Rehabilitation of degraded pastures in the tropics of Mexico

Javier Francisco Enríquez Quiroz [a*]

Valentín Alberto Esqueda Esquivel [b]

Daniel Martínez Méndez [c]

[a] Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias (INIFAP). Campo Experimental La Posta, Km. 22.5 Carretera Federal Veracruz-Córdoba. 94277, Medellín, Veracruz, México.

[b] INIFAP. Campo Experimental Cotaxtla, Medellín, Veracruz, México.

[c] Centro de Bachillerato Tecnológico Agropecuario 251. General Felipe Ángeles, Oaxaca, México.

*Corresponding author: enriquez.javier@inifap.gob.mx

Abstract:

Extensive livestock production systems are common in Mexico. Overall, livestock production uses about 108.9 million hectares nationally, which represents over half (55.5 %) of the country's surface area. Approximately one quarter of Mexico is in the tropics and livestock grazing is one of the most important economic activities in this region. In at least 24 states the cattle population is estimated to exceed grassland carrying capacity based on forage production. This situation results in gradual grasslands degradation and a consequent decrease in forage productivity. It also reduces the products and services obtained from them, primarily forage, meat and milk, but also water and recreational space. Grassland rehabilitation research has been active in Mexico for at least ten years, and has mainly focused on weed control by mechanical and chemical means, which provide satisfactory short-term results. However, grassland degradation continues in Mexico due to inadequate pasture management, particularly in the form of animal loads in excess of pasture forage production capacity. This review provides an overview of grassland degradation, mainly in

Mexico's tropical regions, summarizes grasslands recovery research by the INIFAP, and analyzes medium- and long-term prospects.

Introduction

Constant worldwide population growth drives a need for increasing food production. By 2050 there will be an estimated 9.6 billion inhabitants on the planet (more than 2 billion more than in 2021), and they will have fewer available resources and will need to generate less pollution[1]. Over the last 40 yr, world meat production has increased 90 percent, and in the tropics that increase has been as much as 200 %[1]. In Mexico, around 108.9 million hectares are used for livestock production, an area representing 55.5 % of the country's total surface area[2]. The national cattle population consists of 32.6 million head, highlighting the importance of this industry[3]. Livestock production occurs in all of Mexico's ecosystems, but is particularly prominent in dry and humid tropical zones. Approximately 40 % of national meat production and 18 % of dairy production occur in these zones[4]. Around 56 million hectares are used for livestock production in these regions, of which more than 23 million hectares are for grazing[5]. The main source of feed for cattle in these regions is forage produced in pastures, and consumed directly by the animals. This is the most cost effective means of transforming grassland biomass into high nutritional quality food, such as meat and milk. In at least 23 states cattle population exceeds environmental carrying capacity in terms of forage production in pastures; in other words, overgrazing is common[6]. Pastures gradually degrade under these circumstances, progressively producing less forage, water and recreational space. As a consequence, meat and milk production decrease. This review summarizes the factors that affect pasture degradation and discusses potential solutions to this problem, in addition to presenting the results of INIFAP research on grasslands rehabilitation in the Mexican tropics.

Grasslands

Grasslands, a vegetation type dominated by grasses, are present on five continents, cover a quarter of the earth's surface, and contribute to the livelihoods of more than 800 million people[7]. The main source of feed in animal production systems involving ruminants is forages produced on native and cultivated grasslands as well as agricultural land[8]. Future grassland health will clearly be an essential element when considering how to feed the nine billion people who will inhabit the planet in 2050[9].

Grasslands provide numerous environmental services, ranging from ground cover to prevent wind and water erosion, to recreational space and habitat for ornamental and medicinal plant species[10]. Grasses are also effective at retaining water[11], especially when in good condition, because they improve soil filtration[12]. Grasslands can potentially sequester carbon, particularly when moderately grazed[12], and this capacity is augmented if they are associated with legumes[13].

Grasslands in Mexico

The cattle industry in Mexico includes approximately 1.4 million ranches, feedlots, multi-purpose companies and other parties[3]. Carcass meat production in 2019 was 2.027 million tons, and per capita domestic beef consumption was 14.9 kilograms. In the same year, milk production was 12.275 million liters, which is 16th worldwide, and per capita domestic consumption was 95.1 L.

