**DOI:** https://doi.org/10.29298/rmcf.v9i47.166

Article

# Contenido de nitrógeno en regosoles bajo manejo en matorral desértico micrófilo y rosetófilo

# Nitrogen content in regosols under management in microphyllous and rosetophyllous desert shrubs

Rodolfo Alejandro Martínez Soto[1], María Inés Yáñez Díaz[1], Israel Cantú Silva[1*], Humberto González Rodríguez[1], José Guadalupe Marmolejo Moncivais[1], Karla Estrella Díaz García[1]

**Resumen**

Las actividades antropogénicas han sido factor de la degradación de los recursos naturales, por lo que se han implementado técnicas mecánicas y naturales como el rodillo aireador y el fuego, para disminuir su impacto. Se evaluó el contenido del nitrógeno total en un suelo Regosol presente en el Desierto Chihuahuense, con vegetación de matorral desértico micrófilo (MDM) y matorral desértico rosetófilo (MDR), bajo tratamiento de manejo con rodillo aireador en tres fechas diferentes: 2004 (RA-04), 2008 (RA-08) y 2011 (RA-11); además de un área incendiada en 2011 (IN-11) y una testigo (T). En cada sitio se recolectaron cuatro muestras compuestas de suelo en profundidades de 0-15 y 15.1-30 cm, para un total de 80, las cuales se analizaron por el método *Kjeldahl*. Los contenidos de nitrógeno, en promedio, en el MDM fueron: T= 0.174 %, RA-04= 0.087 %, RA-08= 0.080 %, RA-11= 0.261 % e IN-11= 0.195 %; mientras que para el MDR se obtuvo T= 0.075 %, RA-04= 0.125 %, RA-08=0.082 %, RA-11= 0.170 % e IN-11= 0.178 %. Con base en el análisis de varianza hubo diferencias ($p \leq 0.05$) por tipo de vegetación y tratamiento, no se observó un efecto por profundidad. Los valores fueron de clasificación baja (MDM RA-08, 15.1-30 cm = 0.051 %) a muy alta (MDM RA-11, 0-15 cm = 0.309 %). En ambos, los contenidos de nitrógeno total variaron, considerablemente, después de los tratamientos mecánicos, dado que el Nt aumenta o disminuye, en relación al tratamiento aplicado y al tipo de vegetación.

**Palabras clave:** Incendio, matorral micrófilo, nitrógeno, matorral rosetófilo, Regosol, rodillo aireador.

**Abstract**

The anthropogenic activities have been a factor in the degradation of natural resources, and therefore natural and mechanical techniques such as the roller aerator and fire have been implemented in order to reduce their impact. The content of total nitrogen content was assessed in a Regosol soil present in the Chihuahuan Desert, with microphyllous (MDS) and rosetophyllous desert shrubs (RDS), under treatment with roller aerator on three different dates: 2004 (RA-04), 2008 (RA-08) and 2011 (RA-11), as well as an area burnt in 2011 (BA-11) and a control area (C). Four composite samples of soil were collected at depths of 0-15 and 15.1-30 cm in each of 80 sites, and they were analyzed using the Kjeldahl method. The average contents of nitrogen in the MDS were: C= 0.174 %, RA-04= 0.087 %, RA-08= 0.080 %, RA-11= 0.261 % and BA-11= 0.195 %, whereas for the RDS they were C= 0.075 %, RA-04= 0.125 %, RA-08=0.082 %, RA-11= 0.170 % and BA-11= 0.178 %. Based on the variance analysis, there were differences ($p \leq 0.05$) by type of vegetation and treatment; no depth-related effects were observed. The values were rated low (MDS RA-08, 15.1-30 cm = 0.051%) to very high (MDS RA-11, 0-15 cm = 0.309 %). In both, the total nitrogen contents varied considerably after the mechanical treatments, as the tN increases or decreases according to the applied treatment and to the type of vegetation.

