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Article

Alternativas de fertilización para producir *Prosopis laevigata* (Humb. & Bonpl. ex Willd.) M. C. Johnst en vivero

Fertilization alternatives to produce *Prosopis laevigata* (Humb. & Bonpl. ex Willd.) M. C. Johnst at the nursery

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Resumen:

Actualmente se conoce poco sobre las diferentes opciones que involucran el uso de fertilizantes hidrosolubles y de liberación controlada, así como las dosis de aplicación en la producción de *Prosopis laevigata* en vivero. El objetivo del presente estudio consistió en evaluar la eficiencia de los fertilizantes hidrosolubles Triple 16 (T16), Triple 19 (T19) y *Poly-feed*® (Pf), en dosis de 100 mg L^{-1}, combinados con 3 y 6 g L^{-1} de fertilizante de liberación controlada (*Multicote*® = M) en sustrato, así como los costos implicados en su aplicación. Los tratamientos evaluados fueron: 1 (0 g M + agua), 2 (3 g M + agua), 3 (3 g M + T19), 4 (3 g M + Pf), 5 (3 g M + T16), 6 (6 g M + agua), 7 (6 g M + T19), 8 (6 g M + Pf) y 9 (6 g M + T16) dispuestos en un diseño experimental completamente al azar con arreglo factorial y cuatro repeticiones. Las variables de interés fueron la altura, el diámetro, la biomasa seca total y el índice de robustez. Los fertilizantes hidrosolubles, de liberación controlada y la combinación de ambos tuvieron un efecto significativo en las variables evaluadas ($p < 0.001$). Se obtuvieron alturas de 27.49 a 30.37 cm y los diámetros más destacados variaron de 3.37 a 3.59 mm. El índice de robustez en los tratamientos 1, 2, 5, 6 y 8 fueron menores a 8. Se concluye que la mayoría de las variables respondieron mejor al tratamiento 7, pero fue más costoso que el 5, que produjo resultados similares.

Palabras clave: Costos, crecimiento, fertilizante de liberación controlada, fertilizantes hidrosolubles, mezquite, restauración.

Abstract:

At present, little is known about the different options that involve the use of water-soluble and controlled release fertilizers, as well as the application doses in the production of *Prosopis laevigata* at the nursery. The aim of the present study was to assess the efficiency of the water soluble fertilizers Triple 16 (T16), Triple 19 (T19) and Poly-feed® (Pf), in 100 mg L^{-1} doses, combined with 3 and 6 g L^{-1} of controlled release fertilizer (Multicote® = M) in substrate, as well as the costs involved in its application. The assessed treatments were: 1 (0 g M + water), 2 (3 g M + water), 3 (3 g M + T19), 4 (3 g M + Pf), 5 (3 g M + T16), 6 (6 g M + Water), 7 (6 g M + T19), 8 (6 g M + Pf) and 9 (6 g M + T16) arranged in a completely randomized experimental design with factorial arrangement and four replications. The variables of interest were height, diameter, total dry biomass and the robustness index. The water-soluble and controlled release fertilizers, as well as the combination of both had a significant effect on the addressed variables ($p < 0.001$). Heights of 27.49 to 30.37 cm were obtained and the most outstanding diameters varied from 3.37 to 3.59 mm. The robustness index in treatments 1, 2, 5, 6 and 8 were less than 8. It is concluded that most of the variables responded better to treatment 7, which was more expensive than 5, and had similar results.

Key words: Costs, growth, controlled release fertilizer, water-soluble fertilizers, mesquite, restoration.

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Introduction

Mesquite, *Prosopis laevigata* (Humb. & Bonpl. ex Willd.) M. C. Johnst, lives mainly in arid and semi-arid zones. It is important as it can fix nitrogen, favors soil enrichment at its surroundings, promotes growth of shrubs associated to the site, and therefore, helps to decrease soil erosion; also, it acts as a nurse plant of many species of birds and rodents (García *et al*., 2012; Ríos *et al*., 2012). It is also used for several other ends. Some marginal communities subsist from products derived from mesquite such as wood, which is used to make furniture; flowers which attract bees for the production of honey; the exudate from the trunk that emits mesquite gum (Rodríguez *et al.,* 2014), which is a product of great industrial use (López *et al.,* 2006) and pods for human or animal food (Barba *et al.,* 2006; Andrade *et al*., 2011).