As a percentage of total national production, forage accounts for 42 % and livestock for 8 %. Of these totals, the Northwest region represents 7% of forage production and 6 % of livestock, the Northeast 24 % and 22 %, the Central Western 37 % and 43 %, the Center 11 % and 12 %, and the Southeast 20 and 16 %[2]. In Mexico's tropical regions, more than 50 % of the surface area is used for livestock activities in four states: Tabasco (65.7 %); Tamaulipas (58.2 %); Sinaloa (50.6 %); and Veracruz (50.2 %)[2].

Forage production in Mexico

Annual forage production in Mexico is 183 million tons (dry matter). In general terms, 42 % of this total is produced in pastures, 29 % is from native grasslands, 24 % comes from

agricultural waste and 4.9 % from forage crops[14]. In other words, pastures and native grasslands account for 71 % (136 million tons) of total forage production. However, if adequate management strategies were employed, only a maximum of 60 % (82 million tons) of pasture and native grasslands production would be used, whereas all forage crop and agricultural waste production (55 million tons) would be used. Under this scenario, therefore, Mexico would produce 137 million tons of usable forage. Currently, approximately 34 million animal units use about 170 million tons of forage annually, meaning that there is an annual forage production deficiency of 33 million tons. These figures suggest that in Mexico an excess of animal units is resulting in overexploitation of grazing lands, with serious consequent damage and deterioration of natural resources[15].

Tropical regions

Mexico's humid tropical regions cover 23.9 million hectares[16]. These regions are defined by annual rainfall greater than 1,300 millimeters and an altitude of less than 1,000 meters asl. Dual-purpose and beef cattle ranching is common in these regions and utilizes pastures with a high proportion of introduced or improved grasses[16,17]. Dry tropical regions cover 31.7 million hectares. These are defined as having annual rainfall of 600 to 1,300 millimeters, and can range in altitude from sea level to 2,000 m asl. Cattle production in these areas is largely of calves for growing[16,17]. In both the humid and dry tropics the area covered by introduced grasses, particularly *Brachiaria* sp., has been increasing since seeds were first marketed in 1999. Based on the quantity of seed sold in 2004, an estimated 2,616,130 ha were planted with introduced grasses in the tropics[18,19]. From 2004 to 2020, new pasture coverage has increased substantially as different species and cultivars are planted. A particularly popular species is *Meghatyrsus maximus* (Jacq.) BK Simon & SWL Jacobs, of which the Mombasa and Tanzania cultivars are used. Other grasses planted for their vegetal material production include the harvest forages *Cenchrus purpureus* (Schumach.) Morrone, which has several cultivars apt for intensive planting, pangola grasses (*Digitaria eriantha* Steud.) and African star grass [*Cynodon plectostachyus* (K. Schum.) Pilg.]. All these species and cultivars provide higher forage productivity and quality than native grasses, and have contributed to improving livestock productivity in tropical areas.

Issue overview

From 2010 to 2050, global consumption of meat is projected to increase by 173 % and that of dairy by 158 %; both increases are expected to be much higher in developing countries[20].

Raising production to meet these increases will require greater availability of animal feed. This could, in turn, drive conversion of high-value biomes into grazing land, exerting ever greater pressure to overgraze in livestock production systems based on native grasslands or cultivated pastures[21]. Recent decades have seen a steady degradation of grasslands due to overgrazing, which is the leading cause of damage in all major biomes. Worldwide estimates are that about 20 % of pastures and 73 % of native grasslands have been degraded[22]. In Central America, an estimated 50 to 80 % of grassland areas are in an advanced state of degradation, and can only support an animal load 40 % less than more recently established, properly managed pastures[23]. Grasslands are degrading at a rate of 12 %, and the renewal rate is 5 %, representing a net loss[23,24]. Since overuse of pastures and native grasslands is a major limiting factor in cow-calf and dual-purpose systems, the Forage and Pastures Program of the INIFAP has made rehabilitation of degraded pastures a research priority[25].

Causes of pasture degradation

Pasture degradation due to improper management begins with loss of plant vigor, manifested in narrower leaves, low greenness index values and declines in regrowth capacity (Figure 1). Forage species experience a consequent loss in aerial cover, allowing weed growth or leaving bare soil, which favors compaction by animal trampling and erosion[26,27].

