Colegio de Postgraduados

Invasive grass species: current advances in the ecological niche and areas of interaction with native grasses in Mexico

Rosales-Serna, Rigoberto[1]; Becerra-López, Jorge L.[2]; Santana-Espinoza, Saúl[3]; Domínguez-Martínez, Pablo A.[1]; Jiménez-Ocampo, Rafael[1]; Ríos-Saucedo, Julio C.[1]; Ramírez-Segura, Edith[4*]

[1] Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias-Campo Experimental Valle del Guadiana. Carretera Durango - El Mezquital km 4.5. Durango, Dgo., México. C. P. 34170.
[2] Laboratorio de Cambio Climático y Conservación de Recursos Naturales, Facultad de Ciencias Biológicas, Universidad Juárez del Estado de Durango. Av. Universidad S/N Fracc. Filadelfia, Gómez Palacio, Dgo., México. C. P. 35020.
[3] Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias- Campo Experimental La Laguna. Boulevard José Santos Valdéz 1200 Pte. Matamoros, Coah., México. C. P. 27440.
[4] Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias-Centro Nacional de Investigación Disciplinaria Agricultura Familiar. Carretera Ojuelos-Lagos de Moreno, Ojuelos de Jalisco, México. C. P. 47540.
* Correspondence: ramirez.edith@inifap.gob.mx

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ABSTRACT

Objective: To assess the recent advances in the ecological niche dynamics of two invasive grass species and their interactions with two native grasses from Mexico.

Design/methodology/approach: In 2024, sites exhibiting the presence of *Bouteloua gracilis*, *Bouteloua curtipendula*, *Melinis repens*, and *Pennisetum ciliarewere* identified. Occurrence data were collected, incorporating 19 bioclimatic variables, to conduct correlation analyses, select relevant variables, and generate ecological niche models and distribution maps. Key selected variables included BIO1 (mean annual temperature) and BIO12 (annual precipitation), among others.

Results: The native species and *Melinis repens* (natal redtop grass) demonstrated broad ecological adaptability across Mexico. The bioclimatic variables of shared significance across all species were BIO12 and BIO1, which are critical to their growth and development. The invasive species exhibited an annual biological cycle, influenced by precipitation seasonality (BIO15) and fluctuations in minimum temperature (BIO6). *Melinis repens* displayed the largest potential niche area, spanning 57 million hectares, followed by *Bouteloua curtipendula* (sideoats grama) with 51 million hectares. The most substantial ecological niche overlap, 22 million hectares, was observed between sideoats grama and natal redtop grass. The findings highlight the need for targeted management strategies and technological solutions to effectively control invasive species, restore grassland ecosystems, and enhance forage quality in Mexico.

Limitations/implications: The study focused exclusively on four grass species, thereby excluding potential interactions with other Poaceae members and plant families.

Findings/conclusions: Both native and introduced grasses exhibit considerable economic, social, and ecological relevance in Mexico, underscoring the necessity for comprehensive assessments and the implementation of sustainable management plans to safeguard vital grassland ecosystems.

Keywords: *Bouteloua*, *Pennisetum*, *Melinis*, grassland, diversity, conservation.

INTRODUCTION

Bouteloua curtipendula (sideoats grama) and *Bouteloua gracilis* (blue grama) are native grasses of Durango and other regions of Mexico, where they are highly valued for their adaptability and forage quality for livestock feeding. However, in recent years, native species have increasingly been displaced by exotic grasses such as buffelgrass (*Pennisetum ciliare*[L.] Link, syn. *Cenchrus ciliaris*) and natal redtop grass (*Melinis repens* [Willd.] Zizka, syn. *Rhynchelytrum repens*), which have been naturalized in Mexico for several decades. Buffelgrass is widely distributed across the country, with its greatest persistence in central and northern Mexico. This is largely due to indirect management practices by livestock producers that promote its establishment, such as the intentional dispersal of locally harvested seeds (caryopses, dispersal units, propagules, diaspores). These practices exploit areas with favorable water retention and aim to rehabilitate degraded lands with low vegetative cover. Combined with buffelgrass's high drought tolerance and resilience to intense grazing, these factors contribute to its persistence and dominance over native species, which are more susceptible to hydric stress and grazing pressure. In recent years, natal redtop grass has expanded its invaded range. Its distribution is closely linked to its rapid growth, early physiological maturity, and prolific seed production, with seeds that disperse easily via wind (anemochory), animals (zoochory), and water (hydrochory). Poor rangeland management practices have further accelerated the displacement of native species, particularly those preferred by livestock. In Durango, the invasion and establishment of buffelgrass and natal redtop have been recorded from the arid and semi-arid plains of the northeast (La Laguna region, Durango-Coahuila) to the Western Sierra Madre. Buffelgrass is utilized for livestock forage, particularly during the regrowth season, when it is harvested in areas where the species is abundant, especially in regions with accumulated rainwater. In several rural communities in the municipality of Cuencamé, Durango, buffelgrass seeds (caryopses, propagules, diaspores) are randomly dispersed with the aim of rehabilitating degraded lands. However, there is a general lack of awareness among livestock producers regarding the calculation of pure live seed (PLS) required to ensure successful germination and establishment. Factors such as harvest timing, seed storage, and dormancy must also be considered. The spread of buffelgrass into the mountainous zones of Durango raises concerns, particularly regarding its contribution to the increased incidence of forest fires. Seeds of certain native grasses lack dormancy, while others exhibit only short dormancy periods, allowing germination during favorable conditions for growth and development. Nevertheless, it is crucial to assess the physical and physiological quality of the seeds. Based on these observations, the hypothesis was formulated that "the invasion of exotic species will have minimal impact on the distribution of Mexico's endemic grasses, namely blue grama and sideoats grama." To test this, it was necessary to determine the current extent of these species in Durango and other states of Mexico. Understanding the current expansion of exotic grasses and their interaction with native grass populations will support informed livestock production planning and help reverse rangeland overexploitation, soil degradation, and biodiversity loss.

MATERIALS AND METHODS

Information Used: In 2024, global databases were consulted to obtain occurrence records for four grass species in Mexico (10, https://www.gbif.org/es/). A total of 7,896 presence records were initially compiled: 900 for buffelgrass, 900 for sideoats grama, 2,000 for blue grama, and 4,096 for natal redtop grass. The dataset was processed using the 'distinct' function from the Tidyverse library (11) in R Project, version 4.3.1 (12), which facilitated the removal of 2,322 records due to incomplete information and duplication. Duplicate entries were defined as those occurring within a radius of less than 30 arcseconds (∼1 km) from other locations, to avoid redundancy. A distribution map of the studied species was generated using QGIS version 3.34.9 (Figure 1).

Selection of Bioclimatic Variables: A total of 19 standard bioclimatic variables (Table 1) were incorporated, with a spatial resolution of 30 arcseconds (∼1 km) (13). The M area representing the potential dispersal zone of each species was delineated using QGIS software (14), ensuring that all occurrence points were contained within the designated polygon. Each species-specific polygon was uploaded into R (version 4.3.1), and 10,000 random points were generated within it. These points were then assigned data from the 19 bioclimatic variables available on WorldClim.org (13). A bivariate Pearson correlation analysis was conducted to reduce the number of bioclimatic variables without losing essential information, thereby avoiding multicollinearity. Predictive variables that were highly correlated ($|r| \geq 0.7$) were excluded from further analysis.

