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Effect of cutting, burning and herbicide application on the structure and species diversity of an *Amelichloa clandestina* (Hack.) Arriaga & Barkworth grassland in the Chihuahuan Desert

Efecto del corte, quema y aplicación de herbicida en la estructura y diversidad de especies de un pastizal de *Amelichloa clandestina* (Hack.) Arriaga & Barkworth en el Desierto Chihuahuense

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A B S T R A C T

This study aimed to evaluate various elimination strategies of *Amelichloa clandestina* on the richness and diversity of species in this grassland in northeast Mexico. This species was established after the abandonment of an agricultural area. In two areas of 40 and 60 ha, four treatments were evaluated: cutting of the grass cover, herbicide application , grass burning, and control (undisturbed paddocks). Six replications per treatment were applied in 100 m^2 plots. The vegetation cover of plant species was measured in each corner of the 2 x 2 m plots quadrants, where the species present were identified, and their height and aerial cover were registered. The herbicide treatment resulted in the greatest reduction of *A. clandestina,* with the lowest height (17.5 cm), aerial cover (7.4 cm^2), and density (6,750 plants ha^{-1}) of the dominant species. Also, it presented the highest richness and diversity index with 2.46 nats. It was concluded that herbicide application was the best alternative to maintain the richness and diversity of species in this *A. clandestina* grassland.

K E Y   W O R D S : Species diversity, Invasive species, Herbicide, Opportunistic plants.

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RESUMEN

El estudio se realizó con el objetivo de evaluar algunas estrategias de eliminación de *Amelichloa clandestina* y su efecto sobre la riqueza y diversidad de especies en un zacatal del noreste de México. Esta especie se estableció tras el abandono de una zona agrícola. En dos áreas de 40 y 60 ha se evaluaron cuatro tratamientos: corte de la cobertura de zacate, aplicación de herbicida, quema del zacate y control. Se aplicaron seis repeticiones por tratamiento en parcelas de 100 m^2. Se midió la cobertura de las especies en cada esquina de los cuadrantes en parcelas de 2 x 2 m, donde se identificaron las especies y se registró su altura y cobertura aérea. El tratamiento herbicida resultó en la mayor reducción de *A. clandestina*, registrando la menor altura (17.5 cm), cobertura aérea (7.4 cm^2) y densidad (6,750 plantas ha^{-1}) de la especie dominante. Además, presentó el mayor índice de riqueza y diversidad con 2.46 nats. Se concluyó que la aplicación de herbicida fue la mejor alternativa para mantener la riqueza y diversidad de especies en este pastizal de *A. clandestina*.

PALABRAS CLAVE: Diversidad de especies, especies invasoras, herbicida, plantas oportunistas.

Introduction

Rangeland managers worldwide have focused on invasive species as an environmental concern (Reid *et al*., 2005) because this phenomenon has been identified as the second cause of biodiversity loss in rangelands (Leung *et al*., 2002; Grice, 2006). They affect the trophic structure, cause significant ecosystemic changes, and interact with other factors leading to environmental change (Dextrase & Mandrak, 2006). Invasive plants threaten natural habitats (Simberloff, 2005), causing the extinction of native species (Bellard *et al*., 2016). This issue has become a priority in the Convention on Biological Diversity (CBD), of which Mexico is a member (March & Martínez, 2007).

Several standard features of species invasions have been identified (Kolar & Lodge, 2001). Invasive species come from somewhere, a different native range or invaded region, and are carried to new areas via vectors (Lockwood *et al*., 2005). They affect the establishment of native species and, consequently, the plant community structure (Pearson *et al*., 2018). In addition, they affect the ecological restoration, conservation, and sustainable use of natural resources (Chornesky *et al*., 2005).

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After the abandonment of farmland in northeastern Mexico, Mexican needlegrass (*Amelichloa clandestina*) is frequently established, dominating the herbaceous stratum due to its aggressiveness in colonizing impacted land due to its high production of cleistogama and casmogama seed. It prospers in disturbed places, thickets, grasslands, and stone pine forests between 2,000 and 2,100 m altitude. In Mexico, its distribution includes Coahuila and Nuevo León states (Barkworth, 1982), and according to Villaseñor (2016), it is a native species of Mexico, introduced to West Texas. Its presence was first recorded in Kimble County in the early 1950s and developed in the San Saba River Valley in the 1960s (Russell & Landers, 2017). Although this species is native to northeastern Mexico, it is undesirable in rangelands due to its high adaptation, growth, and speed propagation.

The best-known control practices for undesired vegetation are chemical, mechanical, and biological practices (Masters & Sheley, 2001; van Wilgen *et al*., 2001; Vitelli & Pitt, 2006). Chemical and mechanical controls are the most effective and selective among these alternatives. Mechanical control suppresses unwanted species by cutting the aerial part or removing the plant with its root. However, mechanical control is a costly and laborious task in places where the unwanted species occupies large areas or possesses large patches of undesirable species (van Wilgen *et al*., 2001).

Fire helps manage grasses for livestock in the arid zones of the world (Bernardis, 2008; Russell-Smith *et al*., 2020). In grasslands, prescribed fire is a management alternative due to its low cost, whose primary purpose is to eliminate dry plants that are not consumed by cattle. This practice stimulates the growth of new grass, which is less lignified, more palatable, and of better nutritional quality, consumed by cattle, increasing animal production (Heringer & Jacques, 2021). In the same way, through prescribed burning, the spread of undesirable species can be controlled; thus, the competition of these species against forage species can be reduced, which can accelerate the nutrient cycle of the rangeland (de Moura Zanine & Diniz, 2006).