Figure 1: Causes of degradation in tropical grasslands
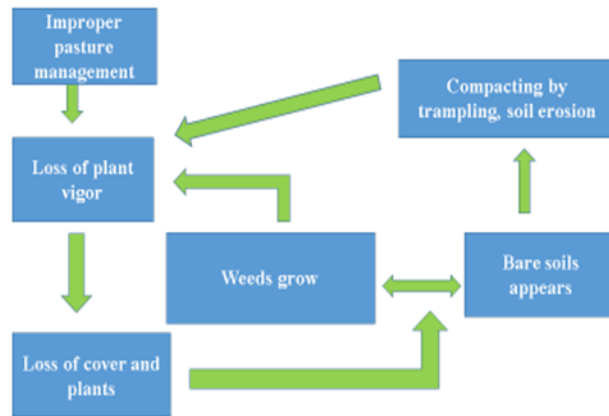
Six criteria are used to evaluate a degraded pasture: 1) Decreased forage production and quality; 2) Decreased vegetation cover and plant density; 3) Fewer new plants from natural propagation; 4) Soil erosion from rainfall; 5) Presence of broad- and narrow-leaf weeds not

consumed by animals; and 6) Colonization by native grasses[27]. The degree of grassland degradation can be classified into four major categories based on the percentage of area occupied by invasive plant species: 1) Productive grasslands, 0 to 10 % invasive species cover; 2) Mild degradation, 11 to 35 %; 3) Moderate degradation, 36 to 60 %; and 4) Advanced degradation, 61 to 100 %[27]. Another four-level classification system is based on the qualitative criterion of plant color, and the quantitative criteria of dead matter, bare soil and weed coverage (%), as well as pasture age (Table 1).

Table 1: Four-level pasture degradation scale based on qualitative and quantitative parameters

Parameters	Degradation Level			
	1 None apparent	2 Low	3 Moderate	4 Severe
Plant color	Dark green	Light green	Green/yellow	Yellow
Dead matter, %	<10	11-20	21-30	> 30
Bare soil, %	<10	11-20	21-30	> 30
Weeds, %	<10	11-20 narrow-leaf weeds	21-30 wide-leaf weeds	> 30 native grasses
Age, years	1-3	4-6	7-9	> 10

Pastures at level 1 (None apparent) include grasslands of one to three years of age (since establishment), intense green leaves and values less than 10 % of dead matter, bare soil and weeds. At the other extreme, pastures at level 4 (Severe) are older than 10 yr, have a yellow leaf color, greater than 30 % dead matter, bare soil and weeds, as well as high native grass colonization[23].

Pasture productivity can decline in response to numerous factors that can cause degradation, including use of species unsuited to environmental conditions; poor grazing management (characterized by overgrazing, especially in low rainfall periods); pest and disease incidence; planting in areas with fragile soils; soil nutrient depletion due to nutrient extraction (higher in improved grass species) and minimal or no fertilizer use; high herbaceous plant and shrubby weeds infestation; and indiscriminate burning[28,29,30]. Poor grassland management, especially in the form of low fertilizer use and overgrazing, will eventually result in decreased grass growth rate, mainly due to nitrogen and phosphorus deficiencies in soils[31]. Grassland degradation reduces animal production rate and increases costs, making it a financial and ecological problem[27].

Pasture use-life

Grassland use-life varies between countries in response to various factors. After pasture establishment in the Amazon region of Brazil, production gradually decreases under traditional management conditions, and can be characterized in four phases: 1) high productivity (3-5 yr after establishment), loads >1.5 animal units (AU); 2) medium productivity (4-7 yr), loads >1 AU; 3) low productivity (7-10 yr), loads = 0.5 AU; and 4) degraded (7-15 yr), animal load <0.3 AU[32]. A study done in Honduras estimated that grasslands have a use-life of ten years, although there were differences caused by grass species; the shortest use-life was nine years with *Brachiaria humidicola* (Rendle) Schweick and *Digitaria swazilandensis* Stent, and the longest was twelve years with *C. plestostachyus*[23]. No scientific research has been published on pasture use-life in Mexico, but personal observations and personal communication with producers suggest that a *D. eriantha* pasture has a use-life of eight to ten years, while one planted with *B. humidicola*, *B. decumbens* and/or *B. brizantha* has one in excess of ten years. The discrepancy between use-lifes may be due to differences in soil fertility requirements and pasture management. For instance, *D. eriantha* requires highly fertile soils, *B. brizantha* medium fertility soils and *B. humidicola* can grow in low fertility soils. For optimum productive performance, each species must be planted in soils with the appropriate fertility level. Overall, the use-life of improperly managed tropical grasslands would probably average about eight years.