Because the species is considered an invasive plant in some grassland areas and lands abandoned by agriculture (Trucios *et al.,* 2012), it has been deforested and there has been an irreversible loss of its genetic diversity (Buendía *et al.,* 2007). Of the 633 876 km^2 of surface that initially existed of mesquite and scrub in Mexico, 66 793 km^2 were lost from 1976 to 2007 (Rosete *et al.,* 2014); this led to the erosion and dispersal of nutrients stored under the plants and affected their survival (Gutiérrez and Squeo, 2004).

In recent years, interest has grown in producing mesquite for the restoration of disturbed ecosystems (Prieto *et al.,* 2013; Cervantes *et al.,* 2018). In the period 2000-2007, a deceleration of the speed of loss of this type of vegetation was noticed (Rosete *et al*., 2014). The main limiting factors for the reforestation of mesquite in *Durango* are the small size of the seedling produced in the nursery (<20 cm), the low availability of water and the attack of rodents such as hares (*Lepus californicus* Gray, 1837) (Ríos *et al.,* 2012).

Another important factor is plant quality, which through morphological and physiological attributes can be correlated quantitatively with their performance (Wilson and Jacobs, 2006), since they have been shown to be essential characteristics for the success of *Quercus ilex* L. plantations. (Palacios *et al*., 2009). However, there is little knowledge about the different techniques that involve the generation or adaptation of technologies in forest nurseries where mesquite is produced (Prieto *et al*., 2013; Salto *et al*., 2013).

To improve the quality of the plant, alternatives have been sought among which, fertilization is a substantial practice for cultivation (Rueda *et al*., 2012), because it consists on the application to the substrate and foliage (Fageria *et al.,* 2009) of essential nutrients that plants require for their optimal development; controlled release and water-soluble are the two most common methods of fertilization in nurseries (Bi *et al.,* 2010). The controlled release have gained recognition in forest production (Rose *et al*., 2004), and are an option for plants during their development, and can be delivered in a single application (Aguilera *et al.,* 2016). Soluble fertilization is usually complemented with fertilization of the growing media (Soria, 2008), and can be adjusted precisely at each stage of seedling development (Rincón *et al.,* 2007).

Starting from the relevance of improving plant quality, this work analyzed fertilization options through the use of controlled release materials, supplemented with water-soluble agricultural type fertilizers, which provide nitrogen (N), phosphorus (P) and potassium (K) at a low cost, and have the potential to improve the production of mesquite plant at the nursery; in addition, the cost of the different fertilizer combinations was evaluated. It was assumed that at least a combination of controlled release fertilizers and water-soluble agricultural fertilizers favor the growth of the plant in the nursery and reduce costs, compared to the typical fertilization practices used at present in the forest nurseries.

Based on the above, the aim of this research was to quantify the effect of two doses of controlled release fertilizers and three types of water-soluble agricultural fertilizers, in the height growth of the aerial part and in the root collar diameter, as well as in biomass and robustness index of *Prosopis laevigata* at the nursery; and, to determine the costs of plant production to compare them between the different fertilization options.

Materials and Methods

Production conditions

The study was conducted in the nursery of the *Facultad de Ciencias Forestales de la Universidad Juárez del Estado de Durango* (School of Forest Sciences of the Juarez University of the State of Durango), located in *Durango* city, *Durango* State, at 24°00'49" N and 104°40'58" W, at 1 860 masl. The experiment lasted five months and the first four were under greenhouse conditions (covered with 720-gauge polyethylene plastic treated against ultraviolet rays, a 60 % shadow mesh was placed on the polyethylene plastic); during the fifth month the plant was out in the open. The average temperature recorded under greenhouse conditions was 27.9 °C and in the open air of 29.0 °C.