Herbicides control invasive species due to their rapid effectiveness and low cost (Kettenring & Adams, 2011). Some herbicides can control unwanted species, while non-chemical methods only kill plant shoots but may fail to prevent the emergence of regrowths. Glyphosate is one of the most widely used post-emergent herbicides with a broad spectrum of plant control, low toxicity, non-selective, and systemic action (de Souza *et al*., 2019). Generally, when it comes into contact with the ground, it is rapidly inactivated and has low toxicity for mammals (McComb *et al*., 2008). It controls susceptible plants by penetrating through the leaves and transporting itself to the chloroplasts, where it acts; it is a commercial herbicide that inhibits a specific enzyme within the shikimate metabolic pathway, responsible for the synthesis of aromatic amino acids and the production of other essential plant metabolites (Heap & Duke, 2018). The objective of this study was to evaluate the effect of different treatments on the richness and diversity of species in a grassland dominated by *Amelichloa clandestina* in the northeast of Mexico, established in an abandoned agricultural area.

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Material and Methods

Study area

The study was conducted in northeastern Mexico (25° 06´30´´ N 100° 59´ 18´´ W; Figure 1), with an average altitude of 2,150 m (Pérez, 2012). The topography of the experimental field comprises valleys, medium ranges with narrow peaks, and low hills (Vázquez, 2011).

The climatic formula, according to the Köeppen climate classification system, modified by García (2004), is BSo kw (e'), where BSo means that it has a dry climate with a precipitation/temperature ratio greater than 22.9 mm/16 °C. The letter k indicates the temperature regime, with hot summer and average monthly temperatures between 7 and 14 °C. It has a rainfall regime, represented by the letter w, which indicates the existence of two rainy seasons throughout the year, May to October with 86.7 % of the annual total rainfall and the second from November to April with 13.3 % of the annual precipitation (350 mm) (García, 2004).

The soils in the valley have a superficial dark to reddish-brown horizon rich in organic matter. In the mountains, it is possible to observe uniform soils throughout the profile, of dark colors formed by dark humus rich in organic matter, with a loamy-clayey to loamy texture. In the hills, these soils do not represent diagnostic horizons; they present erosion due to the steep slope (Pérez, 2012).

Treatments

In two abandoned agricultural areas of 60 and 40 ha invaded by *A. clandestina,* 24 plots (10 x 10 m) were established. Each group included 12 plots with a distance of 3 m between them, with a total of 1.76 ha^{-1} (Figure 2).

The treatments were: T1 = controlled burning, T2 = herbicide application, T3 = hand cutting, and T4 = Control.

Treatment 1: Before burning, fire breaks were made to leave free strips of vegetation surrounding the land; in this way, fire was prevented from spreading to other areas.

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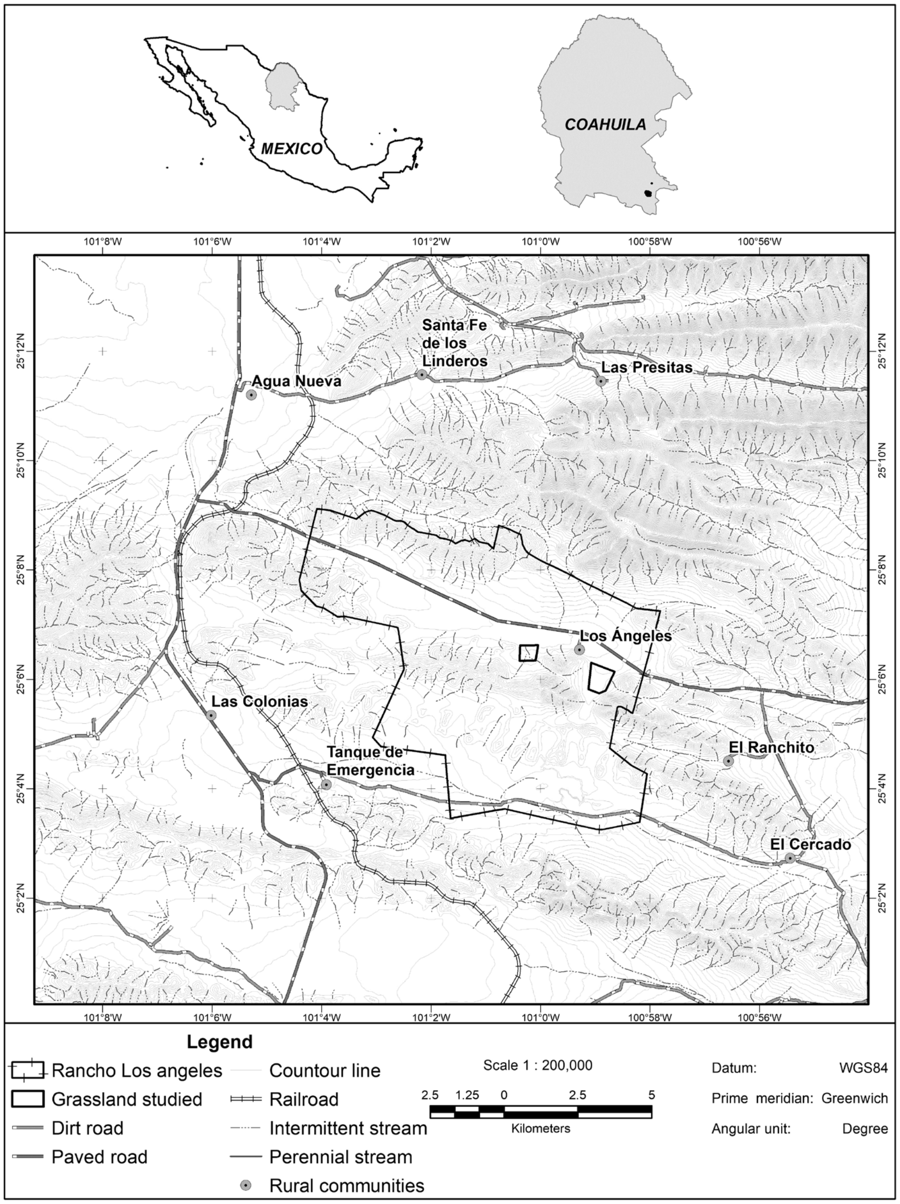

Figure 1. The geographical location of the study area in northeastern Mexico.

