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Review

The grasslands and scrublands of arid and semi-arid zones of Mexico: Current status, challenges and perspectives

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Abstract:

The objective was to review the current state of the semi-arid grasslands and arid scrublands of northern and central Mexico, as well as to analyze the challenges and perspectives of the use of these ecosystems. Since the 1950s, INIFAP, in collaboration with other institutions, has generated and transferred knowledge on rangeland management, which has reflected in the use of management practices on cattle ranches in the country. The grasslands and scrublands have suffered disturbances –particularly the opening of land for crops– and are deteriorated mainly from overgrazing. The use of grasslands and scrublands through grazing should include adequate stocking, grazing systems, and strategic grazing distribution practices. Despite the deterioration, there is a great diversity of genetic resources, mainly pastures, which can be used for conservation and seed production for the rehabilitation of grasslands. Although costly and risky, re-seeding is an option for restoring decayed grasslands or shrublands. These ecosystems can provide environmental services, mainly carbon sequestration, to mitigate climate change. The challenges are to generate, transfer, and apply knowledge and technological innovations in order to achieve sustainable management of grasslands and scrublands, despite some threats such as low investment in science and technology, climate change, and human greed. The joint and committed participation of all the actors and institutions involved in the use of these ecosystems is essential to attain this goal.

Key words: Range condition, Grazing management, Genetic resources, Seed production, Rangeland reseeding, Soil carbon.

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Introduction

The grasslands and shrubs of the arid and semi-arid zones of central and northern Mexico are natural resources that comprise approximately 25 % of the national territory[1] and have the ability to provide several products and environmental services to society. One of these products is ruminant meat from extensive livestock farming, while carbon sequestration is one of their most important environmental services. Grasslands and scrublands have undergone major transformations, mainly due to changes in land use, the climate, and overgrazing, which cause a serious deterioration of these resources.

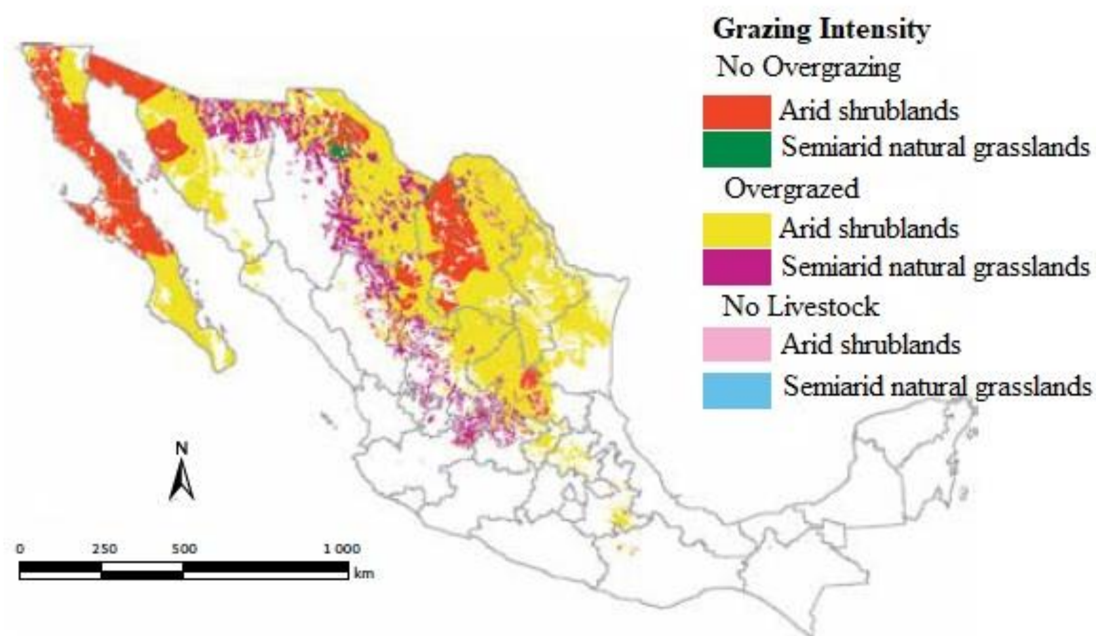
Grassland rehabilitation is a necessary activity for correcting this deterioration. Fire is an ecological, low-cost alternative for grassland improvement[2,3], while adjusting the stocking rate along with practices for improving grazing distribution are recommended to conserve or improve the condition of arid and semi-arid grasslands[4,5]. Re-seeding pastures, although a risky and costly practice due to erratic rainfall and to the high cost of land and seed preparation, is still an option for improving pastures.