The plant was produced in polystyrene trays of 77 cavities, 35 cm wide, 60 cm long, 15 cm high and 170 mL per cavity. As a substrate, a mixture composed of 50 % peat (peat moss) and 50 % pine bark was used. Prior to sowing, the seed was subjected to a pregerminative treatment with immersion, for 60 seconds in water at 94 °C; to prevent the development of fungi, 2.5 g L^{-1} of Benomyl was applied during sowing.

Assessed treatments

Nine treatments composed of two doses of controlled-release fertilizer and three types of water-soluble fertilizers were evaluated, as well as the control in which only water was applied (Table 1). The controlled release fertilizer (8-9 months of release) Multicote® 18N-$6P_2O_5$-$12K_2O$ + 2MgO + micronutrients (Haifa Chemicals Ltd.) was incorporated into the substrate in doses of 3 and 6 g L^{-1}. The water-soluble fertilizers were applied every 48 h at a constant dose of 100 mg L^{-1}. The fertilization process began 20 days after sowing (DDS) and lasted three months, with July 10, 2015 as deadline.

Table 1. Composition and dosage of the treatments evaluated.

Treatment	**Controlled release fertilizer ($g\ L^{-1}$)**	**Water-soluble fertilizer (N-P-K)**
1	0	Water
2	3	Water
3	3	Triple 19 (19 N -19 P_20_5 -19 K_2O)
4	3	Poly-feed® (20 N - 9 P_20_5 - 20 K_2O)
5	3	Triple 16 (16 N – 16 P_20_5 – 16 K_2O)
6	6	Water
7	6	Triple 19 (19 N – 19 P_20_5 - 19 K_2O)
8	6	Poly-feed® (20 N – 9 P_20_5 – 20 K_2O)
9	6	Triple 16 (16 N - 16 P_20_5 – 16 K_2O)

Evaluation

At 116 DSD, eight plants were evaluated per experimental unit. The response variables considered were: the height of the aerial part (cm), which was registered with a graduated rule of 30 cm (Trupper® 14387) and the measurement was taken with approximation up to tenths of a centimeter; the diameter of the stem (mm), taken at the height of the root collar with a digital vernier with precision of hundredths of a millimeter (SURTEK™ 122204).

For the dry biomass of the aerial part and the root system (g) a FELISA™ FE-291D drying oven was used at 70 °C for 72 h, then weighed on a Ohaus™ PA214 analytical balance. Each section was previously packed in paper bags with its respective registration data (treatment, replication and plant number). With the above variables, the robustness index was determined, which is an indicator of the quality of the plant.

The cost of the fertilizer used during the experiment was calculated based on the applied proportion of each type of water-soluble fertilizer per treatment. Additionally, the cost of controlled release fertilizer was included based on the defined treatments, with average prices of 2017.

Experimental design and statistical analysis

The treatments were distributed in a completely randomized experimental design with a factorial arrangement, with four replicates per treatment. As the data did not fulfill the assumption of normality, the Kruskal-Wallis non-parametric statistical test (Kruskal and Wallis, 1952) was used for all the variables evaluated, in addition to the Bonferroni-Dunn means separation test ($p < 0.05$) (Pohlert, 2014). The statistical analysis was performed with the statistical software R 3.2.3 (R Core Team, 2015). The statistical model used was the following:

$$Y_{ij} = \mu + A_i + B_j + (AB)ij + e_{ijk}$$

Where:

Y_{ij} = Response variable

μ = Mean general effect

A_i = Effect attributed to the $_i$-^{eth} of the water-soluble fertilizer factor level

B_j = Effect attributed to the $_j$-^{eth} of the controlled release fertilizer factor level

$(AB)_{ij}$ = Effect attributed to the interaction between the $_i$-^{eth} level of the A factor and the $_j$-^{eth} level of the B factor

e_{ijk} = Random error

Results and Discussion

Controlled release fertilizers

The application of controlled release fertilizer Multicote™ had significant effects on the variables evaluated ($p < 0.001$); in the height of the aerial part and the root collar diameter, the dose of 3 g showed statistical equality with respect to the specimens that received the dose of 6 g; however, in the total dry biomass the highest dose was located in the upper statistical group (Table 2). It is evident that the lack of supply of the controlled-release option caused a lower growth in the plants.