**Key words:** Fire, microphyllous desert shrubland, rosetophyllous desert shrubland, nitrogen, Regosol, roller aerator.

Fecha de recepción/Reception date: 14 de diciembre de 2017
Fecha de aceptación/Acceptance date: 14 de marzo de 2018

[1]Facultad de Ciencias Forestales, Universidad Autónoma de Nuevo León, México.
*Autor por correspondencia, correo-e: icantu59@gmail.com

# Introduction

The Chihuahuan Desert is a region of great biological importance, with an area of 505 thousand square kilometers, whose altitudinal range varies from 1000 to 3 050 m, with predominant calcareous soils. This region covers territories of central and northern Mexico, as well as the southern part of the United States of America (Villareal-Quintanilla *et al.,* 2017).

The microphyllous desert shrubland (MDS) is characterized by the predominance of small shrub elements; it occurs on flat terrains and on the lower parts of the mountains (Rzedowski, 2006). While the rosetophyllous desert shrubland (RDS) is characterized by the predominance of subshrub or shrub species of long, narrow leaves, that take the appearance of a rosette, and corresponds to what Rzedowski (1965, 1978) referred to as calcicolous desert shrubland (Granados-Sánchez *et al.*, 2011).

The change in land use is one of the main factors of the degradation of natural ecosystems; its impact has been cited as occurring at the global level (MEA, 2005), since it modifies the nitrogen and water transfer processes and thus reduces their productivity (Celaya *et al.*, 2015).

The arid and semi-arid zones, at the global level, are very extensive and are characterized by a low availability of resources, which restricts agricultural activities; therefore, their main use is for grazing (Asner *et al.*, 2004). Changes in the vegetation and land use are spatial and dynamic; their magnitude and impact are recognized and identified, also, as one of the great challenges for environmental science (Aragón *et al.*, 2013).

Nitrogen is one of the limiting elements for plants, and its fixation in the soil is decreasing as a result of the burning of fossil fuels and the application of chemical fertilizers, with consequent effects on the diversity of species (Zhang *et al.*, 2017). The nitrogen (N) losses of terrestrial ecosystems are mainly due to their volatilization, denitrification, washing and erosion (García, 1996).

The reabsorption of nutrients that are transferred to the ground from the plant implies a conservation mechanism for nitrogen; this process involves the hydrolysis of the nutrients. Nitrogen is one of the elements most often limited in the primary production (Gallardo *et al.,* 2009); it is essential for the degradation of the organic matter used by microorganisms to induce a greater mineralization, which allows them to meet their needs for this element (Ferrera and Alarcón, 2001).

The nitrogen contents are related to the origin of the soil; volcanic ash derivatives are characterized by a high N content (Fassbender, 1993). The total nitrogen (tN) content covers a broad range, but a common value for the so-called topsoil is 0.2 to 0.7 % (Fassbender, 1987). In their study on land uses, Cristóbal-Acevedo *et al.* (2011) determine that the tN concentration is highest within the first 30 cm, due to the accumulation of organic remains, and it decreases in relation to the depth after the first 30 cm. The tN content behaves in a uniform manner.

The more water enters the soil, the greater the possibility to preserve it and make it available for plant growth. One of the mechanical practices that reduce the degree of compaction is the use of implements like the roller aerator (Velásquez *et al.*, 2012). The roller aerator is a heavy metal cylinder with helically welded teeth or blades covering its entire length in order to achieve greater penetration in the soil and more efficiency in the rolling, because with this design the whole weight of the cylinder is concentrated in one or two knives at the same time (Rubio, 2009).

Today, forest fires are the main cause of the natural disturbance, and their effects on the nitrogen cycle are important, because they are a critical element for maintaining terrestrial ecosystems (Fernández *et al*., 2017). According to Muqaddas *et al*. (2016), the prescribed low-intensity burnings increase the nitrogen concentrations; however, repeated applications cause losses in their reservoirs. In Mediterranean areas, prescribed burning leaves the nature of the soil unaffected for agricultural use (Montoya *et al.*, 2014).