Studies on the management and rehabilitation of grasslands and scrublands in Mexico began in the 1950s at the La Campana Experimental Ranch of the now extinct National Institute for Research in Livestock (Instituto Nacional de Investigaciones Pecuarias). Subsequently, since the creation, in 1985, of INIFAP –which merged the agricultural, livestock and forestry research institutes–, these studies were intensified in its Livestock Experimental Stations in the north of the country, such as "La Campana" in Chihuahua, "Carbó" in Sonora, "Aldama" in Tamaulipas, and "Vaquerías" in Jalisco. The results of these works are reflected in countless publications and have been transferred to the producers through courses, workshops, and demonstrations. During the 1970s and 1980s, they were supported by livestock organizations, state governments and CONACYT, while in the 1990s and the early XXIst century, research and grassland technology transfer were promoted by the State Produce Foundations. In the last 20 yr, Federal Programs such as SAGARPA's PROGAN have supported INIFAP in training a large number of producers and technicians in rangeland management. In addition, INIFAP has participated in the promotion of grassland management through the co-organization of Symposiums, Conferences, and Forums with different universities in central and northern Mexico and the Mexican Society for Range Management. The socioeconomic and environmental impact of pasture research carried out at INIFAP and other institutions is palpable in the management of cattle ranches. For example, a large part of the ranches in the north and center of the country, including some ejidos, carry out grazing management practices such as deferred grazing or pasture fallowing, adjustment of animal load, and supplementation of livestock during drought. This has allowed the conservation and improvement of the condition of certain grassland and scrubland areas. Today, there is a large amount of knowledge and technological innovations available to achieve sustainable management of grasslands and scrublands, generated by INIFAP, universities, and research centers. This document presents the current status of arid and semi-arid grasslands and shrubs in relation to certain strategic themes, as well as the main challenges and perspectives which must be faced with endeavor for conserve and sustainable exploitation of these ecosystems.

Grassland and scrubland condition

The semi-arid grasslands of Mexico are distributed in a strip from north to southeast of the country, from Sonora to Guanajuato, while the arid scrublands extend widely from Baja California to Oaxaca[6] (Figure 1). These ecosystems have suffered reductions by 14 % in grasslands and 26 % in shrublands as a result of their conversion to agriculture in the last 50 years, so that they currently comprise around 9.77 and 40.95 million ha, respectively[1]. Unfortunately, 95 % of the grasslands and 70 % of the shrublands are overgrazed, according to official sources (Figure 1).

Figure 1: Intensity of grazing in grasslands and natural shrublands of Mexico. Source: Dirección General de Ordenamiento y Conservación de Ecosistemas, INE, SEMARNAT, México. 2003



The first studies at the national level during the decades of 1950 to 1970 indicate that the semi-arid grasslands of central and northern Mexico consisted mainly of native grasses of low and medium size, such blue grama (*Bouteloua gracilis*), sideoats grama (*B. curtipendula*), hairy grama (*B. hirsuta*), Rothrock's grama (*B. rothrockii*), purple grama (*B. radicosa*), slender grama (*B. repens*), black grama (*B. eriopoda*), sprucetop grama (*B. chondrosioides*), scorpion grama (*B. scorpioides*), six weeks three awn (*Aristida adscencionis*), poverty three-awn (*A. divaricata*), spidergrass (*A. ternipes*), buffalo grass (*B. dactyloides*), while in arid or halophytic grasslands the most common grasses included the tobosa grass (*Pleuraphis mutica*), alkali sacaton (*Sporobolus airoides*), and saltgrass

(*Distichlis spicata*)[6]. However, recent studies report some changes in its floristic composition and the appearance of exotic grasses. In northeastern Sonora, semi-arid grasslands are mainly composed of native grasses of the *Aristida* and *Bouteloua* genera[7], while in the central plains of the state, approximately 800 thousand hectares of exotic buffel grass (*Pennisetum ciliare*) are used for cattle raising and that were originally native scrublands[7]. Unfortunately, the overgrazing caused by beef cattle industry has degraded and reduced condition of short grass prairies, affecting the economic income of families[8].

In the case of the Chihuahua grasslands, the most common grasses are of the *Bouteloua* and *Aristida* genera, and among the arid grasslands, the dominant species are the tobosa, alkali sacaton, and alkali lovegrass (*Eragrostis obtusiflora*)[9]. In addition, an invasion of shrubs such as the catclaw mimosa (*Mimosa biuncifera*) and whitebrush (*Aloysia gratissima*), as well as exotic grasses such as Lehmann lovegrass (*Eragrostis lemahnniana*) and natal grass (*Melinis repens*)[9,10]. Local studies confirm a high degree of deterioration, as well as losses of 378 thousand to 2.72 million hectares[11,12], attributed to the opening of land to cultivation, overgrazing[10,12], climate change, human settlements, and inadequate public policies in the grasslands of Chihuahua[12].