Bioclimatic Data and Variable Selection: Following data refinement and sampling bias adjustment, 257 records for buffelgrass, 281 for sideoats grama, 644 for blue grama, and 1,140 for natal redtop grass were removed. This process prevented species overrepresentation in specific localities. To further mitigate sampling bias, data were filtered to ensure a single observation per locality, minimizing spatial redundancy. The final variables selected after the correlation analysis included: BIO1 (mean annual temperature), BIO5 (maximum temperature of the warmest month), BIO6 (minimum temperature of the coldest month), BIO7 (annual temperature range), BIO12 (annual precipitation), BIO14

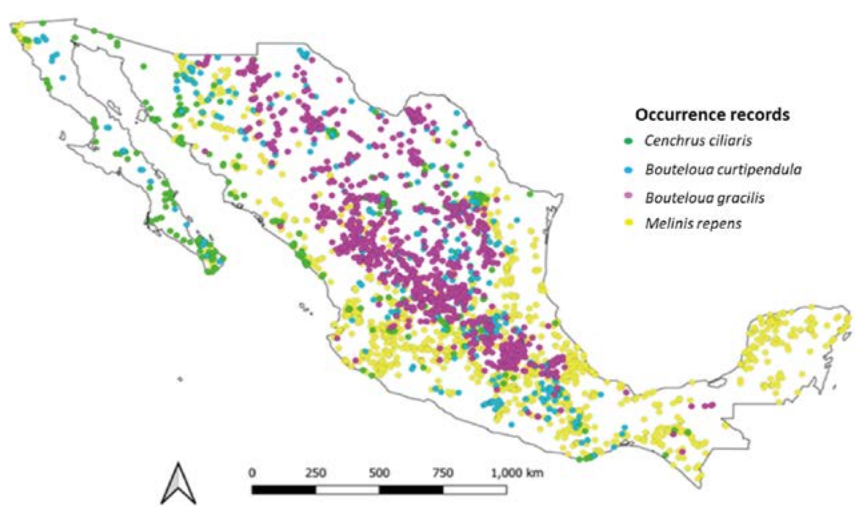

Figure 1. Graphical representation of the presence points for four grass species observed in Mexico.

Table 1. Bioclimatic variables used in the ecological niche analysis for four grass species present in Mexico.

Variable	Description	Variable	Description
BIO1	Average Annual Temperature	BIO11	Average Temperature of the Coldest Quarter
BIO2	Average Temperature Range	BIO12	Annual Precipitation
BIO3	Isothermal Range	BIO13	Precipitation of the Wettest Month
BIO4	Temperature Seasonality	BIO14	Precipitation of the Driest Month
BIO5	Maximum Temperature of the Warmest Month	BIO15	Seasonality of Precipitation
BIO6	Minimum Temperature of the Coldest Month	BIO16	Precipitation of the Wettest Quarter
BIO7	Annual Temperature Range	BIO17	Precipitation of the Driest Quarter
BIO8	Average Temperature of the Wettest Quarter	BIO18	Precipitation of the Warmest Quarter
BIO9	Average Temperature of the Driest Quarter	BIO19	Precipitation of the Coldest Quarter
BIO10	Average Temperature of the Warmest Quarter		

(precipitation of the driest month), and BIO15 (precipitation seasonality). Subsequently, a presence polygon was generated for each species (Figure 2), and the layers of the selected bioclimatic variables were clipped accordingly to a defined study area.

Calibration for Maximum Entropy Modeling: Ecological Niche Modeling (ENM) calibration was performed for each species to reduce oversampling bias within the

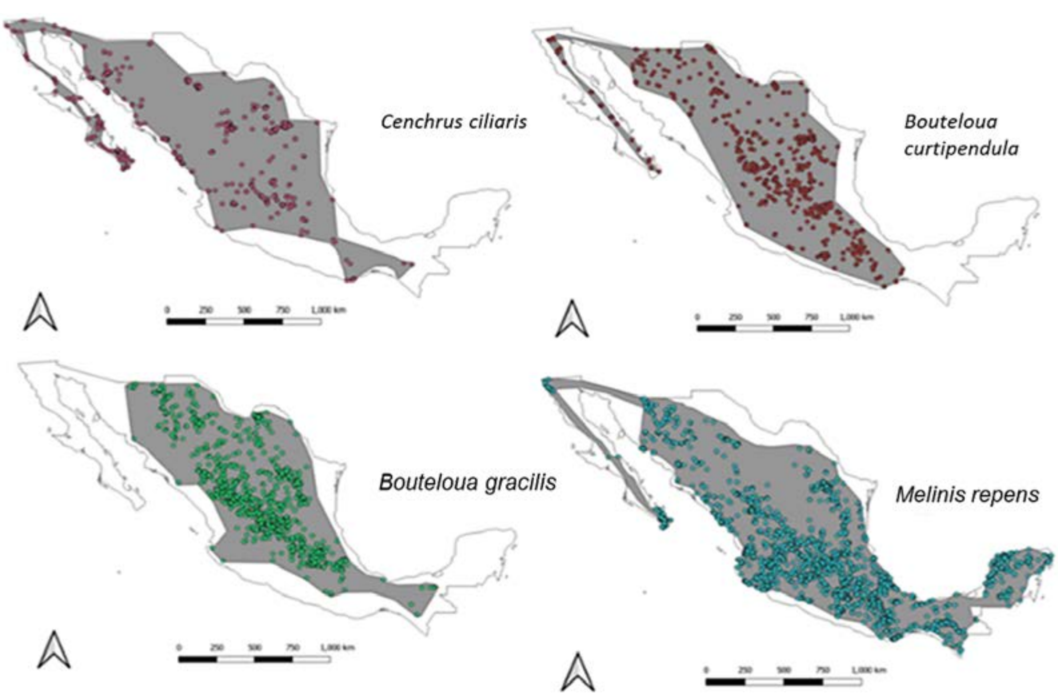

Figure 2. Presence polygons for four grass species evaluated in Mexico.

datasets (15). The selected climatic layers were clipped using each species' presence area as a reference mask, then uploaded and stacked in R. A projection was applied using the WGS84 datum, species occurrence records were loaded, and calibration was conducted using the "Enmeval" function from the "ENMevaluate" package (16).

Modeling with MaxEnt: Potential ecological niche models were developed using MaxEnt (Maximum Entropy Species Distribution Modeling), version 3.4.4 (17, 12). To build these models, occurrence records (species, latitude, and longitude) were combined with bioclimatic variables associated with both realized and potential niches (15). The software was then calibrated using the regularization multiplier (RM) and feature classes (FC), applying the specific values identified during the calibration phase for each species.

