Inoculation of (*Prosopis Laevigata*) by Arbuscular Mycorrhizal Fungi in Different Doses of Organic Matter in Two Types of Soil

Abdul Khalil Gardezi[1*], Sergio Roberto Márquez-Berber[2], Eduardo Valdés Velarde[3], Manuel Ortega Escobar[4], Miguel Jorge Escalona-Maurice[5], Gabriel Haro-Aguilar[6], Mario Ulises Larqué-Saavedra[7]

[*1,4,6] Postgraduate College, Agricultural Science, Department of Hydrosciences, Montecillo Campus, Km. 36.5 Carretera Fed. México-Texcoco, Montecillo, Texcoco, Estado de México, México, 56230.

[2]Crop Science Department, Chapingo Autonomous University, Km 38.5 Carretera Fed. México-Texcoco s/n, Col. Chapingo, Texcoco, Estado de México, Mexico, 56230.

[3]Agroforestry Center for Sustainable Development, Chapingo Autonomous University, Km 38.5 Carretera Fed. México-Texcoco s/n, Col. Chapingo, Texcoco, Estado de México,Mexico, 56230.

[5]Postgraduate College, Rural Development, Regional Geographic Analysis, Montecillo Campus, Km. 36.5 Carretera Fed. México-Texcoco, Texcoco, Estado de México, México, 56230

[7]Metropolitan Autonomous University, Azcapotzalco, Mexico

[*1]Corresponding author: Dr. Abdul Khalil Gardezi, Postgraduate College, Agricultural Sciences, Department of Hydrosciences, Montecillo Campus. Km. 36.5 Carretera Fed. México-Texcoco, Texcoco, Estado de México, México, C.P. 56230. Tel. 595-95-20200 ext. 1165, 1167 or 1171.

Abstract—*The mesquite tree (Prosopis laevigata), besides its conventional uses, has a high potential to recover agricultural areas with salinity problems. It improves the physical and chemical properties of the soil, and in the rehabilitation of degraded arid and semi-arid zones, or those tending to desertification.The aim of this research was to test the effect of organic fertilization and inoculation with Glomus sp. on mesquite trees. We did the experiment under greenhouse conditions. The effect of applying Glomus sp. and organic matter in different doses during the growth of shoots and roots was evaluated in 13 agronomic variables in mesquite seedlings grown in Lithosols and Xerosols soils. We used a complete randomized block design with three replications. After 180 days, we analyzed the data using Statistical Analysis Software (SAS) version 9.2. We observed a positive and significant effect on the growth of the agronomic variables studied under greenhouse conditions, and inoculation with Glomus sp. The organic matter factor presented significant differences ($p \leq 0.05$). We determined that the ideal dose was 55 g per experimental unit. According to the soil used, positive effects ($p \leq 0.05$) were observed for 50% of the agronomic variables in the Xerosols soil with relation to the Lithosols soil. We concluded that the inoculation of Prosopis laevigata with Glomus sp., and adding organic matter favors the growth of both the shots and the roots of the plant.*

Keywords— Earthworms, Glomus sp., Lithosols soil, mesquite tree, vermicompost, Xerosols soil.

I. INTRODUCTION

Mesquite [*Prosopis laevigata* (Humb. Et Bonpl. ex Willd).M.C. Johnst.], has multiple uses: as wood for fuel (firewood and coal), for construction of fences (live fences or walls of logs), for handicrafts and kitchen tools. Also, the use of its pods is for forage and food. The industry uses its resins to manufacture glues, varnishes, and other solvents. The mesquite flowers are very important for honey production because of the nectar bees collected from the trees. We can also use it as a medicinal plant to treat different diseases (Meraz *et al*., 1998; Ríos-Gómez *et al*., 2010). Mesquite trees grow in the desert and semi-desert regions of Mexico. We can find them along the central and southern Pacific coast, the arid regions of the northeast and in the central highlands of Mexico (Sauceda *et al*., 2014).

Mesquite trees and beans (*Phaseolus vulgaris* L.) are very important in the ecosystems because they can fix nitrogen and their organic matter increases the fertility of the soil when incorporated. Thus, improving the nutrition of nearby plants (Gardezi *et al*., 2016; López *et al*., 2010; Prieto-Ruiz *et al*., 2013).