In Durango, semi-arid grasslands are mainly composed of native grasses of the *Aristida, Bouteloua, Elionurus, Eragrostis,* and *Heteropogon* genera, while in arid grasslands, saltgrass, scratch grass (*Muhlenbergia asperifolia*), alkali grass, chino grama (*Bouteloua ramosa*), and toboso are the most common[13]. However, overexploitation of grasslands, adverse climatic conditions, and the introduction and invasion of exotic species such as the rose natal grass have caused a significant reduction of the state's grasslands[13], as well as the change of an association of *Bouteloua* - *Bothriochloa* grasses to another of natal grass/tanglehead (*Heteropogon contortus*)[14].

For the semi-arid grasslands of Zacatecas, the most common associations are *Aristida / Bothriochloa / Bouteloua* and other exotic grasses such as buffel, weeping lovegrass (*Eragrostis curvula*), lehmann lovegrass and natal grass, while in arid-halophyte grasslands the most common is the alkali sacaton[15]. In addition, most Zacatecas grasslands appeared to be in a moderate health state, although the properties of the soils are acceptable, the vegetation exhibits a high degree of deterioration[16].

In the case of the semi-arid grasslands of Aguascalientes, the dominant grasses are sprucetop grama, blue grama, and wolfgrass (*Muhlenbergia phleoides*), which exhibit a good condition, with 80% of the original vegetation, especially of the *Bouteloua* genus[17]. As for the state of Jalisco, *Bouteloua / Microchloa / Aristida* are the most prevalent communities in the semi-arid grasslands[18], which were in moderate to extreme health conditions in 2002[19], the main problem being the deterioration of the vegetation. In San Luis Potosí, the most common grasses are blue grama, wolfgrass, buffalo grass, and the invaders buffel and natal grass[20].

Unfortunately, a recent study indicates that overgrazing has impacted the composition of grasslands in central Mexico throughout history, but that it is still possible to improve the grasslands[(21)].

In the 1970s, the scrublands of the Sonoran Desert were represented by shrubs such as saguaro (*Carnegia gigantea*), burro-weed (*Ambrosia dumosa*), elephant tree (*Bursera microphylla*), ironwood (*Olneya tesota*), yellow paloverde (*Parkinsonia microphylla*), and the creosote bush (*Larrea tridentata*)[(6)]. Recent studies on the vegetation of Sonora indicate that the predominant shrubs in the central plains region are the ironwood and brittlebush (*Encelia farinosa*); in the central coast, the elephant tree and *Jatropha cinerea*; in the highlands, the yellow paloverde, *Cylindropuntia* , *Opuntia*, and saguaro, and in the Lower Colorado River Valley, the *Larrea* / *Ambrosia* association[(7)]. In the case of the xerophilous shrubs of the Chihuahuan Desert, the dominant species are the creosote, the tarbush (*Flourensia cernu*a), lechugilla (*Agave lechuguilla*), ocotillo (*Fouquieria splendens*), Chihuahua whitethorn (*Acacia vernicosa*), and others of the *Dasylirion, Opuntia*, and *Yucc*a genera[(6)]. At present, viscid acacia (*Acacia neovernicosa*), honey mesquite (*Prosopis glandulosa*), spiny allthorn (*Koeberlina spinosa*), guajillo (*Acacia berlandieri*) and Warnock's snakewood (*Condalia warnockii*) are also common, while in Coahuila there is also *Hechtia* spp, candelilla (*Euphorbia antisyphilitica*), leatherstem (*Jatropha dioica*) in the north, and *Allenrolfea* sp., *Atriplex* sp., *Suaeda* sp., and mesquite in the south[(22)]. Other dominant shrubs such as cenizo (*Leucophyllum frutescens*), mariola (*Parthenium incanum*), creosote bush, mesquite, lechuguilla, catclaw mimosa (*Mimosa aculeaticarpa*), guajillo, and *Gutierrezia microcephala* have also been reported in the xerophilous shrub of northern Coahuila[(23)]. For the more arid area of the Chihuahuan Desert in the south of San Luis Potosí, there are shrubs such as the creosote, tarbush, honey mesquite, and chamiso (*Atriplex canescens*)[(22)].