The calibrated model outputs were projected across the entire Mexican territory using MaxEnt software, incorporating the Linear (L), Quadratic (Q), Hinge (H), Product (P), and Threshold (T) feature classes. These models integrated the previously described environmental variables along with an elevation (altitude) layer. A total of 100 replicates were executed to produce ecological niche models, represented geographically as habitat suitability maps under current climatic conditions in Mexico for blue grama, sideoats grama, buffelgrass, and natal redtop grass. To select the most accurate final models, Area Under the Curve (AUC) values from the Receiver Operating Characteristic (ROC) analysis and Jackknife tests were used as evaluation criteria. For model parameter optimization, the Corrected Akaike Information Criterion (AICc), regularization multiplier (RM), and feature class combinations (FC) were calculated using R and the ENMeval package (15). The specific RM and FC values used for each grass species are presented in Table 2. Subsequently, species distribution models were constructed based on configurations with the lowest AICc values (18).

RESULTS AND DISCUSSION

Variations were observed among species regarding the requirement of baseline functions for transforming the variables included in the study and modeling habitat suitability areas (Table 2).

Results of the Analysis: The analysis revealed marked differences in the breadth of the potential ecological niche among the grass species, with the realized niche currently being the most restricted for buffelgrass (Figure 3). Native species sideoats grama and blue grama exhibited a broader ecological niche across diverse Mexican

Table 2. Statistical values obtained during the calibration of the analysis.

Species	ΔAIC	Regularization Multiplier (RM)	Feature Classes (FC)
Buffelgrass	0	0.5	LQHPT
Sideoats grama	0	1.5	LQHPT
Blue grama	0	0.5	LQHP
Natal redtop	0	0.5	LQHPT

L=Linear, Q=Quadratic, H=Hinge, P=Product, T=Threshold.

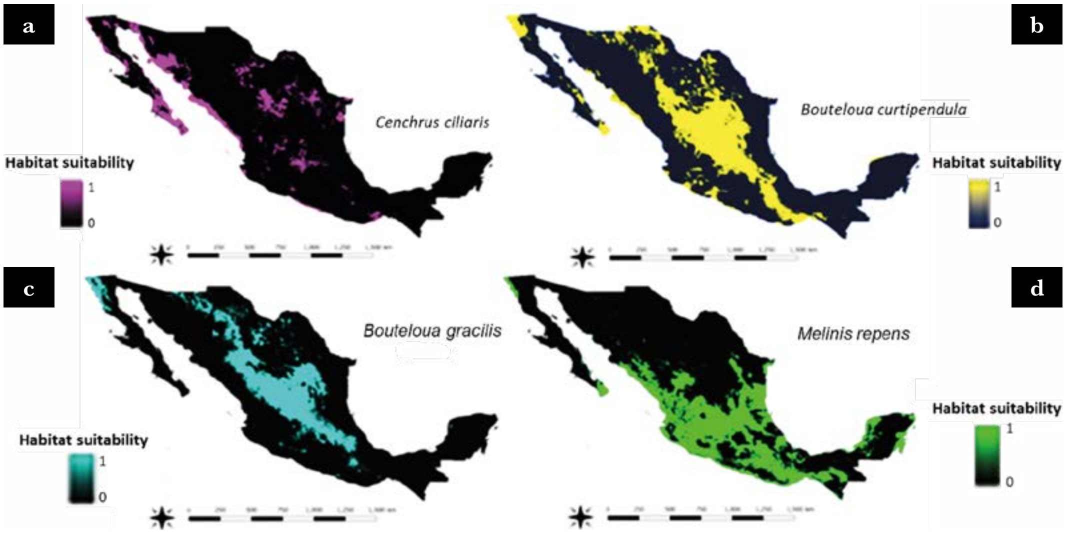

Figure 3. Potential ecological niches for four grass species present in Mexico: a) buffelgrass, b) sideoats grama, c) blue grama, and d) natal redtop grass.

regions, ranging from plains to the foothills of mountainous areas. In particular, sideoats grama demonstrated potential colonization capacity in the northwestern, western, and southern coastal plains, as well as in the semi-desert zones of northern Mexico. In contrast, natal redtop grass exhibited an ecological niche favorable for establishment in central, western, and southern Mexico, with additional presence in the northwestern and northern regions. It was also observed in mountainous zones and agricultural lands within the state of Durango.

Contribution Analysis: The most influential variables across all species were annual precipitation (BIO12) and mean annual temperature (BIO1), both of which are fundamental to the growth and development of the grass species studied. Precipitation seasonality (BIO15) had a greater effect on the invasive species, reflecting their reliance on accumulated summer rainfall. Minimum temperature of the coldest month (BIO6) significantly influenced the establishment of buffelgrass and natal redtop grass, as both originate from warm regions and exhibit primary growth during the spring-summer cycle.

Table 3. Mean contribution and importance values of various bioclimatic variables influencing the adaptation, distribution, and persistence of four grass species in Mexico.

Variable/Species	Sideoats grama	Blue grama	Buffelgrass	Natal redtop grass (Pink grass)
BIO 1	28.3	13.7	33.3	11.1
BIO 12	16.5	50.3	23.7	23.9
BIO15	2.1	1.1	12.4	20.3
BIO 6	--	--	12.6	9.9
BIO 5	36.8	5.3	10.6	14.3
BIO 14	3.0	3.2	3.8	6.3
BIO 7	5.3	26.4	3.7	14.3

In the case of sideoats grama (*Bouteloua curtipendula*), the maximum temperature of the warmest month (BIO5) was identified as a primary factor influencing its adaptation. This was followed by the invasive species, which were also affected by elevated temperatures coinciding with low precipitation levels during the driest month (May-June, depending on the site) (BIO14). These conditions increase environmental stress, leading to soil dehydration and desiccation of young plant tissues across multiple vegetation types (19, 20).

Blue grama (*Bouteloua gracilis*) showed marked sensitivity to the annual temperature range (BIO7), followed by natal redtop grass and the remaining species in the study. This contrasted with previous research in Mexico, which reported minimal influence from this variable (21). Nevertheless, other studies have shown significant effects of mean annual temperature and other similar variables to those considered in this research (22). Blue grama has demonstrated a rapid physiological response to temperature shifts, particularly in seed germination (>25 °C) (23), spring regrowth, vegetative growth, and the onset of reproduction.

Moreover, sideoats grama was strongly influenced by precipitation during the wettest four-month period (BIO16), due to its sensitivity to soil saturation and limited adaptation to flooded areas (24). Response curves indicated that the optimal temperature range for sideoats grama lies between 6 and 27 °C (Figure 4a). These results align with previous findings identifying this species as tolerant to both low temperatures and drought (25). For blue grama, the ideal temperature range for establishment was found to be between 13 and 29 °C (Figure 4b). This response is associated with the presence of two distinct genetic population groups within the species, each adapted to different environmental