Such an increase in organic matter also contributes to improving the stability and structure of the soil, reducing erosion of marginal soils, degraded soils, and tepetates soils. Tepetates are indurated earthy materials from Mexico that have been reported with different names in different countries in the USA is known as silcrete. The soil capacity for storage water increases, as does the infiltration rate. Mesquite trees have one of the highest photosynthetic rates because of their optimal use of nitrogen and water (Ruiz-Tavares, 2011).

Mesquite (*P. laevigata*.) is the only tree in the ecosystem that has a great potential to rehabilitate arid and semiarid regions prone to desertification Gardezi *et al*., (2008). Also, it can recover agricultural lands with problems of salinity in the soil and water.

Recently, there has been a growing trend to produce mesquite trees in degraded ecosystems for restoration (Prieto-Ruiz *et al*., 2013). Around nine million plants of *Prosopis laevigata* and *Prosopis glandulosa* (Torr.) were produced in 2011 for reforestation programs in Mexico per the National Forestry Commission (Comisión Nacional Forestal (CONAFOR), 2012).

On a different matter, the application of natural and biological fertilizers has received great interest by researchers because they have increased yields with a reduced ecological footprint when compared with the chemical ones (Vessey, 2003; Dadrasan *et al*., 2015). Vermicompost is compost produced when some earthworms (*Eisenia foetida, Eisenia andrei, Lumbricus rubellus*, as an example) transform organic residues into a stable sub product (Soto and Muñoz, 2002). Also, characterized by materials finely divided as peat, with high porosity, good drainage, and great moisture retention. It has a large surface able to absorb and keep essential nutrients in forms easily assimilated by plants, such as nitrates, exchangeable phosphorus, soluble potassium, calcium, and magnesium (Atiyeh *et al*., 2000a; Atiyeh *et al*., 2000b). The organic matter added to the soil improves soil properties such as density, porosity, and the capacity of water absorption (Sree Ramulu, 2001; Singh and Agrawal, 2007).

We have found that the dual inoculation with arbuscular mycorrhizal fungi (*Glomus fasciculatum*), and *Rhizobium* strains helped trees from the genus *Leucaena* and *Prosopis*to mitigate the adverse effects of sodium chloride on the growth and development of juvenile seedlings (Dixon *et al*., 1993). Therefore, the aim of this study was to test the effects of *Glomus* sp., and the application of organic matter on the shots and root growth of mesquite trees (*Prosopis laevigata*) in two different soils.

II. MATERIALS AND METHODS

2.1 Experimental site description

The study was done under greenhouse conditions at the Postgraduate College, Montecillo Campus, State of Mexico, in the spring and summer of 2017. We used two soil types, one red (Xerosols) and the other grey (Lithosols), with the characteristics shown in Table 1. Lithosols soils limited in depth by continuous coherent and hard rock within 10 cm of the surface. Xerosols*soils* have a weak ochric A horizon and an aridic moisture regime; lacking permafrost within 200 cm of the surface.We obtained the soil from Salinas, San Luis Potosi, Mexico (Fig. 1). The location of Salinas is 2,200 meters above sea level, its geographical coordinates are Longitude: 22º 46 '32' ', Latitude: -101º 47' 06 ".

TABLE 1
ANALYSIS OF TWO TYPES OF SOILS

Soil	SP	EC	pH	OM	N inorg	P	K	Ca	Mg	Fe	Cu	Mn	Zn
		$dS\ m^{-1}$	1:02	%	$mg\ kg^{-1}$								
Xerosol (red)	28	0.54	8.3	1.78	35.27	0.85	477.04	6413.24	110.0	12.33	0.11	19.18	1.90
Litosol (gray)	34.7	0.65	7.07	2.05	28.86	1.07	453.58	2249.79	209.6	21.96	2.81	47.96	2.28

Key: SP=Saturation point, EC=Electric conductivity, pH= Hydrogen potential, OM= Organic matter, N inorg= Inorganic nitrogen.