In Durango, xerophilous bushes are represented by creosote, tarbush, spiny allthorn, honey mesquite, leatherstem, candelilla, and *Opuntia*, as well as lechuguilla / guapilla (*Hechtia glomerata*) / Ocotillo associations, the latter species being dominant in the bushes of the north and center of the state of Durango, and the *Henricksonia* genus standing out as endemic to the Durango and Coahuila scrublands[(24)]. In contrast, the scrublands of Aguascalientes have diverse associations where the most common species are nopal cacti (*Opuntia* spp), catclaw (*Mimosa monancistra*), huisache (*Acacia schaffneri*), and creosote bush / mariola, exhibiting a high degradation and preserving only 20 % of its primary vegetation[(17).]

The availability of practical tools and methodologies is critical for documenting the changes in grasslands and scrublands due to the effects of management and climate. The use of remote sensors has been shown to be a practical tool for estimating forage / productivity and plant cover[(25,26)] and the extent and fragmentation of grasslands and shrubs[(27).]

Grazing management and utilization of grasslands and shrubs

The use of pasture forage resources as primary food is the basis of the cow-calf production system, as well as of the exploitation of goats and sheep under extensive conditions. The alarming deterioration of the grasslands has been largely attributed to the overuse of the resource; therefore, the development of an adequate grazing management program should be considered as preventive. This program is based on a series of principles already established and discussed by numerous authors[28,29], mainly highlighting: a) the use of the optimal stocking rate, b) the determination of the best grazing season, c) the implementation of the most appropriate grazing system, d) the use of the optimal species or combination of animal species, and e) the establishment of practices for a uniform distribution of grazing.

Since the 1980s, lines of research have been established to document the aforementioned aspects. The research results obtained during the first 50 yr of the La Campana Experimental Ranch, in the selection of the diet, the voluntary consumption of forage and the ethology of the cattle have been detailed by some authors[30]. Table 1 shows the ranges in some components of the diet selected by cattle, with a marked seasonal fluctuation in two types of grasslands and a scrubland that are representative of the state of Chihuahua[30]. Other research efforts on the grasslands of Jalisco[31,32] and a Baja California Sur scrub[33] report similar trends that reflect nutritional deficiencies in grasslands and scrubs during the dry season. Likewise, in a study carried out in a medium grassland invaded by catclaw and huisache, the diet of goats showed protein deficiencies during the dormant season of the grasslands of Guanajuato[34].

Table 1: Ranges reported in components of the diet of beef cattle in three types of vegetation in the state of Chihuahua

Component	Short grass prairie	Bunchgrass prairie	Creosotebush scrublands
Crude protein, %	4.9 – 11.5	5.3 – 11.8	6.5 – 12.5
Metabolizable energy, Mcal kg^{-1}	1.83 – 2.27	1.7 – 2.38	1.58 – 2.22
Digestibility, %	54.1 – 67.2	50.6 – 70.6	46.2 – 66.7

Chávez and González[30].

Within this context, voluntary forage consumption is undoubtedly the most important component in regulating the energy balance of grazing cattle. Likewise, it is an essential variable for a correct estimation of the carrying capacity of grazing lands. Several studies[35,36] have extensively reviewed the factors that control willing forage consumption, inherent to the animal and to the characteristics of the vegetation, justifying studies in this regard. Average consumption values fluctuate between 1.8 and 3.5 % of live weight, depending on the type of vegetation, the time of the year, and the physiological state of the cattle[30]. Close data were obtained in an oak-bunchgrass grassland of Chihuahua, reporting intakes of 2.6 and 3.1 % of live weight, for pregnant and lactating cows, respectively[37].

According to several authors, stocking rate is the most critical factor in the implementation of a grazing and utilization management scheme[4,38,39,40]. The first utilization studies carried out since 1965 at the La Campana Experimental Ranch, showed an increase in vegetation cover using moderate loads. The interaction between animal load and grazing systems has been evaluated[5], confirming the impact of stocking rate as a primary management factor. In regard to research on grazing systems, some authors have pointed out the statistical complexity and high costs of this type of study[41], which has been a limitation from a methodological and financial point of view. In general, rotational grazing systems have been used as a tool to counteract the unwanted effects of selective grazing[4]. However, the evidence generated during the last 60 yr does not indicate a superiority of rotational grazing over continuous grazing, and the supposed advantages of rotational systems are based more on the perception of "anecdotal interpretations" than on an objective evaluation of the experimental evidence[39]. Finally, research in grazing systems should not be focused about finding a best method, but to identify and quantify the grazing principles and processes that support an adaptive management and decision making[42].