Table 2. Effect of the controlled- release and water-soluble fertilizers on the substrate after 116 days of sowing.

Kind of fertilizer	Height of the aerial part (cm)	Root collar diameter (mm)	Total dry biomass total (g)	Robustness index
Controlled- release fertilizer				
0 g	10.13 ± 0.65 b	2.14 ± 0.12 b	0.43 ± 0.03 c	4.51 ± 0.28
3 g	26.88 ± 0.54 a	3.45 ± 0.03 a	2.29 ± 0.05 b	7.80 ± 0.15
6 g	28.73 ± 0.56 a	3.55 ± 0.03 a	2.60 ± 0.04 a	8.09 ± 0.15
Water-soluble fertilizer				
Water	20.49 ± 1.12 b	3.02 ± 0.09 b	1.58 ± 0.12 b	6.44 ± 0.24
Triple 19	28.93 ± 0.79 a	3.49 ± 0.04 a	2.50 ± 0.08 a	8.30 ± 0.21
Poly-feed®	28.23 ± 0.70 a	3.52 ± 0.04 a	2.53 ± 0.06 a	8.03 ± 0.19
Triple 16	28.39 ± 0.74 a	3.54 ± 0.04 a	2.60 ± 0.05 a	8.04 ± 0.23

Different letters in the same column indicate significant differences, according to the Bonferroni-Dunn test ($p < 0.05$).

These results coincide with those of Bustos *et al*. (2008), who evaluated the growth of three tree species (*Nothofagus dombeyi* (Mirb.) Oerst., *Nothofagus nervosa* (Mirb.) Oerst. and *Eucryphia cordifolia* Cav.) by applying three doses of the controlled release fertilizer Osmocote™ (2.5 to 7.5 g L^{-1}); they concluded that the highest doses were the most favorable.

On the other hand, Aguilera *et al.* (2016) also observed that in *Pinus montezumae* Lamb seedlings. produced with three doses (4, 6 and 8 g L^{-1}) of Basacote™ Plus, Multicote™ and Osmocote™ Plus on two substrates, the doses of 6 and 8 g L^{-1} further stimulated their growth.

Water-soluble fertilizer

The use of water-soluble fertilizers during irrigation only recorded differences in the response variables ($p < 0.001$) with respect to the control; that is, where it was watered without water-soluble fertilizer. In the treatments in which the different water-soluble fertilizers were applied in water, the results of the variables evaluated ($p < 0.001$) were similar to each other (Table 2).

Controlled-release and water-soluble fertilizers

The application of the controlled release fertilizer and the water-soluble fertilizers generated significant differences in the height of the aerial part, in the root collar diameter and in the total dry biomass ($p < 0.001$); in addition, they showed a robustness index slightly higher than that indicated by Prieto *et al.* (2012) (< 8), but which can be satisfactory (Table 3).

Table 3. Results of the variables evaluated and costs for fertilizers 116 days after sowing.

Treatment	Height of the aerial part (cm)	Root collar diameter (mm)	Total dry biomass (g)	Robustness index	Cost of fertilizer per plant (MXN)
1	10.13 ± 0.65 c	2.14 ± 0.12 b	0.43 ± 0.03 c	4.51 ± 0.28	0
2	23.40 ± 1.03 bc	3.37 ± 0.08 a	1.81 ± 0.09 bc	6.96 ± 0.30	0.026
3	27.49 ± 1.06 ab	3.38 ± 0.05 a	2.25 ± 0.11 ab	8.12 ± 0.28	0.048
4	28.52 ± 1.00 ab	3.48 ± 0.06 a	2.50 ± 0.09 a	8.21 ± 0.30	0.064
5	28.14 ± 0.90 ab	3.58 ± 0.07 a	2.59 ± 0.07 a	7.90 ± 0.29	0.050
6	27.95 ± 1.16 ab	3.56 ± 0.08 a	2.50 ± 0.11 a	7.84 ± 0.26	0.053
7	30.37 ± 1.11 a	3.59 ± 0.07 a	2.74 ± 0.10 a	8.49 ± 0.32	0.075
8	27.95 ± 1.00 ab	3.55 ± 0.06 a	2.56 ± 0.08 a	7.86 ± 0.26	0.091
9	28.64 ± 1.20 ab	3.51 ± 0.05 a	2.61 ± 0.08 a	8.18 ± 0.36	0.077

Different letters in the same column indicate significant differences, according to the Bonferroni-Dunn test ($p < 0.05$).