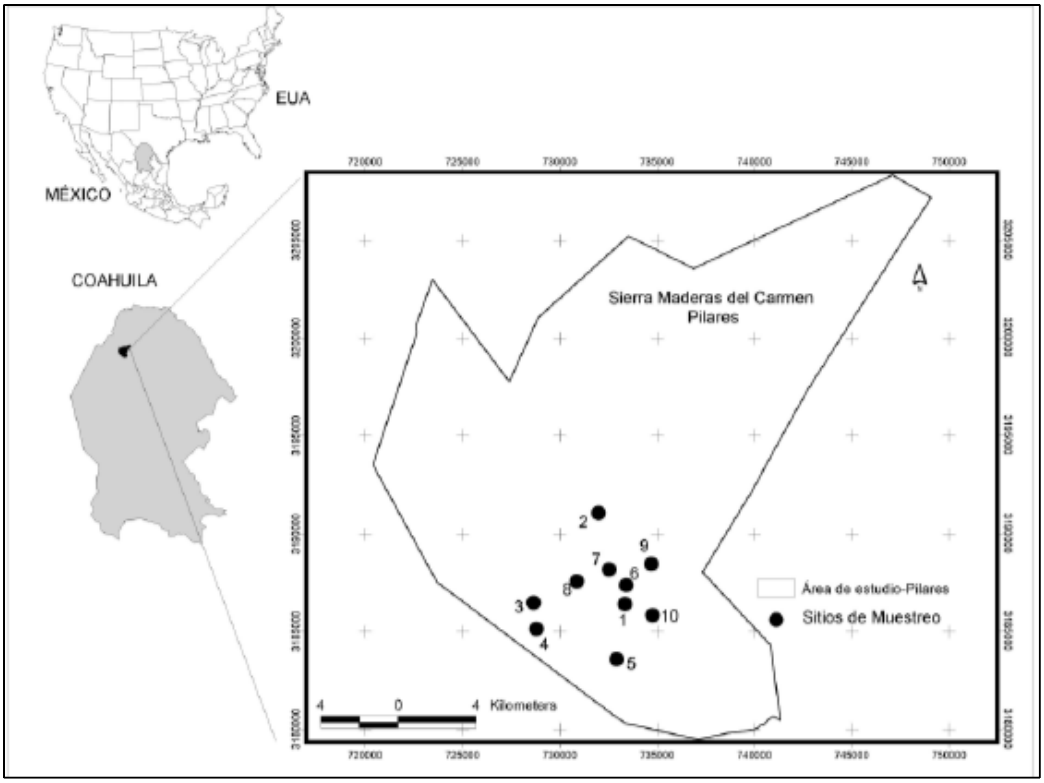
Regosols are mineral soils that have few unconsolidated materials and lack an umbric or mollic horizon; they are not very shallow or very rich in gravel (leptosols), arenas (arenosols), or with fluvic materials (fluvisols); they are present in eroded land, particularly in arid and semi-arid areas, as well as in mountainous terrain (IUSS-ISRIC-FAO, 2007).

The objective of this research was to determine the effect on the nitrogen content in regosols subjected to mechanical treatment (with a roller aerator) and to fire in microphyllous and rosetophyllous shrublands of the Chihuahuan Desert, under the hypothesis that the nitrogen content is different in areas under management of microphyllous and rosetophyllous desert shrubs.

# Materials and Methods

## Location of the study area

The study area was located at the *Pilares* ranch, which functions as a conservation area (Figure 1); it is located between the geographic coordinates 29°22.45' and 28°42.21' N, and 102°56.23' and 102°21.08' W, at an altitude of 1 182 m. The average annual precipitation is 237.5 mm, and the average temperature is 21.5 °C. It belongs to the physiographic province of the Eastern *Sierra Madre*, in the subprovince of the *Sierras* and plains of *Coahuila* (INEGI, 1983). The predominant soils are kastanozems, calcic soils, rendzins, chromic vertisols, lithosols and calcaric regosols (SPP 1982a; 1982b; 1983). The different types of vegetation present are oak (*Quercus*), pine (*Pinus*) and fir (*Abies*) forests; submontane shrubs; grasslands, and Chihuahuan desert shrublands, which include microphyllous and rosetophyllous shrubs, and halophilic and gypsophila communities (INE-Semarnap, 1997, cited by Medina-Guillén *et al.*, 2017a).