In Jalisco, Deferred Rotational Grazing was found to preserve the condition of the pasture, compared to continuous grazing[43]. Short-term grazing systems (STG) have also been the object of evaluation, with not very favorable results. For example, this system exhibited a 49 % reduction in vegetation cover in a Chihuahua grassland[44]. This same negative trend for STG was observed after 12 yr of assessment in three grasslands and a Chihuahua scrubland[45], with a 75 % decrease in plant cover, while in continuous grazing (CG), a 124 % increase was obtained. Similar results have been reported in a 7-yr study in a semi-arid pasture in Jalisco[46], with biomass production reductions of approximately 72 and 43 % for STG and CG, respectively. In addition, an increase in forage availability has been observed at a greater distance from the water, reaching up to 110 % at 1 km from the center of the grazing cell, suggesting an inefficient distribution of grazing with STG in a Chihuahua grassland[44].

Genetic resources and grass varieties

The deterioration of grasslands has led to the need to conserve germplasm or diversity of forage genetic resources in order to search among them for plant alternatives that stabilize both the ecosystems and the economy of grasslands in Mexico[47]. To this end, INIFAP began to collect and evaluate germplasm of native and introduced grasses since the late 1970s, in collaboration with germplasm banks from different parts of the world. Some of the native species of greatest interest have been the sideoats and blue grama, and introduced species such as weeping lovegrass, wilman lovegrass (*Eragrostis superba*) and buffel. The germplasm was established in different states of Mexico, achieving greater persistence in the evaluations in San Luis Potosí, and, as a result, outstanding accessions were identified and later registered with the Seed Inspection and Certification Service (SNICS). In sideoats grama, accessions from different states of the republic have been evaluated, identifying several outstanding ecotypes for forage production such as INIA-235-ZAC, INIA-426-COAH, INIA-315-JAL, with values of 3.0 to 3.1 t of dry matter (DM) ha^{-1}, out of a total of 59 accessions(48); while, in San Luis Potosí, 147 accessions from several central states of the country were assessed and, as a result, the variety called "*Banderilla Diana*", with average yields in rain-fed conditions of 1.85 t DM ha^{-1}, with crude protein (CP) from 8.6 % in the flowering stage and 3.6 % in maturity(49). The "Cecilia" variety of blue grama was obtained through a selection program, where 53 genotypes from various states in the center of the country were evaluated. This variety can produce up to 0.98 t DM ha^{-1}, with 9.7 % CP in the flowering stage and 3.4 % in maturity(50). Regarding the introduced species, the weeping love grass of the "Imperial" variety was selected and registered, out of 205 evaluated genotypes. This variety can obtain an average yield of 1.2 t DM ha^{-1}, under rain-fed conditions. In addition, it has a CP content of 10.2 % at the beginning of flowering and 4.6 % at maturity(51). In the collection of wilman love grass, the outstanding accession of 14 genotypes was "Hercules", whose average yield in rain fed conditions was 1.2 t DM ha^{-1}, with 10.2 % CP at the beginning of flowering and 4.6 % at maturity(52). In the buffel grass germplasm, of the 78 evaluated accessions, two outstanding genotypes were identified and registered as "Titan" and "Regio". The yields recorded for these varieties were 2.12 and 2.25 t DM ha^{-1}, with 6.1 % and 5.8 % CP in flowering, and 5.8 %, and 4.0 % and 3.3 %, respectively, while in maturity(53). Varieties of buffel grass are available in northeastern Mexico; "Milenio", in the states of Tamaulipas and Nuevo León(54), and "Zaragoza 115" and "Zaragoza 119", in the state of Coahuila(55).

In recent years, vegetative material collections have been made and morphological, productive and genetic attributes of native grasses have been evaluated. For example, researchers from the College of Postgraduates (Colegio de Postgraduados) managed to identify and register the varieties NDEM-5, NDEM-125, NDEM-303, NDEM-417, and NDEM-LA ZARCA of sideoats grama(56). In Mexico, a wide genetic, morphological and productive diversity of this grass has been reported, with yields from 13.7 g to 1,213 g DM plant^{-1}, from a collection carried out in 13 states from Sonora to Guerrero(56,57). In addition, in a collection of 55 populations of sideoats grama from the state of Chihuahua, values of 4 to 260 g DM plant^{-1} were found(58). In a germplasm bank established in Zacatecas with 17 ecotypes, yields of 1,320 to 3,337 kg DM ha^{-1} were found during the rainy period(59). The morphological diversity within this species can be attributed to its great variation in the ploidy level[60], since other researches mention that the ploidy level can have effects on the anatomy, morphology, and physiology of plants[61].