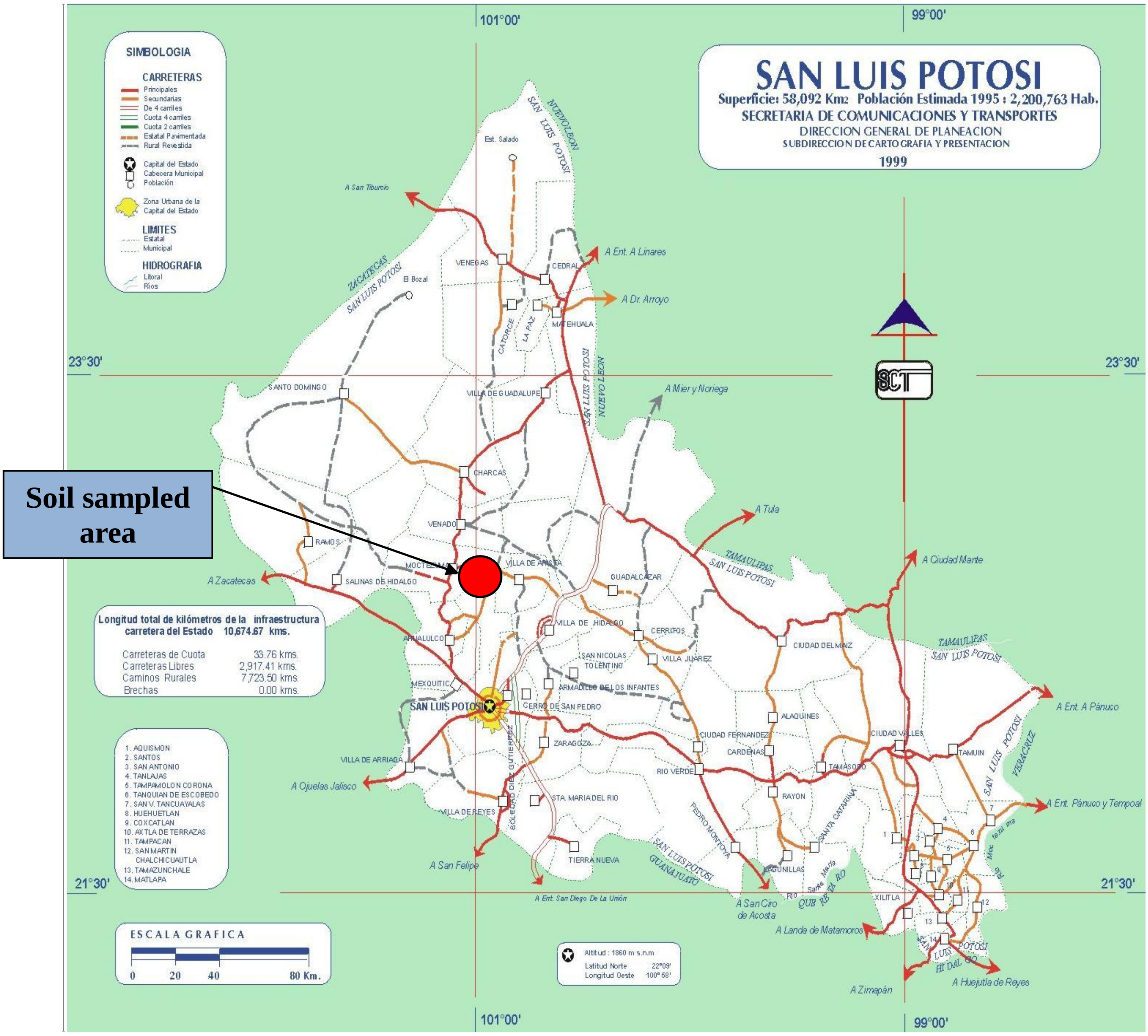

FIGURE 1: Soil sampled area at San Luis Potosi, Mexico
Source: Ministry of Communications and Transport. Mexico.

2.2 Soil analysis

We used the Walkey and Black method to determine the soil's organic matter and the Olsen method for phosphorus. We measured interchangeable bases using ammonium acetate pH 7:1 Normal (CH_3COONH_4) and micronutrients with diethylenetriamine penta-acetic acid (D.T.P.A.).

