0.78	-14.40	0.80
Constant	231.62	0.00	183.14	0.00	234.27	0.00
Prob. > F	0.000		0.026		0.000	

Coef. = Coefficient; *p*-value = Probability value; Ref. = Reference category.

agement cost of prescribed burning ($29/ac) is less costly than that of mulching ($222/ac) and brush management ($152/ac). Inter-state cost variability in mulching (mean range: $115–$401/ac), brush management (mean range: $116–$272/ac), and prescribed burning (mean range: $13–$55/ac) is also observed (Table 1). Although the practice cost of prescribed burning is lower than that of mulching and brush management, its practice unit size (239 acres/unit) is larger than that of other two strategies (3.19 and 132 acres/unit, respectively). These practice cost differences within state may arise due to the current intra-state material and labor costs and the fair marketplace compensation for opportunity costs of land use (NRCS, 2021b). We also found inter-state variability in the practice unit sizes of mulching (mean range: 0.51–10.06 acres/unit), brush management (mean range: 33–293 acres/unit), and prescribed burning (mean range: 83–320 acres/unit). Both strategy- and state-level unit size variations might be influenced by a variety of variables, such as land type, invasive tree species, and tree cover density, among others

Brush management and mulching have higher practice costs than prescribed burning, with state-level variances (Table 1). This outcome supports our second hypothesis, with our analysis quantifying the association of management strategy with practice cost. The management cost of prescribed burning, for example, is $148.70 lower than mulching. This result highlights the idea that prescribed burning has a cost advantage over mulching and could be a cost-minimizing option under the cost-unit size-strategy framework for rangeland conservation. The findings of our multi-criteria decision-making analysis (Table 2) based on both practice cost and unit size criteria also support previous insights relating hypotheses 1 and 2. Although land type, tree cover density, and expected rental value of grassland are major factors of inter-state cost differentials, implementation cost (e.g., equipment mobilization and installment costs, seasonality in fuel cost, etc.) might directly influence this variability. Willingness to participate in the cost-sharing program of the NRCS and the resulting high demand for cost-sharing of the Environmental Quality Incentives Program Conservation Incentives Contract are sometimes considered as determining factors. As prescribed burning is less costly and covers larger areas, conservation managers could use this management strategy as a part of their cost-minimizing approach during the early stages of woody invasion when invasive tree height and density are low. It is also important to note the challenges associated with the implementation of prescribed burning (Ryan et al., 2013; Stroman et al., 2020; Twidwell et al., 2013).

As stated in our third hypothesis, practice or management unit size has a significant and negative association with practice cost (Table 3). Considering management strategies and states together in Model 1, an increase in 1 acre in practice unit size results in a decrease of $0.18 in practice cost. While additional model variables or perspectives could be determining factors, our sensitivity analysis validates the robustness of the relationships and magnitudes of the coefficients. Note that Models 2 and 3 consider unit size and strategy separately, resulting in comparable relationships and magnitudes within considerable ranges. Our estimate infers that increasing the management unit by 100 acres could save $18 in practice cost. Practice size differences in mean were found at the state level, but they were not statistically significant. Although the size of prescribed burning is larger than that of brush management in most states, brush management size is larger in Montana and Wyoming (Table 1). Different states have different numbers of participating landowners and allocations for the cost-sharing program (Simonsen et al., 2015; Tanaka et al., 2011), which might explain the convenient unit sizes for implementation. It is important to examine the land type and woody density of individual states to establish state-level conservation strategies for reducing and removing invasive and woody plants from grazing lands.

Given that multiple external and policy-level causes are related to the practice cost and unit size differences and variations, the findings of this study should be interpreted as basic. We recognize that the study only looked at the three common management strategies; in other cases, different strategies may be more desired in certain regions (Tanaka et al., 2011). Despite the fact that the NRCS (2021a) provided us with the most recent practice cost data for mulching, brush management, and prescribed burning a landowner may incur a different cost per practice or management unit size in some instances due to equipment access and implementation-related constraints. Given that state-level land use and land conversion (Claassen et al., 2011; Drummond, 2007) data are not accessible with the NRCS's payment data (NRCS, 2021a), it is critical to explore this aspect using administrative data in a future sub-group analysis to reveal actual implementation cost per practice with land type and use variations.

Despite the above limitations, the results of the study have considerable policy implications for whether a conservation strategy should be cost-minimizing or not within the practice cost-unit size framework. The primary focus in rangeland conservation is mostly based on a "proactive versus reactive strategy" selection. However, our "practice cost-unit size" perspective considers both strategies simultaneously as part of the decision-making process. A holistic approach with relevant perspectives might solve this dilemma, but policymaking uncertainties cannot be avoided. In comparison of a reactive strategy, it is clear that imple-

menting a proactive technique like prescribed burning during the early stages of woody invasion is less expensive and needs fewer financial resources. Note that minimizing practice management cost differences within a short period of time could be impractical because of the various land types and state policy factors. In such circumstance, conservation policymakers and managers can consider increasing the typical unit sizes of less-covering strategies (e.g., mulching, brush management) for removing more invasive plants from grasslands. Available financial resources together with land type could influence this policy option.

5. Conclusions and policy ideas

In the Great Plains, the practice costs and unit sizes of various invasive plant management strategies vary from state to state. Within the practice cost-unit size framework, our findings imply that employing a prescribed burning-like proactive approach instead of a mulching or brush management-like reactive strategy is a potential cost-minimizing and high-coverage strategy during the early stages of woody invasion to reduce invasive and woody plant encroachment. Alternatively, increasing the typical unit sizes of less-covering strategies (e.g., mulching) may be considered where practicable, based on necessary field assessments. Given the woody encroachment trend in the US, which is increasing at a rate of <0.10%–2.30% per year (Barger et al., 2011), these findings may have potential policy implications for grassland management research and strategy prioritization. As changing socio-ecological transition (e.g., land use, landowner's perception) is another inevitable aspect of grassland conservation (Mccollum et al., 2017; Uden et al., 2019), any prospective analyses aiming to estimate management costs under different scenarios, including socio-ecological contexts such as willingness to participate in the conservation program, terrain type, tree height, and tree density in tree-encroached areas, are essential.

Ethics approval and consent to participate

Not applicable. The data used in the study are publicly available at https://www.nrcs.usda.gov/.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

CRediT authorship contribution statement

Mazbahul G. Ahamad: Conceptualization, Methodology, Validation, Formal analysis, Data curation, Writing – original draft, Writing – review & editing.

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