Regarding blue grama, a great genetic diversity has been found within this species[62], which may be due to the fact that the center of origin of this species is located in central Mexico[63]. Likewise, there is the possibility of selecting high yielding blue grama germplasm, since from only 145 ecotypes collected in Chihuahua, a yield range from 0.3 to 48 g DM plant^{-1} in a single cutting was reported[64]. In Zacatecas, yields ranging from 842 to 1,957 kg DM ha^{-1} were observed in 20 genotypes[59]. A great genetic and morphological diversity has been found in Chihuahua in Arizona cottontop (*Digitaria californica*), reporting two outstanding accessions in forage production, out of 91 ecotypes collected[65]. For green sprangletop (*Leptochloa dubia*), a wide genetic variability was found in 32 genotypes, with yields ranging from 6 to 174 g DM plant^{-1}[66]. Finally, it was concluded that there is a wide genetic variation in plains brittlegrass (*Setaria macrostachya*), and three populations with forage potential were identified, from a collection made in 44 sites[67].

Grass seed production

The main value of the production of grass seeds lies in its use for the reseeding or rehabilitation of grasslands, but it also has a great value for the conservation of soils. However, the commercial production of grass seeds for semi-arid zones has been recently developed in Mexico. From 2001 to 2016, the National Catalog of Plant Varieties[68] has documented 27 varieties and hybrids of grasses, 12 of which are suitable for semi-arid areas and belong to five species. Therefore, it can be said that there already exists genetic material to produce qualified seed.

Research on production of grass seeds for arid and semi-arid zones date back to the 80s and can be seen in Table 2. These works have mainly determined the volume of production and quality characteristics of the seeds, in some cases with fertilization and irrigation trials. The two most studied species have been buffel grass and sideoats grama.

Table 2: Maximum seed production of different species of grasses in arid and semi-arid zones of Mexico

Especies	Variety/Accession	Seed production (kg ha^{-1})	Management	Reference
Panicum coloratum L.	Kleingrass 188	70.2	Rainfed. Fertilized.	Eguiarte and González[69]
	Buffel Zaragoza 115	100	With irrigation, Fertilized	Hernández *et al*.[55]
	Buffel Biloela	30.4	Rainfed. Fertilized.	Eguiarte and González[69]
	Buffel Milenio	182	Rainfed	Garza[54]
Pennisetum ciliare (L.)	Common buffel	324.0	With irrigation. Fertilized.	Sáenz-Flores *et al*.[70]
	Buffel Titán	527.0	With irrigation. Fertilized.	Beltrán *et al*[53]
	Buffel Regio	566.2	With irrigation. Fertilized.	Beltrán *et al*.[53]
Bouteloua gracilis H.B.K. (Lag.)	Cecilia bluegrama	414.0	With irrigation. Fertilized.	Beltrán *et al*.[50]
	Alma bluegrama	289.0	With irrigation. Fertilized.	Sáenz-Flores *et al*.[70]
Bouteloua curtipendula (Michx.) Torr.	(Sideoats grama ecotypes: INIA-365-NL, INIA-315-JAL, INIA-426-COAH, INIA-235-ZAC, INIA-263-ZAC)	326-374	Rainfed	Rubio[48]
	Chihuahua sideoats grama 75	922	With irrigation. Fertilized.	González[71]
	Sideoats grama AN Selección 75	752	With irrigation. Fertilized.	González[71]
	Diana sideoats grama	998.5	With irrigation. Fertilized.	Beltrán *et al*.[49]
	Niner sideoats grama	707.0	With irrigation. Fertilized.	Sáenz-Flores *et al.*[70]
	Diana Sideoats grama	1,305.1	With irrigation. Fertilized. One crop, second year	Velázquez *et al*.[72]

			after establishment.	
Leptochloa dubia (Kunth) Nees.	Van Horn green sprangletop	670.0	With irrigation. Fertilized.	Sáenz-Flores *et al*.[70]
Eragrostis curvula (Schrad) Nees	Imperial weeping lovegrass	685.0	With irrigation. Fertilized. One crop in a year.	Beltrán *et al*.[51]
Eragrostis superba (Peyr).	Wilman lovegrass	1619.0	With irrigation. Fertilized.	Sáenz-Flores *et al*.[70]
	Hercules wilman lovegrass	1651.0	With irrigation. Fertilized. One crop in a year.	Beltrán *et al*.[52]

Grassland seeding in arid and semi-arid zones

Considering the deterioration of grasslands and shrublands, grass seeding is a common practice to reverse this decay, which consists in establishing vegetation through the artificial dissemination of seeds of a single species or in a mixture, using adapted species and appropriate seedbeds. This is done in order to increase the productivity and quality of forage and stocking rate and diversification of diet for livestock, in addition to reducing erosion and invasion of less desired species; however, this practice is expensive and high risk. In general, range seeding is recommended in sites with areas with less than 15 % coverage of native grasses[73,74,75].