Rehabilitation strategies for tropical grasslands

Various factors must be considered if a grassland is to recover, including soil physicochemical factors, plant species, and how degraded are the grass species to be restored. What recovery treatment is most apt for a degraded pasture and its cost will depend on the degree of pasture degradation. When degradation is not too advanced (e.g. <10 % broadleaf weed cover), techniques can be applied to recover pasture production capacity, but when degradation is severe it is usually most viable to establish a pasture anew. Some of the practices used to increase the population and production of desirable species are agricultural, such as improving soil physical properties, fertilization, weed control and replanting[27].

Fertilization is vital to pasture rehabilitation. After many years of grazing or cutting, soils can become depleted, biomass production begins to decline and desired grasses are replaced by other species. One study of a pasture with 20 % *B. decumbens* cover and native grasses on the remainder evaluated different treatments, including soil preparation or removal systems, and fertilization with only 22 kg ha^{-1} phosphorus or complete formulas (22 kg ha^{-1}

P, 45 kg ha^{-1} N, 25 kg ha^{-1} K-CaO, 28 kg ha^{-1} MgO and 15 kg ha^{-1} S)[33]. Fertilization increased average *B. decumbens* coverage up to 72 % while the control without fertilizers reduced *B. decumbens* to 18 %. Forage production in the control was 844 kg ha^{-1}, with phosphorus only fertilization it was 3,386 kg ha^{-1}, and with complete fertilization it was 4,266 kg ha^{-1}. Soil preparation and removal systems had no effect on pasture recovery, possibly because these techniques function better with stoloniferous plants since their removal encourages replanting of stolons.

These results coincide with two other studies. One, of a degraded *B. decumbens* pasture with over ten years of use, evaluated application of macro- and micronutrients and field tilling. Recovery was best when macro- and micronutrients were applied, while tilling negatively affected root development and dry matter production and had no effect on pasture recovery[34]. The negative response was due to destruction of plants during the tillage process, preventing any response to the fertilizers. Another study found that tilling alone has no significant effect on pasture recovery in nutrient-deficient soils, so this practice requires post-tillage fertilizer application. In the absence of fertilization, mechanical treatments made no improvement to pasture development or productivity[35]. Stoloniferous grasses such as *D. eriantha* and *C. plectostachyus* may be the exception since they benefit from tilling as a recovery technique as this results in overseeding.

The planting of legumes is a viable technique for rehabilitation of degraded *B. brizantha* meadows. One study in Brazil found that manual sowing of legumes and fertilization with 50 kg P increased dry matter production[36]. Another study of a degraded *Hyparrhenia rufa* (Nees) Stapf pasture more than 15 yr old and with 60 to 70 % weed cover evaluated three recovery methods (weed control; weed control + P fertilization + legumes; and weed control + planting *B. humidicola* + legumes), low and high animal loads, and continuous and rotational grazing[37]. The most efficient method for recovery or replacement of the degraded *H. rufa* pastures was weed control + planting *B. humidicola* + legumes, since this produced a larger quantity of forage with better chemical composition, allowed for a higher animal load and resulted in greater animal weight gain. Because of its aggressiveness and broad adaptation, as well as its association with legumes, *B. humidicola* produced better quality forage which resulted in higher animal production parameter values than in the other treatments.

Pasture rehabilitation using chemical weed control

High weed concentrations are characteristic of degraded grasslands. Weeds occupy the spaces left by grasses to the point where competition for water, light and nutrients becomes critical[38]. Suites of weed species make more efficient use of these resources than do grasses, because they encompass different species with different needs and abilities in conjunction with non-uniform spatial distribution and development stages[39]. These qualities allow them to more efficiently explore the environment in search of the elements essential to growth, thus reducing availability for grasses[40,41]. Although both monocotyledonous and dicotyledonous weeds can occur in pastures, the latter are generally more important because they have greater diversity and frequency of appearance[42,43]. On occasion grass weeds can become dominant[44].