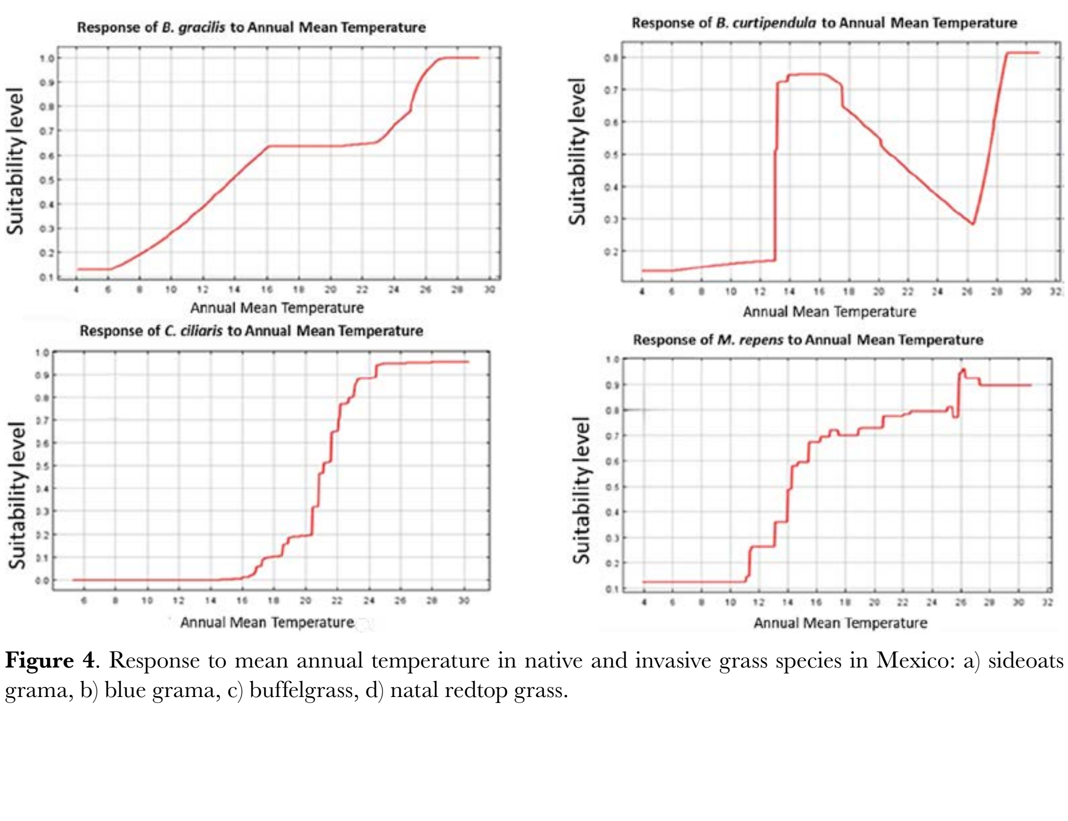

Figure 4. Response to mean annual temperature in native and invasive grass species in Mexico: a) sideoats grama, b) blue grama, c) buffelgrass, d) natal redtop grass.

conditions (21, 26). Buffelgrass exhibited adaptation to temperatures ranging from 16 to 30 °C (Figure 4c). Similar values (12 to 18 °C) have been reported, with 35 °C considered the optimum (27). The species can also tolerate low temperatures (<5 °C), although some researchers have noted that extreme heat may impair seedling growth (28). Natal redtop grass responded positively to intermittent increases in temperature starting at 11 °C, reaching high suitability at 26 °C, followed by a slight decrease, and then stabilizing at high suitability levels from 27 °C onward (Figure 4d). These results differ slightly from other reports that place the optimal temperature range between 15 and 30 °C (4). All grass species exhibited varying responses to mean annual temperature, as part of their adaptive strategies to cope with climatic variability across Mexico's diverse altitudinal gradients and ecosystems.

The response curves to average accumulated rainfall levels revealed a peak around 500 mm for sideoats grama (Figure 5a), with a primary adaptation range between 200 mm and 300 mm, and diminished suitability beyond 800 mm (25). Blue grama exhibited a sharp increase beginning at 250 mm, reaching a peak at 500 mm, followed by a gradual decline as accumulated rainfall increased (Figure 5b).

Native species and grass ecotypes are adapted to the precipitation patterns across various regions of Mexico. Consequently, any imbalance in this climatic factor could significantly reduce both the potential and realized niche suitability for each grass type.

Buffelgrass exhibited its highest response at approximately 250 mm of precipitation, with notable fluctuations extending up to 1,250 mm (Figure 5c). This variability is associated with its status as an exotic species introduced into Mexico from diverse populations, including both landraces and improved cultivars. These populations display a wide range

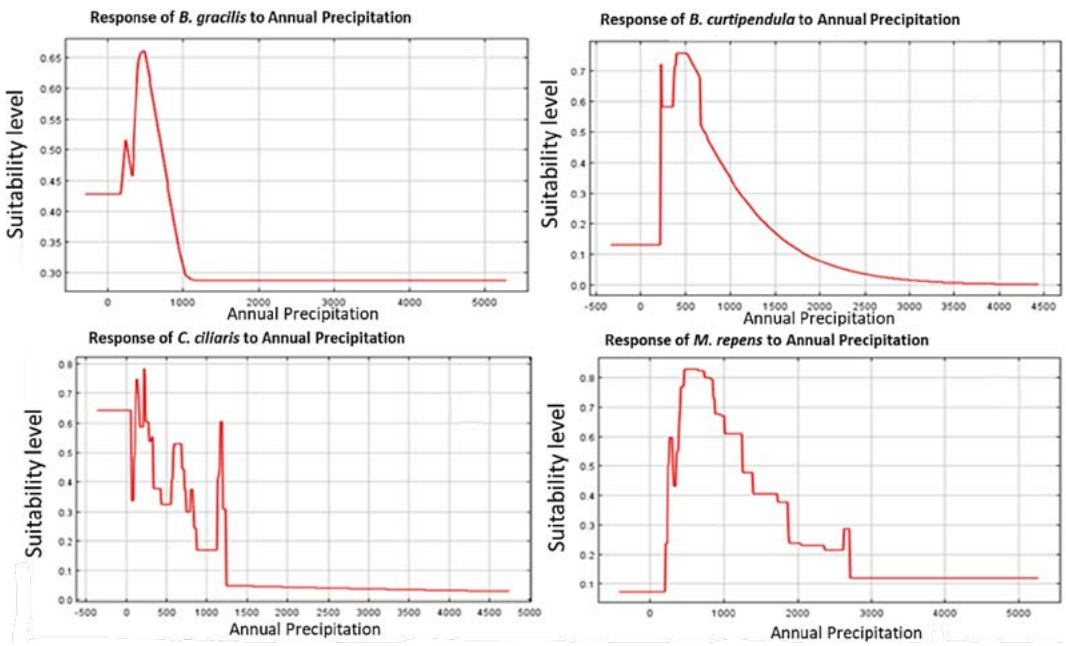

Figure 5. Response to annual precipitation in native and invasive grass species in Mexico: a) sideoats grama, b) blue grama, c) buffelgrass, d) natal redtop grass.

of adaptive mechanisms to varying rainfall conditions across the ecosystems where the species is now present. It has been documented that buffelgrass naturally thrives in areas receiving annual rainfall between 270 mm and 3,500 mm, although it is susceptible to prolonged flooding events (29).

Natal redtop grass showed high suitability in areas with 500 mm of rainfall, reaching maximum response between 600 and 700 mm, and then decreasing intermittently beyond 800 mm of accumulated precipitation (Figure 5d). This species is considered optimally adapted to regions with annual precipitation ranging from 700 to 1,500 mm, though it can tolerate levels between 500 and 2,500 mm (4).