For better control over the fire, water was applied to the fire breaks. The concentric burning technique was used, consisting of making an ignition line at the opposite end to the direction of the wind, and then the ignition was started at the other end so that both lines meet and turn off

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each other. Three brigades of four people were formed, one of them started the fire, while the remaining two brigades (six people) prevented the fire from exceeding the treated area; this was done using forestry shovels and water sprinklers. All the coal fragments that could reignite the fire were extinguished at the end of the burning. The burning was carried out with gasoline torches on March 18, 2020, when the grass was dry, with an average height of 55 cm.

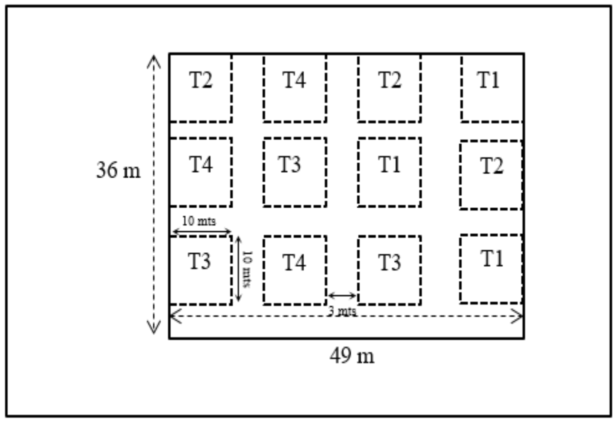

Figure 2. Distribution of experimental paddocks in the study site.

Treatment 2: The amount of water/ha was calculated, considering the size of the invasive grass to achieve total coverage in the areas to be treated. A minimum dose of glyphosate (Russell & Landers, 2017) consisting of 2.3 L ha^{-1} was applied, to which it was complemented with liquid soap (500 mL ha^{-1}) as an adherent. The application was made without grass cutting at an average height of 55 cm.

Treatment 3: *A. clandestina* was cut at a height of 10 cm above the ground. Cut foliage (leaves and culms) was left inside the plot to decompose and integrate into the soil.

Treatment 4: Plots were left undisturbed.

Determination of plant cover, density, and species richness

During the rainy season in the summer of 2020, in the 10 x 10 plots, we assess the vegetative cover of all plant species present. At each corner and in the center of the plots, 2 x 2 m quadrants were placed (Figure 3). Within each quadrant, vegetation cover and height were measured employing a cross-measurement of the aerial part of each species, measured by placing a flexometer at the base of each species and registering the height of each species found.

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Additionally, botanical samples of the species not recognized during the sampling were collected for subsequent identification in the ANSM herbarium. The time elapsed from the application treatments to the measurement was two years.

Floristic composition

The floristic composition was determined by quantifying the relative importance value index (RIVI) of the species; this consists of the sum of the values of relative density, relative dominance, and relative frequency and indicates the relative ecological importance of the plant species in a community (Legendre & Legendre, 2012).

The formula used was:

$$RIVI = RDe + RDo + RFc \quad \text{equation 1}$$

Where:

RIVI = Relative Importance Value Index

RDe = Relative density

RDo = Relative Dominance

RFc = Relative frequency

Species diversity

After identifying the species at each experimental site, the following diversity indices were calculated: Margalef, Shannon-Wiener (H), Simpson (D), and Pielou (J). Diversity as a unique value combines species richness and evenness indices, fundamental factors defining a plant community's diversity.

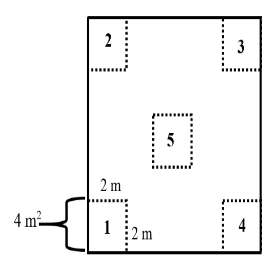

Figure 3. Distribution of 2 x 2 m quadrats to determine species richness.

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Species accumulation curve

It is the number of species accumulated throughout a sampling effort (UM) measure. In ecological studies, one of the main objectives is to know how many species inhabit a particular area (Moreno, 2011). One method to see a community's total species richness is the species accumulation curves. The curves indicate the number of accumulated species as the collection effort is increased in a site so that the species richness will increase until it reaches a maximum and stabilizes at an asymptote (Escalante, 2003). The species accumulation curves were generated using EstimateS 9.1.0 software and graphed using Excel, yielding the number of accumulated samples and species. The STATISTICA 10 software was used to fit the Clench model. The method for estimating model parameters was chosen, and Simplex and Quasi-Newton methods were employed. The coefficient of determination (R^2) was calculated along with the parameters of the "a" and "b" functions, and a graph illustrating the fitted function to the data was generated.

Statistical analysis

An ANOVA analysis was performed using the statistical program JMP 15. When the effect of the treatments was detected ($p < 0.05$), the Tukey test was carried out to compare means and determine the significance between treatments for plant height, aerial cover, and number of plants present.

Results

Species richness and diversity

Sixty-four plant species were recorded, corresponding to 56 genera and 22 families. The families with the highest number of species were: Asteraceae, with 16 species, Poaceae (12), Convolvulaceae (4), and Lamiaceae (4). Figure 4 shows a species richness of 91 % for the burning treatment, 77 % for reliability in the sampling effort, for cutting, 82 % for herbicide application, and 77 % for the control.