2.3 Experimental materials

The seeds of *Prosopis laevigata* were collected from Acatlán, Hidalgo State, Mexico and the inoculation were done at planting, mixing 5 g of sand with sorghum roots with 85% colonization of *Glomus sp.* and 1050 spores per 100 g of inert material. The fungus was provided from the collection of the laboratory of microbiology, Department of Agricultural Sciences, Postgraduate College. We applied two levels of mycorrhiza *Glomus* sp., (with and without *Glomus*). Then the mesquite seeds were treated with mechanical scarification (scarification drum with fine sandpaper) for five minutes. Later on, we put the seeds to germinate in foam trays with sterile red volcanic rock as a substrate.When the plants reached an average height of 5 cm, they were transplanted to black polyethylene bags with 3kg of soil and pasteurized with steam water for 4 hours for two consecutive days.

We applied organic matter as a source of vermicompost, prepared by using 60 kg of bovine manure, 25 kg of melon waste, and 15 kg of wheat straw. The mixture was subjected for four months to the action of earthworms. We put four doses of 0, 18.5 g, 37 g, and 55.5 g of vermicompost mixed in three kg bags. The equivalent of 0, 25, 50, and 75 t ha^{-1} of organic matter.

The study lasted 180 days, from planting until harvest, as recommended by Gardezi *et al*., 2009. Thirteen agronomic variables were tested: plant height (cm), the number of branches, leaf area (cm^2), the number of leaves, root length (cm), root volume (cm^3), root fresh weight (g), root dry weight (g), stem diameter (mm), leaves fresh weight (g), leaves dry weight (g), shoot fresh weight (g), shoot dry weight (g). Length measurements were taken with a ruler, diameter with a caliper, weight with an Ohaus digital scale model 605, and leaf area with a Li-Cor LI-3100C area meter.

2.4 Experimental design and treatments

A factorial arrangement with 16 treatments (4x2x2) was used with a randomized block design using three replications. An analysis of variance for all variables registered was done using SAS Computer Software version 9.2, and a Tukey means comparison test for the significant variables (Bautista-Calles *et al*., 2008).

III. RESULTS AND DISCUSSION

3.1 Primary effects

In this study, the treatments influenced all variables but root fresh weight (g). The inoculation of mycorrhiza presented the same tendency. Regarding the application of organic matter, most variables but leaf area (cm^2), the number of leaves, and root fresh weight (g) had significant differences ($p \leq 0.05$). The soils used in this experiment mainly affected the growth of the shoot part (Table 2).

The inoculation with mycorrhiza interacted with the organic matter applied in growth of the mesquite plants measured in plant height, the number of branches, root length, and root volume. Also, an interaction between the two soils used and inoculation with *Glomus sp*. was found in plant height and the number of branches. An interaction between the two soils used and the organic matter applied hada triple interaction of the organic matter, the soils, and the inoculation with *Glomus sp*. as recorded in the number of branches. Therefore, the branching of the mesquite trees was the most sensitive variable to the factors studied in this experiment (Table 2).

In a similar matter, it was found in another species of mesquite (*Prosopis articulata*), and in *Parkinsonia microphylla* a positive response to (height, the number of branches, and stem diameter) to the inoculation with plant growth-promoting microorganisms, arbuscular mycorrhizalfungi, and compost (Bashan *et al*., 2012).