The exotic species buffelgrass and natal redtop grass exhibited sensitivity to the minimum temperature of the coldest month, with a response concentrated in regions where this variable exceeds 20 °C (Figures 6a and 6b). Natal redtop grass adapts optimally to daily temperatures ranging from 15 °C to 30 °C, though it tolerates a wider range from 4 °C up to 38 °C and can survive temperatures as low as −6.6 °C, often behaving as an annual in colder climates (4). Buffelgrass is best adapted to temperatures between 24 °C and 32 °C, but can survive in regions with temperatures between 5 °C and 15 °C. However, it exhibits poor adaptation to freezing conditions, despite its high tolerance to elevated temperatures, up to 45 °C (30).

Both exotic species also responded to precipitation seasonality, showing intermittent and sustained increases beginning at 70 mm, with maximum suitability around 140 mm during the growing season (Figures 7a and 7b). These results align with findings from previous studies, which highlight the critical role of rainfall in the adaptability of invasive species, particularly buffelgrass (31). Natal redtop grass maintains high seed production even during below-average precipitation years, which enhances its dispersal and establishment across diverse ecosystems (32). This trait is linked to the life cycle shifts these species have adopted in response to seasonal rainfall patterns in Mexico, particularly during the summer growing season (July-September). While buffelgrass is classified as a perennial species (24), natal redtop grass may exhibit a semi-perennial growth cycle under favorable environmental conditions (33).

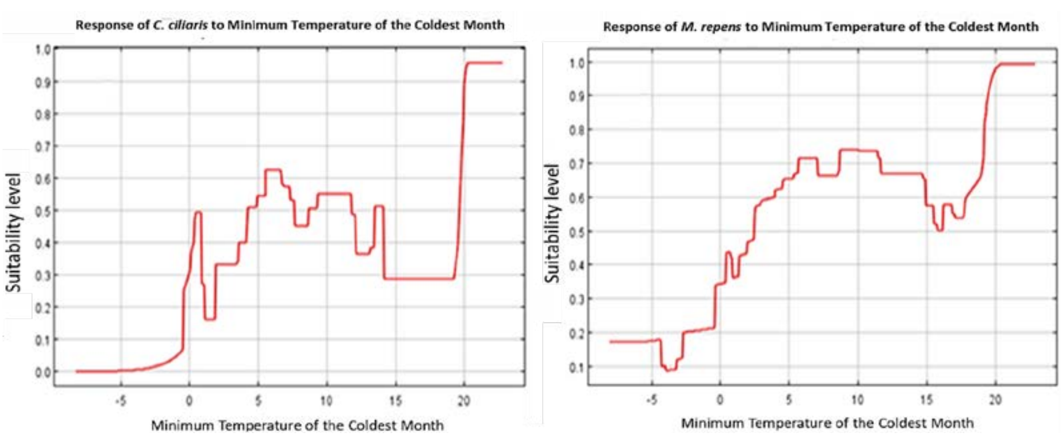

Figure 6. Response to the minimum temperature of the coldest month in two invasive grass species in Mexico: a) buffelgrass, b) natal redtop grass.

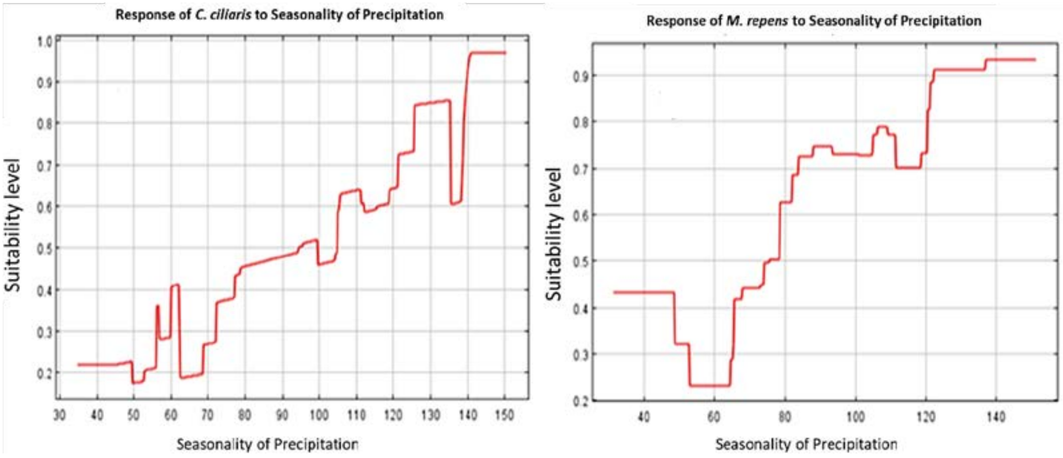

Figure 7. Response to precipitation seasonality in two invasive grass species in Mexico: a) buffelgrass, b) natal redtop grass.

Sideoats grama (*Bouteloua curtipendula*) exhibited sensitivity to high temperatures, particularly those recorded during the warmest month of the year (May or June). Habitat suitability declined notably at temperatures near 16 °C and approached zero at 40 °C (Figure 8). These observations align with previous studies, which reported a high probability of occurrence for sideoats grama in regions with annual temperatures ranging from 13 °C to 19 °C (34).

All grass species included in the study demonstrated variation in their response to mean annual temperature and accumulated precipitation. This variation reflects their respective adaptive strategies to climatic gradients across different altitudinal levels and ecosystems. Additionally, each species showed a marked response to specific bioclimatic variables of particular relevance, enhancing their adaptation to distinct environmental conditions observed in various regions of Mexico.

Jackknife Tests. The Jackknife tests confirmed the relative importance of mean annual temperature (BIO1) and total annual precipitation (BIO12) in defining the ecological niche

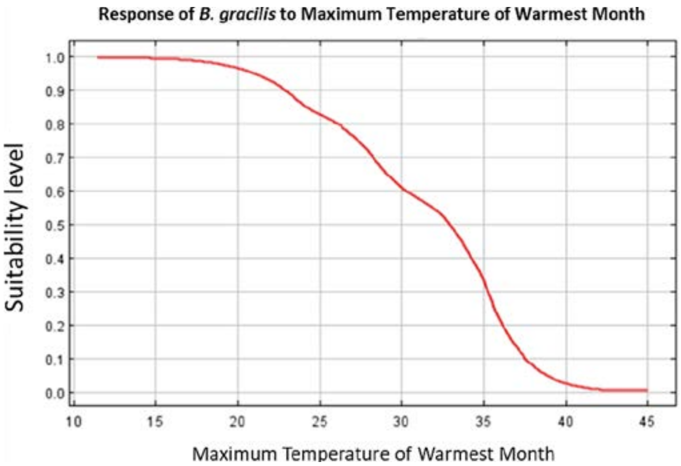

Figure 8. Response of sideoats grama to the maximum temperature of the warmest month.

for all grass species evaluated in this study (Figures 9 to 12). Additionally, the tests revealed that certain variables held individual importance for specific species. For instance, in buffelgrass, precipitation during the driest month (BIO14) and the minimum temperature of the coldest month (BIO6) were particularly influential. These tests illustrate the degree to which bioclimatic variables affect the ecological adaptation of buffelgrass, identifying BIO1 as the environmental variable with the highest individual gain (Figure 9).