It is very important to use species adapted to the soil and climate conditions of the area to be rehabilitated. Native species adapt better to different climate and soil conditions and are more persistent; but they are more difficult to establish. Therefore, it is suggested that the origin of the seeds be not more than 300 km from the site where it is going to be seeded. In general, it is recommended to use a mixture of species, preferably native ones. The advantage of mixing is that the diversity of species can make better use of the variability in the soil conditions of the pasture lands[76]. The main forage grasses used for sowing are: sideoats grama and blue grama, among the native species, and weeping lovegrass, wilman love grass, and buffel, among the introduced ones[77].

The presence or lack of moisture in the soil is the most important variable for the establishment of grass seedlings. Therefore, the land must be prepared for sowing, which is known as "seedbed"; This has the function of loosening the soil, giving it greater porosity, so that it retains a greater amount of water, and providing more favorable conditions for the establishment of grasses in these environments[76,77].

There are many practices for replanting grasslands, ranging from subsoiling, plowing, disking, level borders, “lister” furrows, and the use of aerator roller, among other options. The latter carries out one of the fastest and most effective processes, especially in desert scrublands, as it increases the water infiltration capacity, reduces soil compaction[78], and has allowed a good grass establishment such as blue grama, sideoats grama, Arizona cottontop, and buffel[76,79,80] in Sonora, Chihuahua, and Coahuila. However, such practices as subsoiling plus plowing and disking also favor coverage with values up to 80 % and a yield of 5.0 to 13.6 t DM ha^{-1} in buffel grass in the states of Coahuila and Jalisco, respectively[81,82]. In the state of Sonora, total clearing has had repercussions on loss of soil and plant diversity; therefore, it should be avoided in the preparation of the seedbed[83]. Since the different sowing methods yield different results, it is considered necessary to emphasize that the practices should be adjusted to particular environmental conditions. On the other hand, it is advisable to turn over and break up the soil when wet and harrow it once or twice in order to make a good seedbed[84]. However, it is better to sow in wet soil at the beginning of the rainy season in order to increase the opportunity for the seed germination and plant establishment. The ground can be prepared in advance, by "scratching" counter slope or with plowing and disking. Dry sowing is more risky; therefore, it would be advisable to sow one or two weeks before the rainy season in order to prevent loss of seeds[77].

After seeding, during the first year the weeds can compete for light, space and soil nutrients, which will reduce the potential of the grasses. It is recommended to control the weed mainly with selective herbicide. From the second year on, in order to keep forage production in good condition, it is recommended to carry out chemical or manual weed control tasks at the beginning of the rainy season, although this is a costly practice[77]. However, it is recommended for the control of shrubs when their density increases.

Fertilization will depend on the amount of precipitation; in very dry years with rainfall under 200 mm, it is not recommended to fertilize. In the first year, fertilization is carried out with the 20-20-00 formula and only when the moisture condition is favorable. Once the grass is established, it is suggested to fertilize every year[77]. However, fertilizers must be applied sparingly due to high costs and to the temporal and spatial variability of rainfall. Other options with good results in seeding native grasses are the application of biofertilizers[85] and organic by-products such as biosolids[86].

Carbon storage and sequestration in grasslands and scrublands

Like forests, grasslands and shrubs can provide various environmental services for society, including carbon sequestration. Currently, the world's grasslands have good potential for climate change mitigation through carbon sequestration(87,88), which could reach up to 148 Tg CO_2 year^{-1} through the implementation of grazing management strategies(88).

In Mexico, the grasslands with moderate grazing contain a greater store of soil carbon (800 g C m^{-2}) compared to grasslands that have been overgrazed (650 g C m^{-2})(89). Another study(90) found similar results, detecting higher carbon stores in moderately grazed grassland soils with a high cover of forage grasses compared to overgrazed grasslands with a low plant cover, at an average of 34.5 and 24.3 t C ha^{-1} to 0.3 m in semi-arid and halophyte grasslands, respectively. Considering a soil carbon sequestration capacity of 0.1 t C ha^{-1} yr^{-1}(91) and an area of 9.77 million ha, the semi-arid grasslands of Mexico could capture about 3.5 Tg CO_2 yr^{-1}, with appropriate management of grazing. Regarding the bushlands, no great differences were found with grazing, although the soil carbon stores are low with 21.7 and 23.0 t C ha^{-1} at 0.3 m deep in the creosotebush and lechuguilla bushes, respectively, in the Chihuahuan Desert(90). Semi-arid areas store more carbon than arid areas of Mexico, and in the grasslands, the soil stores 90 % of carbon, while scrubland soil stores only 45 % of carbon(92).