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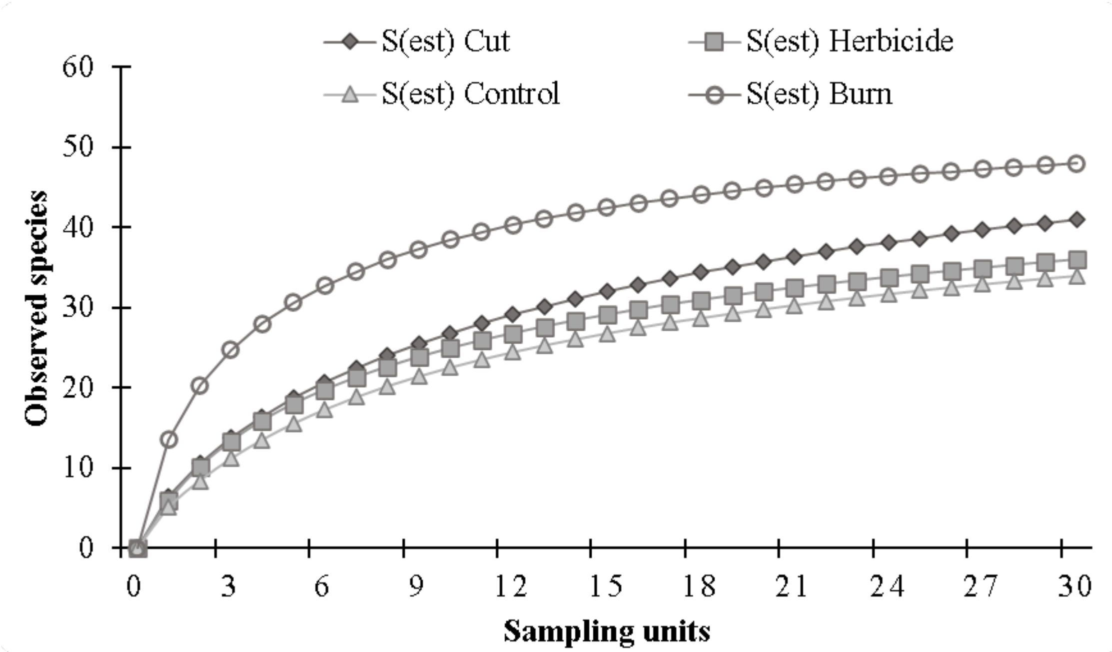

Figure 4. Species accumulation curve for cutting, burning, herbicide application, and control treatments by adjusting the Clech equation.

For the cutting treatment, *A. clandestina* had the highest RIVI, whereas *Dyssodia papposa* had the lowest (Table 1, Table A1). The highest density was for *A. clandestina* and the lowest for *Salvia reflexa*. In the area where the herbicide was applied, *A. clandestina* had the highest RIVI and density, whereas *Sanvitalia angustifolia* had the lowest RIVI; both *Eruca sativa* and *Anoda cristata* presented the lowest density (Table 2, Table A2).

For the burning treatment, *A. clandestina*, had the highest RIVI and density, whereas *Marrubium*

vulgare had the lowest VIF, and *Sanvitalia angustifolia* had the lowest density (Table 3, Table A3). The total sum of the RIVI for five species was 60 %, and the other 40 % corresponded to other plant species (Table 3, Table A3). The species with the highest RIVI and density in the control site was *A. clandestina*, whereas *Erigeron pubescens* had the lowest RIVI and density in this site (Table 4, Table A4).

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Table 1. Structural attributes of grassland dominated by Mexican needlegrass (*A. clandestina*) after manual cutting.

Species	Mean height (cm)	Density (individuals ha^{-1})	RIVI (%)
Amelichloa clandestina	36.9	77,083	52.2
Anoda cristata	6.0	5,166	4.9
Salvia reflexa	21.9	83.3	4.6
Helianthus laciniatus	23.3	416	4.1
Dyssodia papposa	11.4	2,583	3.3
Other species (36)		1,083	30.8

Table 2. Structural attributes of grassland dominated by Mexican needlegrass (*A. clandestina*) after applying herbicide at its minimum dose (glyphosate 2.3 L ha^{-1}).

Specie	Mean height (cm)	Density (individuals ha^{-1})	RIVI (%)
Amelichloa clandestina	17.5	6,750	15.1
Dyssodia papposa	12.3	5,333	8.9
Eruca sativa	5.5	333	8.8
Anoda cristata	9.2	333	8.7
Sanvitalia angustifolia	5.7	1,250	5.4
Other species (31)		2,828	53.1

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Table 3. Structural attributes of grassland dominated by Mexican needlegrass (*A. clandestina*) after applying prescribed burning.

Species	Mean height (cm)	Density (individuals ha $^{-1}$)	RIVI (%)
Amelichloa clandestina	31.0	150,416	37.3
Asphodelus fistulosus	8.2	106,333	8.5
Dyssodia papposa	7.9	46,666	5.7
Sanvitalia angustifolia	5.4	31,583	4.3
Marrubium vulgare	1.5	43,666	3.7
Other species (43)		2,996	40.27

Regarding the richness index, the site with the highest value was cutting and burning, whereas those with the lowest value were herbicide application and the control site. For the Shannon diversity index, the treatments with the highest value were herbicide and burning, and those with the lowest value were cutting and control. The Pielou index was higher for the herbicide application, and the lowest was for the control site. For the Simpson dominance index in herbicide, a maximum value of 0.94 and a minimum of 0.60 for cutting were recorded (Table 5).

Table 4. Structural attributes of a grassland dominated by Mexican needlegrass (*A. clandestina*) in the undisturbed (control) site.

Species	Mean height (cm)	Density (individuals ha $^{-1}$)	RIVI (%)
Amelichloa clandestina	54.3	49,833	56.7
Oenothera kunthiana	7.6	2,083	5.2
Anoda cristata	5.1	167	4.1
Helianthus laciniatus	16.4	333	3.2
Erigeron pubescens	10.2	167	2.6
Other species (29)		1,034	28.0

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Table 5. Shannon-Wiener, Pielou, and Simpson diversity indices for the applied treatments.

Treatment	A	P	Richnees index (Margalef)	Diversity index (Shannon-Wiener)	Equity (Pielou)	Dominance index (Simpson)
Cutting	19	22	5.47	1.83	0.49	0.60
Herbicide	18	18	4.92	2.46	0.68	0.94
Burning	17	31	5.38	2.45	0.63	0.84
Control	17	17	4.78	1.46	0.41	0.83

A= Annual P= Perennial

The height of *A. clandestina* differed ($p \leq 0.0001$) among treatments. *A. clandestina* in the control site showed the highest value, followed by cutting, burning, and herbicide application (Figure 5). Regarding the aerial cover of *A. clandestina*, the control site had the highest average, followed by

burning, cutting, and herbicide application (Figure 6). Regarding *A. clandestina* density, this was highest for burning and lowest for the herbicide application (Figure 7).