Competition from weeds causes a reduction in pasture grass development and vigor, which is reflected in lower forage yield. For example, three studies evaluated three locations with Aw climates in the center and north of the state of Veracruz, Mexico, with the grasses *Digitaria decumbens* Stent., *Andropogon gayanus* Kunth. and *C. plectostachyus*[45]. In different evaluation stages uninterrupted competition from weeds caused reductions in pasture dry biomass production ranging from 54 to 80% in *D. decumbens*[45], from 61 to 81 % in *A. gayanus*[46] and from 57 to 84 % in *C. plectostachyus*[47]. In addition, in *A. gayanus* this competition resulted in a significant reduction in crude protein content after 163 days. In *C. plectostachyus*, reductions in crude protein content were observed after 155 and 224 d.

In a study of *Urochloa brizantha* grass (Hochst. Ex A. Rich) RD Webster in Mato Grosso, Brazil[48], in which weed competition was allowed for 15 d from emergence, reductions were observed of 30.8 % in grass height and 9.5 % in number of tillers. When the competition period was extended to 60 d, grass height declined by 51.1 % and number of tillers by 35.7 %. Competition also resulted in declines in pasture dry biomass of 50.2 % at 15 d and 69 % at 60 d. In another study done in the same pasture[49], weed competition was found to reduce leaf/stem ratio values in a manner directly proportional to competition period. Furthermore, grass crude protein content declined by 7 to 33 % at periods of 60 d or longer.

Of all the effects of weed competition loss of pasture productivity has the most serious impact because it reduces forage availability for livestock. However, some weed species can also cause negative physical effects from stinging thorns or trichomes, or poisoning from intake of bioactive compounds[50,51].

The severe agricultural, financial and livestock health problems caused by weeds highlight the need for their timely control before they can affect pasture productivity and quality.

Several factors influence when control should be implemented, including weed species and density, grass variety and agroclimatic conditions, especially temperature and relative humidity. For example, in warm weather conditions in *U. brizantha* pastures weed control must be done at no later than 9[52], 15[48] or 30[49] days grass-weed coexistence, while in *U. ruziziensis* (R. Germ. & CM Evrard) Crins pastures it should be done before 22 d coexistence[53].

The most widely used methods for weed control in pastures and paddocks are manual or mechanical clearing and application of selective herbicides. Clearing does not completely eliminate weeds, can affect both weeds and grasses and is only a temporary measure. Herbicides are more efficient than clearing because they can completely eliminate weeds without causing significant damage to grasses. The herbicides 2,4-D, picloram, fluroxypyr, aminopyralid and triclopyr are widely used in pastures and grasslands. They are applied alone post-emergence or mixed to function as growth regulators. Metsulfuron-methyl, an amino acid synthesis inhibitor, is also widely used[54]. To avoid or minimize their environmental effects, herbicides need to be applied correctly and using the concentrations, periodicity and seasons recommended by the manufacturer. Workers who apply chemical herbicides should wear appropriate protective clothing to reduce the risk of contamination or poisoning.