In regard to carbon sequestration, it has been reported that native or natural grasslands are carbon sinks, since they can capture up to 0.054 t CO2 ha^{-1} d^{-1}(93). Other authors(94) conclude that the carbon sequestration potential of biomass in induced grasslands varies from 0.99 to 1.51 t CO_2eq ha^{-1} yr^{-1} after 30 and 10 yr of abandonment, respectively. Contrary to expectations, a semi-arid grassland with high plant cover showed to be neutral as a carbon source, and grassland with low plant cover showed to be a carbon sink, while the species composition did not influence the carbon balance(95). Furthermore, another study concludes that semi-arid grasslands could shift from carbon sinks to carbon sources due to the effects of climate change(96).

Although digital images and regression models, exhibited a low adjustment, they have a potential for the prediction of soil carbon levels(97). Other authors propose an ecological model for estimating soil carbon in semi-arid grasslands, with variables such as forage grass cover, mean annual rainfall, and soil sand content(98).

Challenges and perspectives

Given the great reduction in the areas of grasslands and scrublands, as well as their high deterioration, it is urgent to stop the advance of the agricultural frontier and avoid overgrazing. Thus, it is urgent to comply with current federal and state laws on conservation and sustainable use of ecosystems, as well as a rural technology transfer program in order to train and educate all ranchers on the sustainable management of grasslands and shrubs in the north-central region of the country. Technologies such as the use of images and geographic information systems are currently available for monitoring and evaluating grasslands and scrublands. However, it is important to continue with the development of technologies that allow finer detection of the processes and structure of grasslands, such as the identification of plants at ground level, in order to facilitate small and large scale decision making.

Regarding the use of grasslands, it is urgent to implement grazing management strategies that adapt to the vegetation and climate conditions of each ranch, but, above all, an adjustment of the stocking rate that will allow a moderate use of the grasslands. It is also necessary to reactivate studies of diet quality, selectivity, forage consumption and grazing management strategies to achieve efficient use of resources and the response of vegetation, in a more ecological approach, and in order to maximize animal production and rangeland conservation.

In regard to the conservation of genetic resources, more than 1,200 ecotypes of native and introduced grasses have been assessed(48-53,56,57,58). However, up to date, only eight varieties of sideoats grama, eight of buffel grass, and one of each of the blue grama, weeping and wilman love grasses have been generated(99). For this reason, it is important to design financing strategies that will allow to continue performing diversity studies and implementing grass genetic improvement programs. In addition, it is necessary to search for other forage species that grow in arid and semi-arid Mexico, since more than 300 species of grasses have been reported to exist in these regions(13). These actions would allow the generation of new grass varieties, with good potential for establishing and producing forage in the face of the challenges of climate change.

Native grass seeds can be produced with currently available technologies at a lower cost than imported seeds although the main challenges are to reduce production costs, and increase seed yield and quality. In the immediate future, more research should be done on the seed vigor, scarification and coating and fixation of products such as nutrients or insecticides in the seeds in order to improve their performance in the field. Subsequently, the generation of technological guides for seed production of different grasses is essential, evaluating the use of agronomic practices and mechanization of seed harvesting and processing.

For the range seeding, it is recommended to revegetate degraded pastures, preferably with native plants, in order to recover their structure and functioning for the production of goods and services for society. In this activity, the availability of seeds of native species is a great challenge to solve, because, although certain varieties have been released by INIFAP and other institutions, such as blue grama and sideoats grama, the available quantity is insufficient to meet the demand. Establishing seed production lots with cooperating producers is a viable option. Secondly, there is a pressing need to design simple, practical and low-cost equipment for the preparation of land for range seeding.

In regard to carbon capture in grasslands and scrublands, the implementation of moderate grazing in “ejidos” and cattle ranches is urgently needed in order to reduce carbon emissions and increase carbon sequestration. Some important challenges are to generate reliable, fast and simple methodologies for the estimation of carbon sequestration and carbon pools, to include the sustainable management of grasslands and shrublands as an option for buyers of carbon credits in official or voluntary markets, and to promote the advantages of grazing management to increase carbon sequestration through sustainable cattle raising.

Climate change is already affecting grasslands and will directly and much more dramatically reduce the productivity and contribution of environmental services from the grasslands and scrublands of northern Mexico. This will impact the carrying capacity of rangelands with reductions in meat production, loss of biodiversity, decrease in carbon sequestration capacity, and effects on the hydrological cycle of these ecosystems. The new climatic conditions make it necessary to carry out comprehensive research studies in order to find options for the management and rehabilitation of these ecosystems according to these changes.

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