*Área de studio* = Study area; *Sitios de muestreo* = Sampling sites

**Figure 1**. Location of the study site.

## Description of the study areas

Microphyllous desert shrubland. The taxa cited in the literature are: *Rhus microphylla* Engelm., *Rhus virens* Lindh. ex A. Gray., *Agave lechuguilla* Torr., *Dasylirion glaucophyllum* Hook., *Ziziphus obtusifolia* (Hook. ex Torr. & A. Gray.) A. Gray., *Tiquilia canescens* (A. DC.) A. T. Richardson., *Tiquilia greggii* (Torr. & A. Gray) A. T. Richardson., *Cylindropuntia leptocaulis* (DC.) F. M. Kunth., *Echinocereus enneacanthus* Engelm., *Opuntia engelmannii* Salm-Dyck ex Engelm., *Celtis pallida* Torr., *Flourensia cernua* DC., *Parthenium incanum* Kunth., *Viguiera stenoloba* S. F. Blake., *Ibervillea lindheimeri* (A. Grey) Greene., *Ephedra antisyphilitica* Berland. ex C. A. Mey., *Euphorbia antisyphilitica* Zucc., *Jatropha dioica* Sessé ex Carv., *Fouquieria splendens* Engelm., *Koeberlinia spinosa* Zucc., *Acacia constricta* A. Gray., *Acacia greggii* A. Gray., *Prosopis glandulosa* Torr., *Condalia spathulata* A. Gray., *Phaulothamnus spinescens* A. Gray., *Aloysia gratissima* (Gillies & Hook.) Tronc., *Larrea tridentata* (Sessé & Moc. ex DC.) Coville. and *Prolieria angustifolia* (Engelm.) A. Gray. (Medina *et al*., 2015).

Rosetophyllous desert shrubland. It consists mainly of plants with a rosette shape. The species that thrive in the study site are: *Agave lechuguilla* Torr., *Dasylirion leiophyllum* Hook., *Viguiera stenoloba* S. F. Blake., *Flourensia cernua* DC., *Parthenium incanum* Kunth., *Mammillaria heyderi* Muehlenpf., *Opuntia engelmannii* Salm-Dyck ex Engelm., *Echinocereus viridiflorus* Engelm., *Echinocereus enneacanthus* Engelm., *Cylindropuntia leptocaulis* Engelm., *Ephedra antisyphilitica* Berland. ex C. A. Mey., *Jatropha dioica* Sessé ex Carv., *Acacia greggii* A. Gray., *Prosopis glandulosa* Torr., *Acacia constricta* A. Gray., *Condalia spathulata* A. Gray., *Zizipus obstusifolia* Tourn ex L., *Leucophyllum frutescens* (Berl.) I. M. Johnst., *Guaiacum angustifolium* Engelm., and *Larrea tridentata* (Sessé & Moc. ex DC.) Coville. (Medina, 2016).

## Treatments

In the spring of 2014, plots were selected in the same soil type (Calcaric regosol) with the two types of vegetation (microphyllous and rosetophyllous desert shrubs), where roller aerator treatments were applied on different dates —roller applied in 2004 (RA-04), 2008 (RA-08), and 2011 (RA-11)—, as well as an area burnt in 2011 (BA-11) and a control area (C) for each type of vegetation. A roller type Lawson aerator of 11 tons assembled to a tractor, with 15 cm long knives, was used in the improvement practices in the plains of *Sierra Maderas del Carmen*. All areas had a slope of less than 5°.

## Sampling

In each of the treatments, a georeferenced plot with an area of 1 024 $m^2$ (32 m × 32 m) was established, where four soil samples were taken, each made up of four subsamples, adding up to a total of 1.5 kg of soil. The sampling was carried out at two depths (0-15 cm and 15.1-30 cm) for a total of 80 samples, which were taken to the laboratory of the Faculty of Forest Sciences of UANL, where they were prepared for the determination of their total nitrogen content (Medina, 2016).

## Determination of the total nitrogen content in the soil

The total nitrogen content (%) was evaluated using the Kjeldahl method. The analysis was carried out with the Velp Scientifica UDK159 distillation-titration unit, as proposed by Bremner and Mulvaney (1982).