The height of the aerial part was outstanding with treatment 7, which consisted of the highest dose of the controlled-release product and with the water-soluble fertilizer Triple 19. As for the root collar diameter, all the treatments fertilized, either with the controlled release, the water- soluble or combined, were in the upper statistical group and registereddifferences greater than 1.0 mm with respect to the control. The values of the most outstanding treatments varied from 3.4 to 3.6 mm, with a maximum difference of 0.2 mm between them. The values of total dry biomass had an average fluctuation between treatments of 0.48 and 2.74 g, with the best results in treatments 4 to 9 (Table 3).

The Mexican Standard NMX-AA-170-SCFI-2016 "Certification of forest nurseries", establishes that *Prosopis laevigata* must have a height interval between 25 and 30 cm and a root collar diameter of the minimum root of 4 mm at five months of age (SCFI, 2016). In this study, heights were reached in approximately four months, except for treatments 1 and 2; with regard to the root collar diameter , the recommended minimum was not achieved, but the values were very close; therefore, all treatments where fertilized were effective. The root collar diameter is considered one of the most important variables to define the quality of the plant (Sáenz *et al*., 2010; Tsakaldimi *et al*., 2013), and it is related to the height, as well as to the radical development of the plant (Jacobs *et al.,* 2009). On the other hand, Prieto *et al.* (2009) and Sáenz *et al.* (2010) argued that plants with large diameters support bending and resist more damages caused by insects and animals, so this criterion is considered important in the early performance of a plantation.

Prieto *et al.* (2013) evaluated six mixtures of substrates in the production of *Prosopis laevigata*, and applied 7 kg m^{-3} of controlled release fertilizer 15-07-15 of NPK, supplemented twice a week with the water soluble Peters™ Professional (PP) fertilizer, growth (20-09-19 of NPK) in 100 ppm, and PP finalizer (4-25-35 of NPK), in a dose of 100 ppm. After 21 weeks of plant growth, they concluded that the average diameter of the plant fluctuated between 2.91 and 3.05 mm, while the height, from 19.7 to 25.7 cm. In the present study, a greater increase was observed in the two variables in less time (30 days less), which corroborates the influence of N P and K.

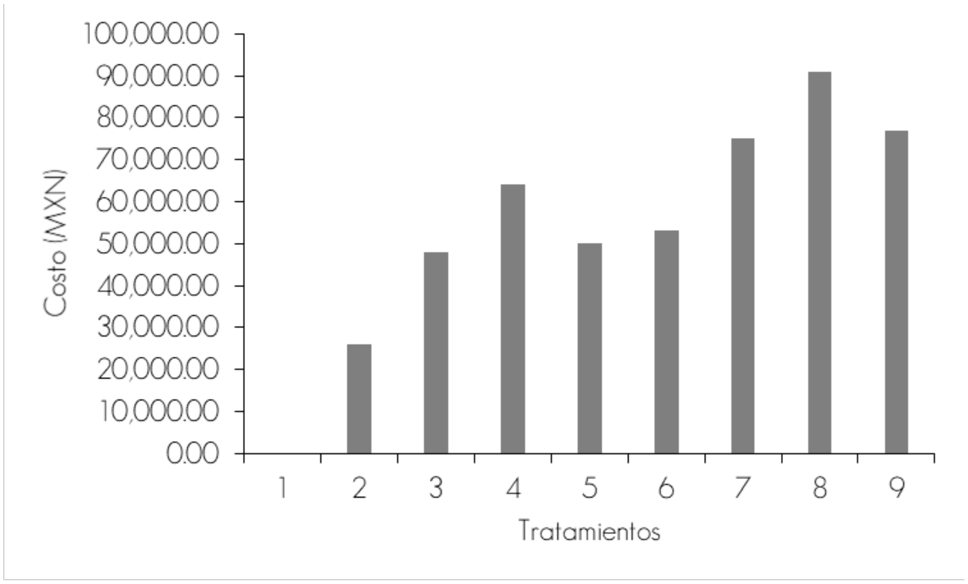
Prieto *et al.* (2012) established that the robustness index for this species must be < 8, which defines a good balance between height and diameter, and allows the plant to survive under conditions of low moisture and desiccation from wind, due to the resistance of woody tissue, in addition to containing water reserves and photosynthates; a higher value describes a disproportionate plant and susceptible to damage by wind, drought and frost (Rodríguez, 2008). Derived from the above, the treatments that received some nutrient source revealed adequate robustness indexes, which shows that the fertilization routines used are correct (Table 3).