In blue grama, other variables were identified as species-specific in importance, particularly the maximum temperature of the warmest month (BIO5) and the annual temperature range (BIO7) (Figure 10). In contrast, for sideoats grama, mean annual temperature (BIO1) was the most decisive variable in niche definition, followed by BIO5 and the minimum temperature of the coldest month (BIO6) (Figure 11). For both blue grama and sideoats grama, the maximum temperature of the warmest month (typically May or June) proved critical, as this variable plays a central role in plant survival during periods of heightened thermal stress especially when water availability is low. Blue grama exhibited greater sensitivity to thermal variability, being more affected by fluctuations between annual temperature extremes. Meanwhile, sideoats grama was primarily influenced by the minimum temperature of the coldest month.

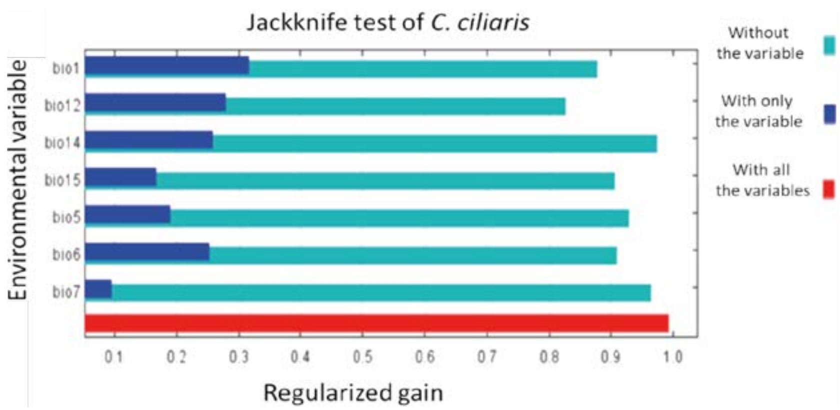

Figure 9. Jackknife test results showing the relative importance of bioclimatic variables in defining the potential niche of buffelgrass.

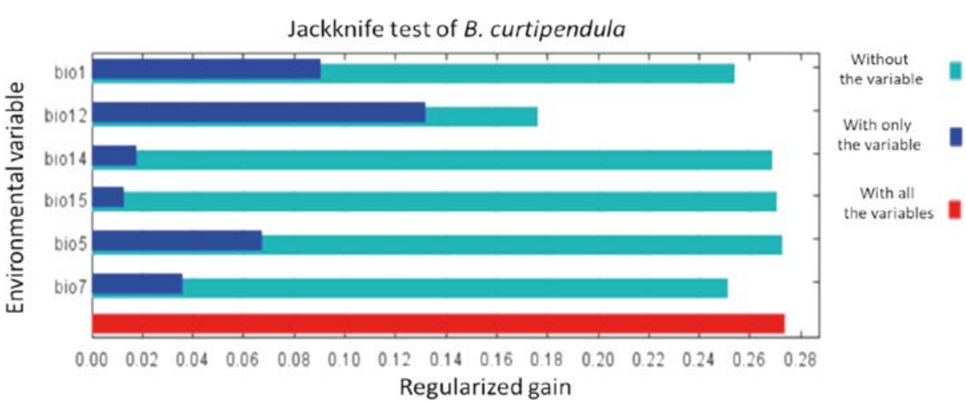

Figure 10. Jackknife test results showing the relative importance of bioclimatic variables in defining the ecological niche of blue grama.

In the case of natal redtop grass, the most influential bioclimatic variables defining its ecological niche were the annual temperature range (BIO7), followed by total annual precipitation (BIO12), minimum temperature of the coldest month (BIO6), and precipitation seasonality (BIO15) (Figure 12). Overall, temperature and moisture-related variables across their various expressions play a defining role in shaping both the realized niche of native grasses and the potential niche of invasive species.

Bioclimatic variables significantly influenced the current adaptation zones (realized ecological niche) of sideoats grama, blue grama, buffelgrass, and natal redtop grass. These grass species exhibit spatial segregation both within species (among ecotypes) and between species (interspecific), observed in both native and invasive types. Intraspecific variation arises from the genetic diversity within populations and the adaptive requirements across different altitudinal gradients, in conjunction with spatial and temporal variations in temperature and precipitation patterns. It is anticipated that climate change will affect the abundance and distribution of tree, shrub, and grass species, where drought tolerance will serve as a key survival mechanism, enabling colonization across diverse ecosystems (34). Based on this, assessing the degree of interspecific interaction and competition becomes

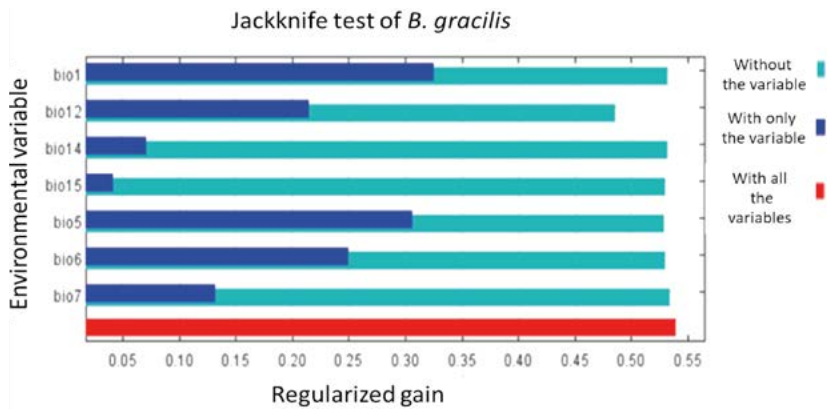

Figure 11. Jackknife test results showing the relative importance of bioclimatic variables in defining the ecological niche of sideoats grama.

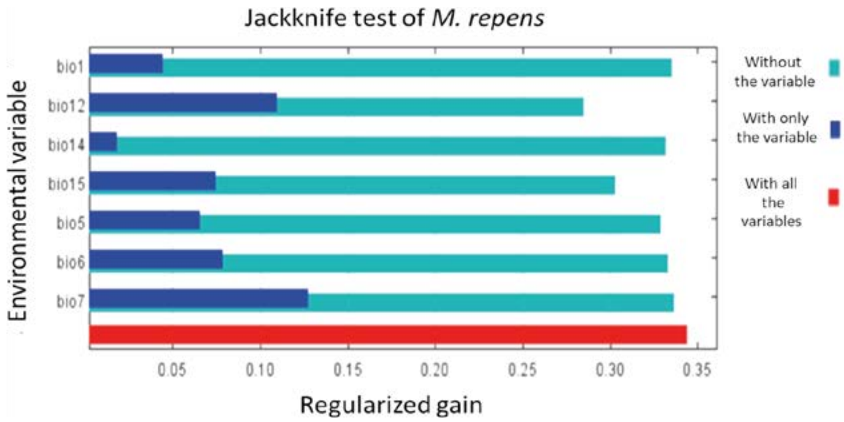

Figure 12. Jackknife test results showing the relative importance of bioclimatic variables in defining the ecological niche of natal redtop grass.

essential to inform efforts aimed at collecting, conserving, and utilizing ecotypes of native grasses. Furthermore, it is necessary to identify effective methods for controlling invasive grasses in critical areas, while exploring the potential utilization of exotic populations in regions where their adaptation exceeds that of native species.