The soil was sifted through a sieve with a 2 mm aperture and dried in the open air; 1 gram of soil was weighed and transferred to the Kjeldahl tube; then, the reagents —two ST catalytic tablets (CT0006609) and 12 mL of concentrated sulfuric acid— were added for its digestion and placed in the grid with 20 tubes of the Velp Scientifica DK 20 Heating Digester at a temperature of 420 °C for 60 minutes; subsequently, the tubes were left to cool to a temperature of 50-60 °C, approximately. The sample digested was placed in the UDK 159 for its distillation and assessment, using the predefined method Num. 27. The reagents and the quantities for their assessment were: 50 mL distilled water, boric acid ($H_3BO_3$) 30 mL, sodium hydroxide (NaOH) 50 mL, and a titrating solution of hydrochloric acid (HCl) 0.2 N.

## Statistical data analysis

Nitrogen data were transformed to square root in order to induce the normal distribution through the Kolmogorov-Smirnov statistic. Three-way variance analyses and Tukey's ($p \leq 0.05$) mean comparison tests were performed in order to determine differences between the treatments, using the SPSS™ software (Statistical Package for the Social Sciences, Standard version 22 for Windows) (SPSS, 2009).

# Results and Discussion

The variance analysis showed significant differences (P≤0.05) between the two types of vegetation and the applied treatments, as well as in the combination of factors of vegetation*treatment; while there were no differences for depth, vegetation*depth, treatment*depth and vegetation*treatment*depth (Table 1). These results indicate that the presence of different ecosystems on the same type of soil (Regosol) has an important impact on the nitrogen content. On average, the ecosystem with the higher content of total nitrogen (tN) was the microphyllous desert shrub (MDS), with 0.159 %, while the rosetophyllous desert shrub (RDS) had a lower tN content, of 0.126 %.

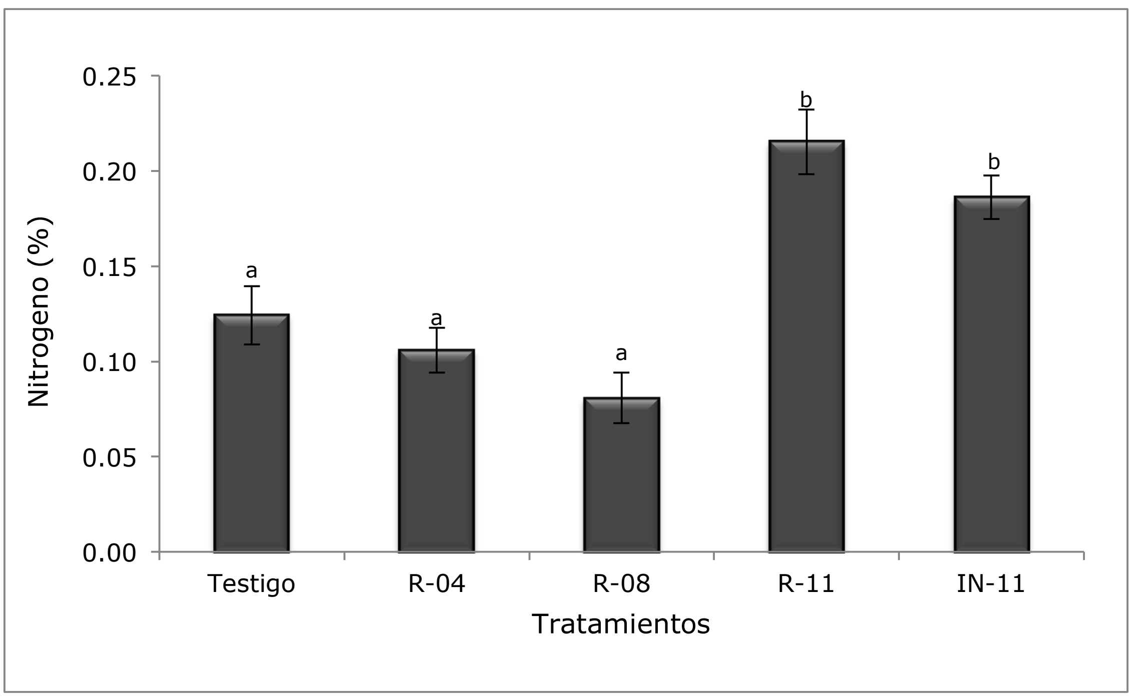
**Table 1**. Variance analysis of the nitrogen content of the soil for the model with three classification criteria (vegetation type, depth and treatment), and Levene's contrast.