Based on the results obtained in the present study, it can be seen that the factor that marked differences between treatments was the controlled release fertilizer applied in two doses, and even with best results in the highest dose (6 g L^{-1}); Rose *et al.* (2004) noted that the most outstanding feature of this type of fertilizer is its ability for nutrients to be supplied once and that they are released gradually and for a long time, which in turn prevents the loss of nutrients by leaching. On the other hand, the same authors indicate that it is convenient to evaluate mixtures of controlled-release fertilizers and water-soluble products, so that the optimal form of nutrition in plants can be determined.

Cost analysis of fertilizers in plant production

The cost from the application of controlled-release fertilizers and water-soluble fertilizers was higher in treatment 7 with MXN$ 0.077 per plant produced; and, in contrast, the lowest cost was that of treatment 2 with MXN$ 0.026 per plant, by investing only in the controlled release fertilizer in a dose of 3 g L^{-1} of water (Table 3).

Thus, to produce one million plants using treatment 7, the cost due to fertilizer would be MXN$ 77 000.00 while with treatment 2 it would only require MXN$ 26 000.00 However, the response of the morphological variables that define plant quality show that treatment 5 is the best, given that in most of the variables evaluated there were no statistical differences with respect to treatment 7 and its cost due to fertilization, for the production of one million plants in this treatment amounts to MXN $50 000.00 which represents a saving of 35 %; that is, MXN$ 27 000.00 (Figure 1).



Costo = Cost; *Tratamientos* = Treatments

Figure 1. Fertilizer cost per treatment for the production of one million plants.

Aguilera *et al.* (2016) refer to the costs of the fertilizer, and determined that the controlled release fertilizer 18-6-12 of N-P-K is the most inexpensive to make plantations of *Pinus montezumae* for restoration purposes; this same product was tested in the present study, and in the same way a significant difference was found in the total dry weight. In addition, it is cheaper to fertilize with 3 g than with the higher dose (6 g), but the higher dose increases the morphological characteristics of the plant. Finally, it is feasible to obtain the minimum recommended sizes for the species with any of the two doses of fertilizer.

Conclusions

The water-soluble fertilizers Triple 16 and Triple 19, together with the controlled-release fertilizer, favored a good response in most of the morphological variables of the plant. Therefore, they work as a support to the applied fertilization in the substrate to optimize the initial growth in field of the seedlings of *Prosopis laevigata.*

The Triple 19 fertilizer with the 6 g dose of added controlled release fertilizer gave the best results in the morphological variables, but it was also the third most expensive.

Based on a balance between the best responses of the plants in the morphological variables and the lower costs of fertilization, it is recommended to use treatment 5.

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Conflict of interests

The authors declare no conflict of interests.

Contribution by author

Gardenia de Jesús Reyes: establishment of the experiment, data taking and capture, review of literature and writing of the document; José Ángel Prieto Ruíz: design and establishment of the experiment, edition of the document; Isaac Vázquez Cisneros: design and establishment of the experiment, review and edition of the document; Miguel Ángel López López: interpretation of fertilization results and review of the document; José Ciro Hernández Díaz: advice on the results of cost analysis and review of the document; Jorge Armando Chávez Simental: review of the document.

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