Niche Overlap

Blue grama Buffelgrass: The interspecific interaction analysis showed that buffelgrass occupies a total potential area of 20 million hectares (ha), while blue grama spans 51 million ha (Figure 13a). The overlapping area between these two ecological niches exceeded 7 million ha, mainly located in the Semi-Arid Mexican Plateau (Figure 13b). Additional zones of overlap were identified in the coastal plains of Sinaloa, Sonora, Baja California Sur, Jalisco, and Guerrero, as well as in the central-northern highlands, the central region, and extending southward to Oaxaca.

Blue grama Natal redtop grass: Natal redtop grass exhibited a potential niche area of 57 million hectares (Figure 14a), while blue grama occupied a total of 51 million hectares. The overlapping area between these two species was extensive, reaching approximately 22 million hectares. This overlap was concentrated in the Semi-Arid and Sub-Humid Plateau of North-Central Mexico, particularly in the states of Guanajuato, Querétaro, Hidalgo, Estado de México, and San Luis Potosí, as well as in the coastal plains of Sinaloa, Baja

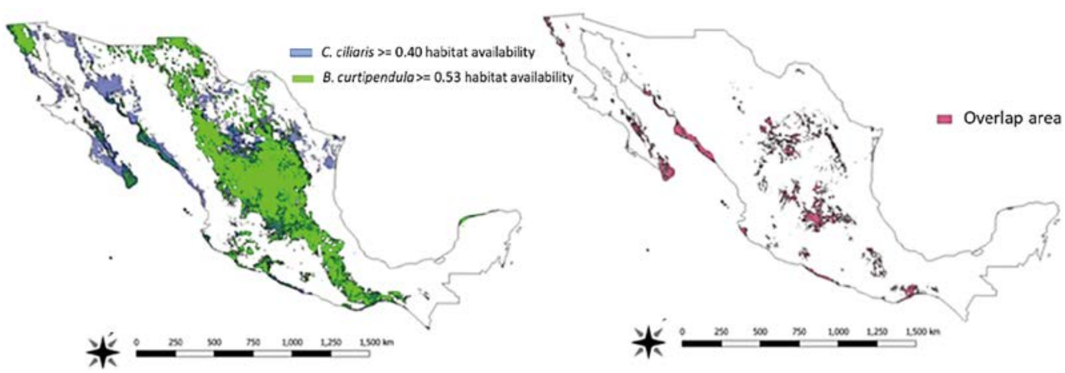

Figure 13. Potential ecological niches and areas of overlap between buffelgrass and sideoats grama.

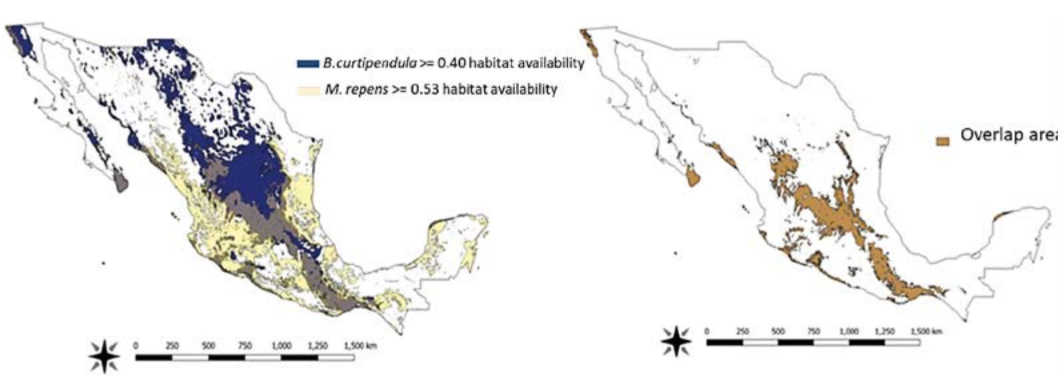

Figure 13. Potential ecological niches and areas of overlap between buffelgrass and sideoats grama.

California Sur, and Baja California (Figure 14b). Additional zones of interspecific interaction were identified along the coasts of Jalisco, Colima, Puebla, Guerrero, Oaxaca, Nuevo León, and Chiapas. In the state of Durango, a significant expansion of natal redtop grass has been observed in recent years, advancing from the northeastern region (La Laguna) toward the foothills of the Western Sierra Madre. It has increasingly occupied communal lands and small private properties near Francisco I. Madero, Durango. Furthermore, it has spread into agricultural areas, facilitated by irrigation water distributed through canal systems connected to the Guadalupe Victoria and Santiago Bayacora dams in the municipality of Durango.

Sideoats grama Buffelgrass: Sideoats grama exhibited a total potential niche area of 39 million hectares, whereas buffelgrass showed an extent of 20 million hectares (Figure 15a). This distribution indicates a high potential for expansion of buffelgrass, as predictive models estimate its possible occupation of up to 42% (82.3 million hectares) of Mexico's continental territory (195.9 million hectares) (3). The overlapping area between the ecological niches of these two species reached approximately 3 million hectares, primarily located in the Semi-Arid and Sub-Humid Mexican Plateau, from Chihuahua to Guanajuato and Querétaro (Figure 15b). Additional zones of co-occurrence with lower interspecific pressure were identified in the coastal plains of Baja California and Nuevo León, as well as in parts of Coahuila, Chihuahua, Puebla, and Oaxaca.

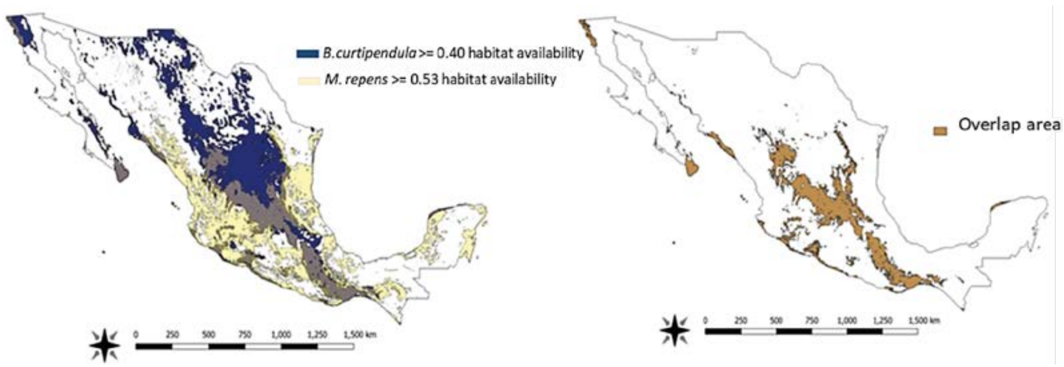

Figure 14. Potential ecological niches and areas of overlap between blue grama and natal redtop grass.