| **ANOVA** | **df** | **F** | ***P* Value** |
|---|---|---|---|
| Vegetation | 1 | 8.381 | **0.005** |
| Treatment | 4 | 25.442 | **0.000** |
| Depth | 1 | 2.593 | 0.113 |
| Vegetation * Treatment | 4 | 7.291 | **0.000** |
| Vegetation * Depth | 1 | 3.216 | 0.078 |
| Treatment * Depth | 4 | 0.518 | 0.723 |
| Vegetation * Treatment * Depth | 4 | 1.341 | 0.265 |
| *Levene* test | 19 | 2.589 | 0.003 |
| Adjusted $R^2$ | | | 0.628 |

Values in bold indicate significant differences (p≤0.05).

## Effects of treatments on the total nitrogen content

According to ANOVA, there were no differences between the applied treatments. Figure 2 shows the mean values; as well as the differences between the treatments, regardless of the vegetation present. The treatments of R-08, R-04 and the control area share the same group, with total nitrogen values of 0.080, 0.106 and 0.125 %, respectively. On the other hand, BA-11 and R-11, presented the effect of short-term treatments, with values of 0.186 and 0.215 % tN, respectively, with regard to the control. Medina-Guillén *et al*. (2017a) determined that the use of the roller aerator in microphyllous and rosetophyllous desert shrub was an efficient soil management alternative that increased the organic matter content; they cite similar results with the use of fire, and therefore both these treatments are viable alternatives, although only in the short term.




Different letters indicate a significant difference (p≤0.05).

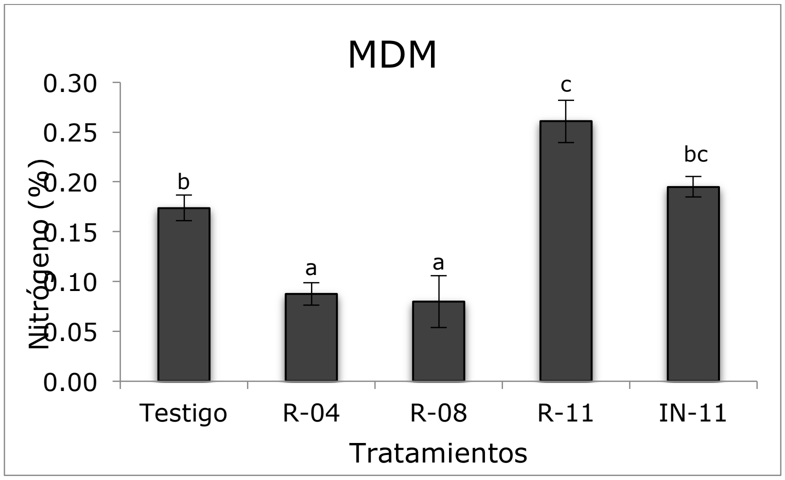
**Figure 2**. Mean values of total nitrogen content (%) of the treatments (n= 16).

According to Rodríguez *et al.* (2008), the use of fire increased the N content in the short term and had an opposite effect in the long term. The highest contents were obtained subsequently to the first year after the fire; however, the contents diminished with time. They also point out that the recovery of the organic matter allows increased ammonification, but not nitrification. Jiménez-Pinilla *et al.* (2016) report that the ashes play an important role after the occurrence of a fire as they increase the water repellency of the soil; they conclude that the water repellency of *Pinus halapensis* Mill. disappears a year and a half after the onset of the fire.

According to Fontúrbel *et al.* (2009), the physico-chemical properties of the soil change due to the severity of the fire; the N had the lowest concentrations when the intensity of the fire was highest. After the fires, the charred vegetation is incorporated in large quantities into the soil, which causes changes in the carbon and nitrogen dynamics and, eventually, an alteration in their availability for the primary production (Knicker, 2007).

## Microphyllous desert shrubland

Tukey's mean comparison test ($p \leq 0.05$) showed differences between the treatments in the two types of vegetation. For the microphyllous desert shrubs, the values of the tN contents ranged from 0.080 %, with the treatments at R-04 and R-08, followed by the control area, with 0.174 %, to BA-11 with 0.195 %; while the treatment at R-11 showed the largest increase, with a tN content of 0.261 % (Figure 3). No differences are shown between the R-04 and R-08 treatments, but the contents were lower than in the control. In the short term, an increase in the nitrogen content is produced by the treatments R-11 and BA-11.