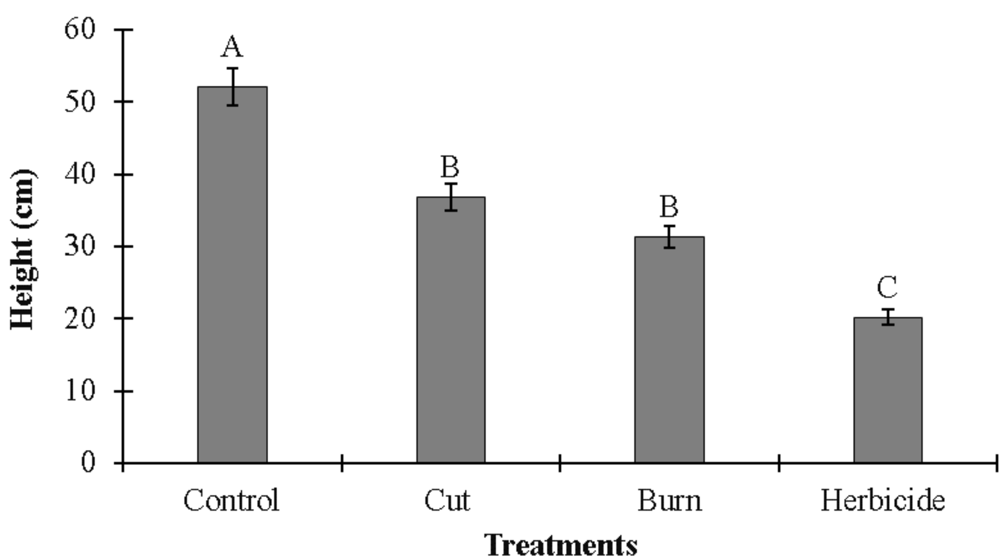

Figure 5. The effect of treatments on the height of *Amelichloa clandestina* (means ± standard error). Bars with different letters differ ($p < 0.05$).

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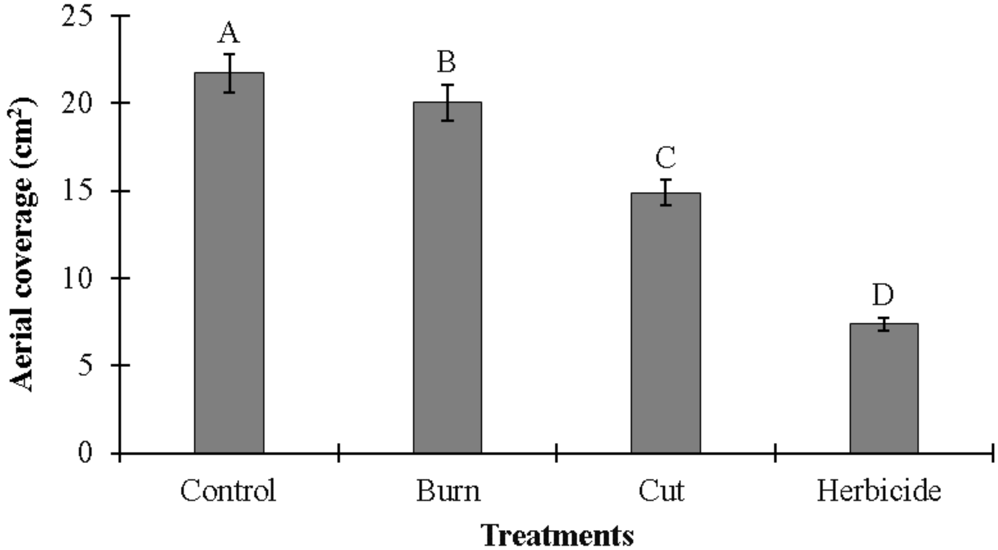

Figure 6. The effect of treatments on the aerial coverage of *A. clandestina* (means ± standard error). Bars with different letters differ ($p < 0.05$).

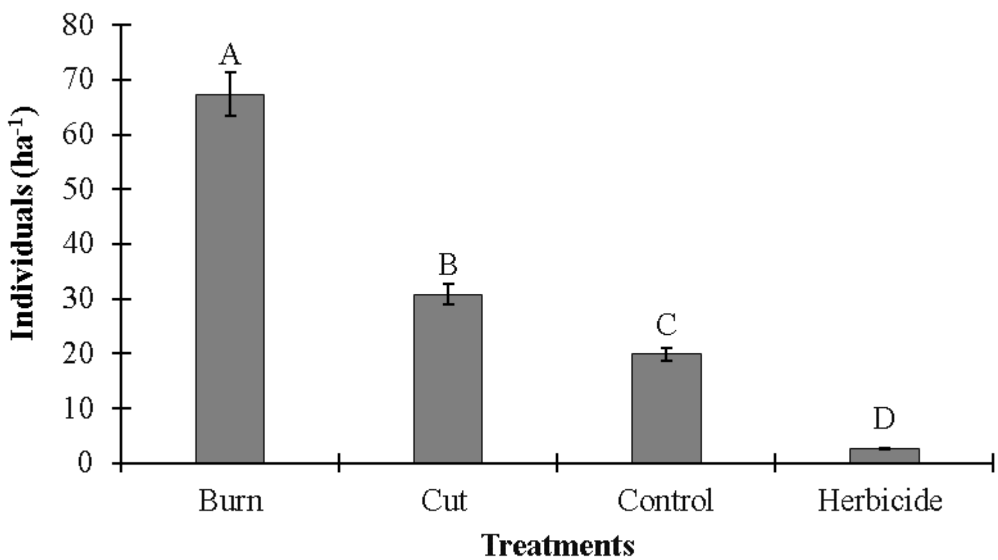

Figure 7. The effect of treatments on the density of *A. clandestina* (means ± standard error). Bars with different letters differ ($p < 0.05$).