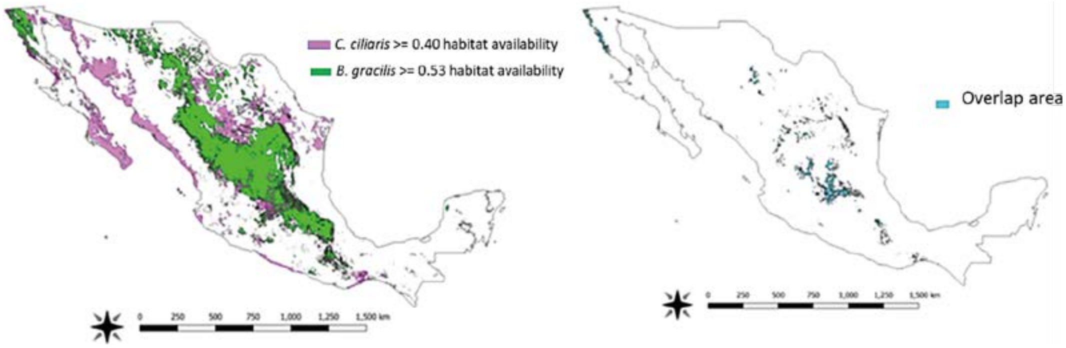

Figure 15. Potential ecological niches and areas of overlap between buffelgrass and sideoats grama.

The level of competition between buffelgrass and sideoats grama populations was comparatively lower than that observed in other grass species interactions. As a result, buffelgrass is intentionally promoted in certain areas of Durango, where sideoats grama shows limited adaptability or where the degree of ecosystem overexploitation is high. In this state, buffelgrass is commonly harvested as forage for livestock, particularly in semi-arid regions. Therefore, it is considered a viable option to enhance livestock production, and its seeds are actively dispersed in croplands and communal-use areas in several ejidos within the warm semi-arid zones, particularly in the municipality of Cuencamé, Durango.

Sideoats grama Natal redtop grass: The interaction analysis between sideoats grama and natal redtop grass revealed that the former occupied a total potential niche of 39 million hectares, whereas the latter extended over 51 million hectares (Figure 16a). The area of overlap between these two species surpassed 12 million hectares, mainly within the Semi-Arid Plateau and sub-humid regions of central Mexico (Figure 16b). Additional areas of co-occurrence with lower competitive pressure were also identified in the coastal plains of Baja California, Nuevo León, San Luis Potosí, Puebla, and Oaxaca.

Although spatial interactions were observed between native and exotic grass species, the ecological and productive adaptability of buffelgrass and to some extent, natal redtop Grass offers opportunities for managed utilization. Buffelgrass has been intentionally promoted in certain disturbed areas of microphyllous scrub to provide forage for livestock and to stabilize bare soils. Colonization of buffelgrass has been particularly noted in water runoff zones along roadsides.

Natal redtop grass has proven useful for improving ground cover in degraded and overexploited areas, helping mitigate water and wind erosion in Mexico's Semi-Arid Plateau. This species has invaded disturbed zones in the breña region near Francisco I. Madero, Durango, as well as shrublands and farmlands in the municipality of Durango, where its spread is facilitated through irrigation canals from the Guadalupe Victoria and Santiago Bayacora dams. In response to this ecological shift, restoration initiatives have been launched to recover grassland and microphyllous scrub areas degraded by overgrazing, erosion, soil degradation, and invasion by buffelgrass and natal redtop grass (2). These efforts include the collection and genetic improvement of native grass populations (35), leading to the development of improved lines and cultivars of sideoats and blue grama

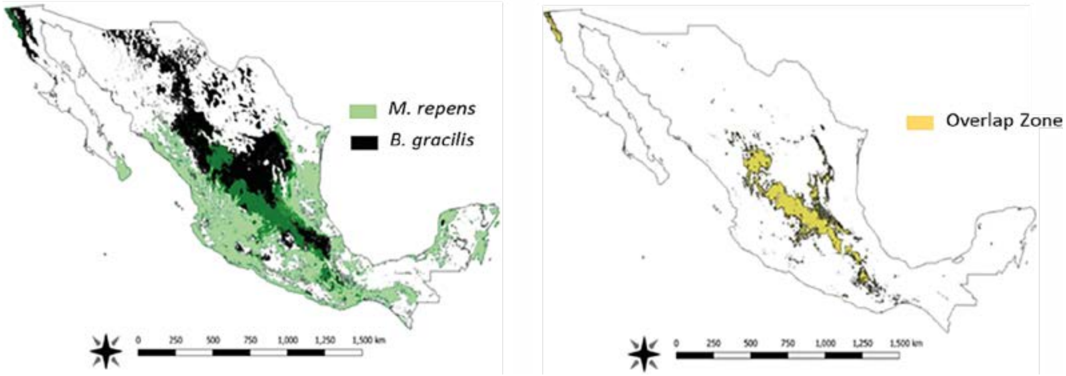

Figure 16. Ecological niches and areas of overlap between natal redtop grass and sideoats grama.

derived from Mexican ecotypes (36). Technologies have also been developed for the production of high-quality caryopses with germination rates ranging from 85% to 96%, supporting effective emergence, growth, and seedling establishment (37, 38). In tandem, rainwater harvesting and retention infrastructure has been implemented to enhance establishment rates and forage productivity (39). Regarding invasive grass control, progress remains limited. Currently, the only recommended method is the controlled use of fire (32). Chemical control has been minimally studied. Therefore, the most practical approach involves efficient utilization of invasive species for forage production during the rainy season and repurposing residual biomass for various uses during the dry season. Discussions are ongoing regarding integrated management systems for invasive species, which exhibit forage quality ranging from poor to good during the rainy period. In specific áreas and only as a last resort buffelgrass and natal redtop grass may be established intentionally to stabilize bare soils and support soil conservation and ecosystem sustainability. Utilizing these species for summer forage production may improve the nutritional quality and performance of livestock under extensive and semi-confined grazing systems, especially in north-central Mexico.

CONCLUSIONS

A significant expansion of the realized ecological niche was recorded for the invasive grass species natal redtop grass and buffelgrass in Mexico. These species have colonized vast areas of the Semi-Arid and Sub-Humid Plateau, as well as portions of the coastal plains within the Dry and Humid Tropics. In several regions, interspecific interactions and competition were observed between native and invasive grass populations, highlighting the need to clearly identify areas requiring restoration to support sustainable meat and dairy production. It is recommended that rangeland restoration efforts prioritize native species such as sideoats and blue grama to rehabilitate grassland ecosystems and certain microphyllous scrub zones. In other areas, it may be necessary to evaluate and validate the controlled establishment of buffelgrass and natal redtop grass to mitigate soil erosion and nutrient depletion though such measures should remain a secondary option. Preference must be given to native species adapted to the specific region and ecosystem. The population expansion and genetic diversity of both native and exotic grasses contributed to the differentiated responses observed across temperature and precipitation gradients throughout Mexico. These species-specific responses should be further studied and leveraged for the selection of superior ecotypes with high adaptability, forage value, persistence, and soil cover potential. Such an approach will enhance the sustainability of grasslands, microphyllous scrub, and other ecosystems in regions of Mexico characterized by limited rainfall and high thermal variability conditions that predispose soils to erosion and physico-chemical degradation.

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