*MDM* = MDS; *Nitrógeno* = Nitrogen; *Testigo* = Control; *IN-11* = BA-11; *Tratamientos* = Treatments

Different letters indicate a significant difference ($p \leq 0.05$).

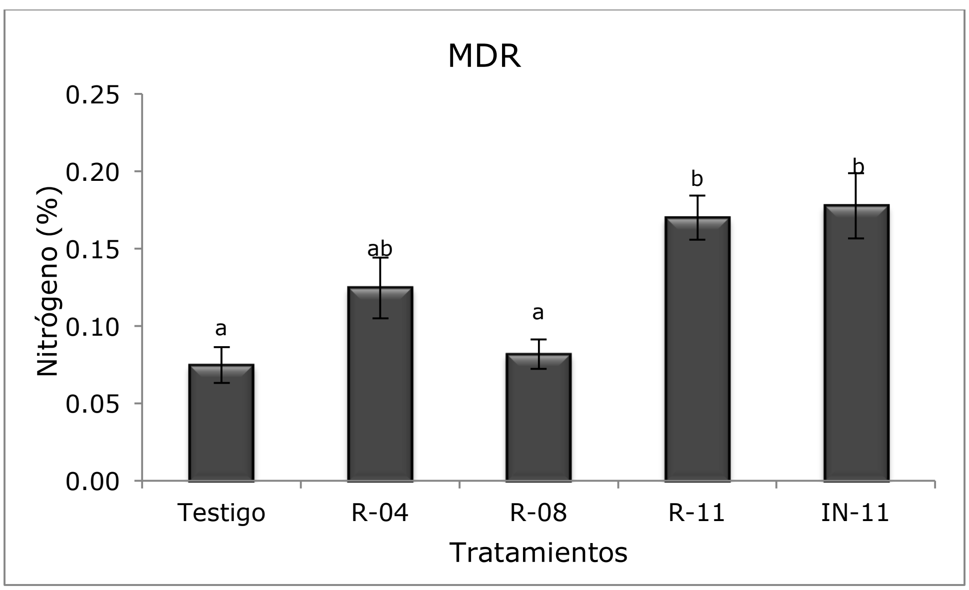
**Figure 3**. Mean total nitrogen content values (%) of the treatments for microphyllous desert shrubs (n=8).

The results obtained by Afif and Oliveira (2006) agree with the above, as they determined an increase in the concentration of total nitrogen immediately after a fire, at the first centimeters of depth, while in the subsurface layer (5-10 cm) the tN decreased gradually. Wang *et al.* (2016) point out that the restoration between uses of the land and the conversion of agricultural land to forest or shrubland has a great potential for total nitrogen sequestration. In a study conducted in the Emas National Park, central Brazil, the soils under three different fire regimes were compared; the results show differences in the characteristics of the soil. The burned site had higher annual values for organic matter, nitrogen and clay than the control site (da Silva and Batalha, 2008).

Medina (2016), who worked in the same area as the present study, documented a greater abundance for the families of the MDS, with three species of legumes. In this regard, the mineralization of N depends strongly on the ability of the legumes to fix $N_2$, and the importance of this biological process lies in that it improves the available N in the soil (Valleys *et al.*, 2008).

## Rosetophyllous desert shrubland

The mean values of tN for the RDS, showed that the control (0.075 %) had the lowest tN content; no differences were found with respect to the treatment at R-08, with which the tN content increased slightly to 0.816 %. The treatment at R-04 presented a mean content of 0.125 %, unlike the treatments at R-11 and BA-11, whose contents were 0.170 % and 0.178 %, respectively, and which formed a statistically different group (Figure 4). The fire is an agent of change in plant communities due to its effect on the availability of resources and the competitive interactions of individuals (Alba *et al.,* 2015).




*MDR*= RDS; *Testigo* = Control; *Tratamientos* = Treatments; *Nitrógeno* = Nitrogen; *IN-11* = BA-11

Different letters indicate a significant difference ($p \leq 0.05$).