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Discussion

The richness value exceeds 70 % in the four treatments, which reveals that the sampling was sufficient to determine species richness. In the burning and control treatments, they showed the lowest and same percentage of 77 %, meaning they have minimum reliability. Still, it provides scientific validity and usefulness for the study and conservation of biodiversity (Jiménez-Valverde & Hortal, 2003).

64 species were recorded, grouped into 56 genera, and 22 families distributed in the grassland (Annex 1). Nevertheless, a previous study carried out in 2020 by Arévalo *et al*. (2021) recorded a higher richness in the studied area with 70 species; it shows a loss of 6 species: *Acalypha monostachya, Pseudognaphalium roseum, Mimosa biuncifera, Muhlenbergia rigida, Opuntia rastrera y Panicum hallii*. The recorded flora represents 2.10 % of the flora reported for Coahuila state in Mexico, according to Villarreal (2001). The specific richness of the grassland is greater than that reported for a burned forest one year after the fire, located on the western slope of the Sierras Chicas de Córdoba, Argentina, where 36 species were found (Verzino *et al*., 2005). It is smaller than a grassland of *Pleuraphis mutica,* with a richness of 109 species (Encina-Domínguez *et al*., 2014). According to Rzedowski (1992), grasslands and xerophilous scrub are home to 6,000 plant species (20 % of the total flora), and 1.06 % of these species occur in the *A. clandestina* grassland.

The most important registered families were Asteraceae with 16 species, Poaceae (12), Convolvulaceae, and Lamiaceae (4); likewise, they are the ones with the highest species richness in halophilic grasslands in northern Mexico (Janos Valley, Chihuahua; Vega-Mares *et al*., 2014).

The high species richness of the Asteraceae family coincides with other regions of Mexico (Villaseñor & Espinosa, 1998) and is due to the high number of genera and species, especially the herbaceous family (Katinas *et al*., 2007; Villaseñor & Ortiz, 2014). The richness of the Asteraceae family can be attributed to its evolutionary adaptations, such as high fertility, dispersal efficiency, and chemical plasticity (Villaseñor, 2018). The 14 species of the Asteraceae family found represent 2.68 % of the 522 reported for Coahuila (Villarreal et al., 1996). The seven registered species of Poaceae represent 3.76 % of the 319 found in Coahuila (Valdés-Reyna, 2015). For the Convolvulaceae family, four species were recorded, which represent 11.7 % of the 34 reported for Coahuila (Villarreal, 2001). The Lamiaceae family of the four species found represented 4.6 % of the 87 reported for Coahuila (Martínez-Gordillo *et al*., 2017).

In the current grassland, the burning, cutting, herbicide, and control treatments showed that *A*. *clandestina* is the dominant species because it presented the highest percentage of RIVI, with a lower RIVI in the paddock receiving herbicide and higher in the control paddocks. The high values of this invasive species are attributed to the advance in secondary succession and the refusal of cattle to graze it. Perennial herbaceous species are favored in the early stages of succession, while annuals tend to disappear (Liu *et al*., 2015).

In the herbaceous stratum, the highest species richness treatment was the prescribed fire, where 48 species were recorded, surpassing the cutting treatment with 41 species, herbicide with 36 species, and control with 34 species. This indicates that the grassland invaded by *A. clandestina* in its initial floristic composition increased by 41 % with the burning treatment, allowing species to be established from the seed bank.

Annual species have greater dispersal capacity and rapid development (Morlans, 2005). Facilitation succession mechanism is an interspecific process in which the first succession species modify the environment so that others can colonize and develop until they reach their physiological maturity (Alcaraz, 2013). For the present study, *Anoda cristata*, *Dyssodia papposa*, and *Eruca vesicaria Salvia reflexa* (Appendix 1) are pioneer species that appeared in the initial stages after the abandonment of the cropland. After them, a sequence of perennial herbaceous plants develops, including *A. clandestina*, an opportunistic species established due to its wide dispersal capacity, tolerance to adverse conditions, and high reproductive rates, dominating the ecological succession (Barkworth, 1982). In the different treatments, they expressed a greater number of perennial species, which indicates a greater advance in the succession of the vegetation and, with it, a greater balance in species diversity (Morlans, 2005).

The highest diversity values (Shannon index) were for the herbicide-treated site. In most natural communities, this index varies between 0.5 and 5.0, although its average value is 2 to 3 nats; values less than 2.0 are considered low, and values of 3.0 are high (Shannon, 1948). These results indicate that cutting and control treatments had low diversity while burning and herbicide had a medium diversity.

For herbicide application, the high value of the Simpson index indicates a greater species richness concerning the control, cutting, and burning site, as well as the abundance or number of individuals per species, which supports the Shannon evenness index (Magurran, 1988). The greatest richness in the herbicide treatment agrees with Burge et al. (2017), where species richness was higher in plots where herbicide was applied. On the other hand, Farthing *et al*. (2018) reported that the Multiple Mow + Glyphosate, Single Mow + Glyphosate, and Vetch Overseed treatments were associated with greater species richness at all sites. Due to the applied treatments, the reduced biomass of *A. clandestina* allowed greater insolation at ground level (Bobbink *et al*., 1989), which increased the number of seedlings and the ability to compete for soil and climate resources (White, 1973). The significant differences in *A. clandestina* height showed that the herbicide gave better results in controlling the height of the invasive species, reducing height by 69 % compared to the control, burning 43 %, and cutting by 33 %. The results agreed with those obtained by Hillhouse & Schacht, (2015) since plots treated with imazapic + glyphosate showed higher yields in the control of winter grasses than the control plots.

Herbicide application resulted in a greater aerial coverage reduction by 67 % than the control, followed by cutting, and burning. According to Masters et al. (2001) and Wallerand & Schmidt (1983), glyphosate and glyphosate + imazapic are more effective in reducing cool-season grasses without reducing warm-season species. Furthermore, Farthing *et al*. (2018) observed that all treatments with glyphosates reduced ≥ 95.36 % of the canopy cover of *Cynodon*

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dactylon relative to controls, which indicates that herbicide application is a viable alternative for the management of grasses weeds.