Several cases of herbicide use in the rehabilitation of degraded tropical grasslands have been reported in Mexico. One study evaluated application of herbicides (2,4-D, picloram+2,4-D, metsulfuron-methyl, or aminopyralid+metsulfuron-methyl) and clearing for weed control in a pasture in the municipality of Medellín, in the state of Veracruz, with an initial coverage of 27 % *U. brizantha*, 15 % other grasses, 56 % weeds and 2 % bare soil. Thirty days after application, the herbicide treatments reduced weed cover an average of 3.8 % and increased *U. brizantha* cover to 88 %; the latter was as high as 98.3 % after 75 d. In contrast, thirty days after clearing weed coverage was 67%, but dropped to 33% after 75 d, while *U. brizantha* coverage was 12 % at 30 and 54 % at 75 d. These differences were reflected in average dry biomass *U. brizantha* production at 75 d, which ranged from 5,475 to 6,381 kg ha^{-1} in the chemical control treatments but was only 1,448 kg ha^{-1} in the clearing treatment[55]. Another study also done in Medellín evaluated application of herbicides (metsulfuron-methyl, 2,4-D and a formulated mixture of picloram+2,4-D) to a pasture with an initial coverage of 23 % pangola grass (*D. eriantha*) and 33 % *Baltimora recta* L.[56]. Compared to a control treatment without herbicide application, after 30 d the herbicide treatments had controlled *B. recta* by more than 90 % and average *D. eriantha* dry forage yield was 51.9 % higher. In a final example, a study was done in a degraded *C. plectostachyus* pasture on the effects of three herbicide mixtures (picloram+2,4-D; aminopyralid+2,4-D; and aminopyralid+fluroxypyr-meptil+2,4-D) in controlling three brush species: *Sida acuta* Burm. F. (66.3 % initial coverage), *Sida rhombifolia* L. (62.5 %) and *Jatropha gossypifolia* L. (42.5 %)[57]. The best control at 45 days was exhibited with the aminopyralid+fluroxypyr-meptyl+2,4-D mixture, which allowed 22.8 % more average grass dry matter production than the picloram+2,4-D mixture, 15.2 % more than the aminopyralid+2,4-D mixture and 199%

more than in the control with no herbicide application. Chemical weed control is clearly the most effective strategy for tropical grassland rehabilitation since it results in much better control than manual or mechanical methods, with consequently higher forage production and quality.

Challenges in and outlook on pasture rehabilitation in Mexico

Short-term (5 years). The expectation is that the data generated on grassland rehabilitation will be well known throughout the tropics and be applied to mitigate the impacts of degradation. This will need to be accompanied by adjustments in animal load and grazing management, the two main causes of pasture degradation. Technicians and producers will require effective training to understand and apply these latter two adjustments. Further research is needed on the economic losses and social costs of pasture degradation on Mexico's livestock industry.

Medium-term (10 years). Massive expansion and opening of new grasslands in the Mexican tropics began with the National Clearing Program implemented by the Ministry of Agriculture and Livestock in the 1970s. In other words, many areas in this region have been under livestock grazing for almost 50 yr. For this reason, research is needed on other factors that affect grassland degradation, such as loss of fertility in soils and their depletion, which result from long-term cutting or grazing of grasslands in the absence of fertilization. Compaction from animal traffic also degrades pastures by reducing the depth to which roots can penetrate the soil, lowering water infiltration rates and generating laminar erosion. To stabilize grasslands and promote a sustainable productive environment, further research is needed to develop rehabilitation methods that involve mechanical means of decompressing soil accompanied by correction of soil nutrient deficiencies, be it via chemical, organic and/or biological means (e.g. legumes).

Long-term (20 years). The overall goal for livestock production in Mexico is self-sufficiency, that is, to meet domestic market demand for meat and milk products. Attaining this goal will involve creating safe products, generating greater profits for the livestock industry and preventing environmental degradation. New technologies will become tools to reverse the pasture degradation caused by ongoing poor management. Multidisciplinary research teams and sufficient long-term financial commitments will be needed to reach this goal, as will infrastructure to carry out innovative technological research applicable to conditions in the Mexican tropics.

Conclusions

The degradation of tropical grasslands in Mexico is the consequence of continuous overexploitation. For decades, animal load has far exceeded pasture capacity and no effort has been made to return nutrients to the soil through fertilization. Chemical control of weeds has proven to be the most efficient method for rehabilitating degraded pastures; indeed, pastures recover high forage production capacity after only one to two cycles of selective herbicide application. Once rehabilitated, however, pastures need to be maintained by implementing grazing strategies that acknowledge seasonal forage production patterns, consider animal load, and return nutrients via chemical or organic fertilizers. Numerous facets of grassland productivity remain to be studied, such as maintenance fertilization of grasslands based on grass species or cultivar nutritional requirements; optimal practices in silvopastoral systems, which are promising sustainable animal production systems in the tropics; optimizing production at cattle ranches; and the best training methods for technicians and producers. Comprehensive research approaches will be needed in grasslands management and rehabilitation to work towards a livestock industry that is both financially profitable and ecologically sustainable.

Acknowledgements

Conflicts of interest

The authors declare no conflict of interest with the research reported herein.

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