**Figure 4**. Mean total nitrogen values (%) for the treatments of the rosetophyllous desert shrubs (n=8).

According to Medina-Guillén *et al.* (2017b), the implementation of the fire reduced the unwanted species, such as vegetation with low tolerance to fire, and favored a larger cover of native vegetation. Hobley *et al.* (2017) conclude that the fire is a very useful tool for the elimination of the aerial biomass in the short term; it also leads to an input of N through the introduction of a subsurface source of organic matter (dead roots). Medina (2016) determined that the treatments with a roller for more than 6 years showed an increase in the RDS cover from 45 % to 75 % and cites 21 species, of which 12 were located in the burned area, with the dominance of three families: Cactaceae, Asteraceae and Fabaceae; the latter is closely related to nitrogen fixers, known as rhizobia (Bottomley and Myrold, 2015).

## Assessment of the nitrogen content

The assessment of the total nitrogen content for the two types of vegetation (MDS and RDS), agrees with the valuation by Woerner (1989), with the mean values in different categories. For the MDS, the treatments presented values rated as suitable (R-04 and R-08), high (control and BA-11), and very high (R-11), with a similar behavior to that of the statistical groups obtained. For the RDS vegetation groups, the treatments ranged from suitable to high, with a similar statistical behavior (Table 2). A relationship was found between the corresponding classification and statistical values; this differs from the findings of Silva-Arredondo *et al.* (2013), who proved that, even with statistical differences in various chemical properties for pastures with varying numbers of years of neglect, some variables have the same valuation according to classifications of the NOM-021-RECNAT-2000 SEMARNAT.

**Table 2**. Assessment of the nitrogen content according to the classification by Woerner (1989).

| Treatments | MDS | RDS |
|---|---|---|
| Control | H | S |
| R-04 | S | S |
| R-08 | S | S |
| R-11 | VH | H |
| BA-11 | H | H |

S= Suitable; H= High; VH = Very High.

The gains or losses of nitrogen content are shown in Table 3. In the MDS, treatments at RA-04 and RA-08 caused losses in relation to the control, whose antiquity is of ten and six years, respectively; while the treatments with a shorter time of application resulted in a gain of this element. In comparison, the RDS had a gain with a variation of 9 % (RA-08) to 138 % with regard to the control, where the greatest impact was obtained with the treatment with a shorter time of application (3 years).

**Table 3**. Variation of the tN content (%) due to the effect of the treatments in relation to the control for the two types of vegetation.

| Treatments | MDS | RDS |
|---|---|---|
| R-04 | -50 | 67 |
| R-08 | -54 | 9 |
| R-11 | 50 | 127 |
| BA-11 | 12 | 138 |

# Conclusions

The contents of total nitrogen in the soil for the microphyllous and rosetophyllous desert shrubs varied considerably after the applied mechanical treatments. In general, the tN contents are greater in the MDS, where vegetation plays a key factor in the behavior of the tN due to the presence of legume species that could be reincorporated to the soil. On the other hand, both the mechanical handling of the roller aerator and the use of fire improve the contents of nitrogen, but only in the short term. The MDS presents an increase for the treatment with a shorter time of application, whereas for the RDS all treatments improve the tN content, which results in higher values with regard to the control (9-138 %) even 10 years after having applied the treatment of roller or fire; therefore, we recommended applying them during longer periods of time than on the MDS.

**Acknowledgments**

The authors would like to thank the *Universidad Autónoma de Nuevo León* (project PAICYT CT263-15) for the support provided for carrying out the present research. Also, we are grateful to two anonymous reviewers for having enriched the manuscript and made critical comments on it.

**Conflict of interest**

The authors declare no conflict of interest.

**Contribution by author**

Rodolfo Alejandro Martínez Soto: development of the research, structure and design of the manuscript; María Inés Yáñez Díaz: statistical analyses, conclusions, revision and editing of the document; Israel Cantú Silva: design of the manuscript and interpretation of the results and editing of the document; Humberto González Rodríguez: site selection, support in results and revision of the manuscript; José

Guadalupe Marmolejo Monsiváis: climate data and revision of the manuscript; Karla Estrella Díaz García: abstract and discussion.

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