In the herbicide treatment *A. clandestina* presented the lowest density compared with all other treatments. The greatest expression in density was burning since it directly removed plant biomass, conditioning the survival of plants, their subsequent growth, and the establishment of new individuals. These results are consistent with an investigation that used Tebuthiuron, glyphosate, and imazapyr + glyphosate to reduce the production of *A. clandestina* (Hillhouse & Schacht, 2015; Anglin, 2018).

Conclusions

The application of herbicides and controlled burning proved to be highly effective in enhancing the diversity and richness of species,, surpassing the cutting and control treatments. Therefore, herbicide application and burning are efficient tools to promote diversity in disturbed grasslands invaded by *A. clandestina*. The lower values of the RIVI in most species showed that they were suppressed by this species, which dominated the initial stages of succession due to its high capacity to respond to disturbances, high reproductive rates, vast dispersal capacity, and tolerance to adverse conditions. The use of herbicide almost eliminated *A. clandestina*. Thus, this treatment presented the best results for controlling *A. clandestina* because it gave the lowest Value of Relative Importance (RIVI) and better height, aerial cover, and density results.

Recommendations

The application of glyphosate has consequences on human health, and its application has to be controlled, mainly in agriculture or food production. This study does not recommend its application or promote its use. However, the objective of using this chemical was to propose a method as an alternative control strategy, and only a single application and low dose were applied. Due to its low residuality and easy degradation, this application did not threaten the ecosystem.

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Conflict of interest

The authors declare that they have no conflict of interest.

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ANEXE 1

Table A1. Structural attributes of a grassland dominated by Mexican needlegrass (*A. clandestina*) after a manual cut.

Species	Mean height (cm)	Density (individuals ha^{-1})	RIVI (%)
Amelichloa clandestina	36.9	77,083	52.2
Anoda cristata	6.0	5,167	4.9
Salvia reflexa	21.9	2,000	4.6
Helianthus laciniatus	23.3	6,083	4.2
Dyssodia papposa	11.0	3,250	3.3
Sanvitalia angustifolia	4.7	3,167	3.0
Erigeron pubescens	5.3	2,667	2.7
Gaura coccinea	7.7	2,917	2.1
Sphaeralcea angustifolia	16.4	1,250	1.8
Marrubium vulgare	0.7	2,917	1.6
Solanum elaeagnifolium	10.4	1,500	1.6
Eruca sativa	5.3	2,000	1.6
Convolvulus equitans	3.8	917	1.5
Oenothera kunthiana	3.1	2,333	1.3
Laennecia coulteri	6.7	667	1.1
Mirabilis oblongifolia	9.3	1,333	1.0
Parthenium hysterophorus	3.0	750	0.9
Asphodelus fistulosus	6.3	2,583	0.9
Asclepias brachystephana	13.7	417	0.8
Glandularia bipinnatifida	1.3	417	0.8
Ipomoea purpurea	4.8	417	0.7
Townsendia mexicana	6.3	833	0.7
Euphorbia serrula	1.3	333	0.6
Oenothera berlandieri	7.0	250	0.6
Euphorbia exstipulata	9.8	333	0.6
Verbena neomexicana	2.9	250	0.4
Bouteloua curtipendula	31.5	167	0.4
Rumex crispus	3.0	167	0.4
Sonchus oleraceus	1.5	167	0.4

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Continuation

Table A1. Structural attributes of a grassland dominated by Mexican needlegrass (*A. clandestina*) after a manual cut.

Species	Mean height (cm)	Density (individuals ha^{-1})	RIVI (%)
Erodium cicutarium	1.5	167	0.4
Symphyotrichum subulatum	21.0	83	0.4
Dichondra argentea	3.0	500	0.4
Buddleja scordioides	23.3	417	0.4
Machaeranthera tanacetifolia	36.0	83	0.3
Disakisperma dubium	60.3	250	0.3
Nassella tenuissima	43.0	83	0.2
Stachys agraria	7.0	83	0.2
Physaria fendleri	5.0	83	0.2
Cylindropuntia imbricata	9.0	83	0.2
Argemone echinata	8.0	83	0.2
Monarda citriodora	29.0	83	0.2

Table A2. Structural attributes of a grassland dominated by Mexican needlegrass (*A. clandestina*) after applying herbicide at its minimum dose (glyphosate 2.3 L ha^{-1}).

Species	Mean height (cm)	Density (individuals ha^{-1})	RIVI (%)
Amelichloa clandestina	37.5	6,750	15.1
Dyssodia papposa	12.3	10,000	8.9
Eruca sativa	5.5	14,417	8.8
Anoda cristata	9.3	5,333	8.8
Sanvitalia angustifolia	5.7	4,917	5.4
Marrubium vulgare	3.1	11,000	4.9
Sphaeralcea angustifolia	14.8	4,667	4.8
Salvia reflexa	19.6	1,833	4.8
Oenothera kunthiana	7.0	6,500	4.5
Laennecia coulteri	1.1	10,500	3.9
Erigeron pubescens	2.9	8,750	3.9

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Table A2. Structural attributes of a grassland dominated by Mexican needlegrass (*A. clandestina*) after applying herbicide at its minimum dose (glyphosate 2.3 L ha $^{-1}$).

Species	Mean height (cm)	Density (individuals ha $^{-1}$)	RIVI (%)
Helianthus laciniatus	16.6	2,333	3.8
Gaura coccinea	18.5	1,750	2.8
Mirabilis oblongifolia	11.5	2,167	2.5
Stachys agraria	1.8	3,250	2.1
Dichondra argentea	5.8	833	1.6
Argemone echinata	17.8	333	1.5
Parthenium hysterophorus	22.2	500	1.3
Erodium cicutarium	5.9	417	1.3
Solanum elaeagnifolium	12.2	500	1.2
Asphodelus fistulosus	21.4	1,250	1.1
Disakisperma dubium	14.8	333	1.1
Buddleja scordioides	12.3	417	0.9
Rumex crispus	12.7	333	0.7
Lactuca serriola	6.0	250	0.6
Machaeranthera tanacetifolia	15.3	583	0.5
Euphorbia serrula	1.3	167	0.4
Glandularia bipinnatifida	1.8	167	0.4
Physalis virginiana	7.3	250	0.4
Aristida havardii	44.0	333	0.3
Convolvulus arvensis	8.0	83	0.3
Parthenium incanum	6.0	333	0.3
Euphorbia exstipulata	16.0	167	0.3
Verbena neomexicana	15.0	83	0.3
Eragrostis barrelieri	10.0	83	0.2
Ipomoea purpurea	5.0	83	0.2

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Table A3. Structural attributes of a grassland dominated by Mexican needlegrass (*A. clandestina*) after applying prescribed burning.

Species	Mean height (cm)	Density (individuals ha^{-1})	RIVI (%)
Amelichloa clandestina	31.0	150,417	37.3
Asphodelus fistulosus	8.3	106,333	8.6
Dyssodia papposa	8.0	46,667	5.8
Sanvitalia angustifolia	5.5	31,583	4.3
Marrubium vulgare	1.5	43,667	3.7
Solanum elaeagnifolium	18.3	11,333	3.2
Glandularia bipinnatifida	2.7	16,667	2.9
Salvia reflexa	15.9	9,917	2.7
Eruca sativa	3.2	9,000	2.2
Euphorbia exstipulata	11.0	5,417	2.2
Euphorbia serrula	1.9	3,917	2.1
Sphaeralcea angustifolia	8.0	5,000	2.0
Anoda cristata	5.5	5,250	1.6
Parthenium hysterophorus	9.4	10,167	1.5
Gaura coccinea	10.5	4,583	1.4
Rhynchosia senna	10.9	4,500	1.4
Verbena neomexicana	10.5	7,083	1.3
Clematis drummondii	14.8	2,250	1.2
Helianthus laciniatus	31.9	5,000	1.2
Convolvulus equitans	6.8	1,083	1.1
Eragrostis mexicana	8.1	3,500	1.0
Argemone echinata	10.7	2,333	0.9
Parthenium incanum	5.2	3,917	0.8
Erodium cicutarium	2.3	1,333	0.8
Erigeron pubescens	4.1	3,083	0.8
Bouteloua dactyloides	10.0	500	0.8
Hoffmannseggia watsonii	5.0	1,167	0.7
Mirabilis linearis	18.3	667	0.6
Cirsium texanum	5.8	917	0.5
Rumex crispus	1.7	1,417	0.5
Oenothera berlandieri	8.9	917	0.5
Aristida havardii	23.3	500	0.5
Disakisperma dubium	49.1	417	0.4
Mirabilis oblongifolia	12.8	1,833	0.4

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Table A3. Structural attributes of a grassland dominated by Mexican needlegrass (*A. clandestina*) after applying prescribed burning.

Species	Mean height (cm)	Density (individuals ha^{-1})	RIVI (%)
Oenothera kunthiana	3.0	1,417	0.4
Oxalis latifolia	4.0	2,417	0.3
Ipomoea purpurea	9.2	333	0.3
Dichondra argentea	2.3	250	0.3
Laennecia coulteri	6.9	1,250	0.3
Chamaesaracha coronopus	5.2	833	0.2
Bouteloua curtipendula	44.7	333	0.2
Amaranthus blitoides	2.5	167	0.2
Salvia reflexa	22.6	333	0.1
Aristida adscensionis	25.0	83	0.1
Setaria leucopila	7.3	333	0.1
Convolvulus arvensis	8.0	83	0.1
Dalea bicolor	5.5	167	0.1
Brassica rapa	29.0	83	0.1
Scleropogon brevifolius	6.0	83	0.1

Table A4. Structural attributes of a grassland dominated by Mexican needlegrass (*A. clandestina*) in the undisturbed (control) site.

Species	Mean height (cm)	Density (individuals ha^{-1})	RIVI (%)
Amelichloa clandestina	54.3	49,833	56.7
Oenothera kunthiana	7.6	6,750	5.2
Anoda cristata	5.1	2,083	4.2
Helianthus laciniatus	16.5	3,500	3.2
Erigeron pubescens	10.2	2,167	2.7
Solanum elaeagnifolium	16.5	1,917	2.6
Eruca sativa	4.0	2,833	2.5
Sphaeralcea angustifolia	17.0	1,750	2.3

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Table A4. Structural attributes of a grassland dominated by Mexican needlegrass (*A. clandestina*) in the undisturbed (control) site.

Species	Mean height (cm)	Density (individuals ha^{-1})	RIVI (%)
Laennecia coulteri	34.1	1,250	1.9
Gaura coccinea	31.0	833	1.9
Sanvitalia angustifolia	2.7	1,000	1.7
Dyssodia papposa	7.4	1,333	1.6
Machaeranthera tanacetifolia	17.6	1,083	1.5
Salvia reflexa	6.8	750	1.4
Stachys agraria	1.7	1,083	0.9
Verbena neomexicana	12.8	333	0.8
Ipomoea purpurea	20.3	333	0.8
Glandularia bipinnatifida	16.8	333	0.8
Mirabilis oblongifolia	16.0	250	0.8
Dichondra argentea	3.3	1,083	0.7
Symphyotrichum subulatum	64.0	167	0.7
Circium texanum	13.0	333	0.6
Disakisperma dubium	35.0	167	0.6
Argemone echinata	8.5	167	0.5
Oenothera berlandieri	18.0	167	0.5
Sonchus oleraceus	2.0	167	0.5
Clematis drummondii	45.0	167	0.4
Marrubium vulgare	3.0	250	0.3
Mirabilis linearis	19.0	83	0.3
Solidago velutina	22.0	83	0.3
Monarda citriodora	30.0	83	0.3
Muhlenbergia torreyi	6.0	83	0.3
Parthenium hysterophorus	4.0	83	0.3
Euphorbia serrula	2.0	83	0.3