TABLE 2
EFFECT OF THE TREATMENTS ON THE VARIABLES MEASURED

Source of variation	Degrees of freedom	Plant height (cm)	Number of branches	Leaf area (cm^2)	Number of leaves	Root length (cm)	Root Volume (cm^3)	Root fresh weight (g)	Root dry weight (g)	Stem diameter (mm)	Leaves fresh weight (g)	Leaves dry weight (g)	Shoot fresh weight (g)	Shoot dry weight (g)
Treatments	15	3330.9111*	4500.1875*	5410.0764*	4040.9097*	57.2097*	80.1875*	36.9973	0.662*	2.2627*	2.9654*	0.8904*	4.205*	1.1857*
Organic matter (OM)	3	2461.8333*	2664.0208*	3677.9097	1721.6875	61.4097*	93.6875*	53.9969	1.0113*	1.9067*	4.4181*	1.6318*	5.813*	2.3528*
Soil	1	9075.0000*	12065.0208*	8295.0208*	7525.0208*	15.1875	20.0208	25.0708	0.0326	0.8008	7.5764*	1.3906*	0.6464	0.0729
OM x Soil	3	250.3889	1982.1875*	1900.5208	745.2431	8.8542	9.6319	32.1747	0.1828	0.0364	0.3116	0.3001	0.8526	0.2107
Glomus sp.	1	26226.7500*	22663.5208*	45325.5208*	33761.0208*	402.5208*	540.0208*	78.5664	4.0542*	21.3333*	19.9563*	5.542*	40.793*	9.4963*
OM x *Glomus sp.*	3	828.1389*	2895.5764*	2138.5764	2948.3542	66.7431*	106.2986*	31.3733	0.6745	1.0311	0.2668	0.0575	0.1128	0.0908
Soil x *Glomus sp.*	1	3710.0833*	4200.0208*	180.1875	42.1875	2.5208	3.5208	21.7487	0.0188	0.6075	1.0121	0.0668	0.1553	0.1863
OM x Soil x *Glomus sp.*	3	110.2500	1982.9653*	1399.7986	1013.1875	8.9653	3.4653	25.6463	0.073	0.7586	0.3154	0.1296	0.3818	0.0222
Error	32	592.8542	553.8958	1900.6458	1373.9167	15.9792	11.6875	21.7923	0.3165	0.5221	1.0169	0.3115	1.7548	0.3847
Coefficient of variation		31.7200	40.3	40.91	36.11	17.09		139.36	49.78	22.7		50.63	42.79	46.25

The numbers followed by an asterisk have significant differences ($p \leq 0.05$).

3.2 Effect of the organic matter

There was a trend to have higher values in most of the variables recorded, with the application of vermicompost. However, only the dry weight of the leaves had a significant difference between the control and the use of organic matter. Just plant height, stem diameter, shoot dry weight, and root volume showed higher values with greater application of organic matter, but the amount used did not have significant differences ($p \leq 0.05$, Table 3). Taking into account all the variables, the medium quantity of vermicompost used (37.5 g) can be recommended.

TABLE 3
EFFECT OF THE ORGANIC MATTER ON THE VARIABLES MEASURED

Organic matter *	Variables									
	X1	X2	X5	X6	X8	X9	X10	X11	X12	X13
55.5	91.667a	61.917ab	26.083a	24.75a	1.5417a	3.6333a	2.7567ab	1.2592a	3.8042a	1.8667a
37.5	84.417ab	77.083a	22.833ab	23.25a	1.0958ab	3.2667ab	3.0392a	1.3875a	3.5142ab	1.5050ab
18.5	71.75ab	52.667ab	24ab	21.5ab	1.0167ab	3.1667ab	2.7483ab	1.2008a	2.7975ab	1.1500b
0	59.167b	41.917b	20.667b	18.25b	0.8667b	2.6667b	1.665b	0.5617b	2.2667b	0.8425b

**** Grams per experimental unit.***
X1= plant height (cm), X2= number of branches X5= root length (cm), X6= root volume (cm^3), X8= root dry weight (g), X9= stem diameter, X10= leaves fresh weight (g), X11= leaves dry weight (g), X12= shoot fresh weight (g), and X13= shoot dry weight (g).
Means with the same letter within the same column are statistically equal (Tukey, $p \leq 0.05$).

It showed that the addition of organic matter to the soil increased the sustainability of the agricultural production. Organic matter has several desirable properties such as high-water retention, elevated cationic exchange capacity, it improves the availability of nutrients, and the ability to sequester contaminants (Aggelides and Londra, 2000; Weber *et al*., 2007; Asgharipour and Rafiei, 2011). Therefore, vermicompost has great potential for agriculture and horticulture as a source of nutrients (Atiyeh *et al*., 2000a; Atiyeh *et al*., 2000b).Also, the amount of compost applied improves the physical properties of the soil(Aggelides and Londra, 2000).

3.3 Effect of the soil

The Xerosol soil promoted a significantly higher growth of the shoot part of mesquite plants ($p \leq 0.05$, Table 4). The higher quantity of inorganic nitrogen, potassium, and calcium (Table 1) contributed to the better development of the plants. The quantity of nitrogen in the environment is a limiting factor for growth (Erisman, 2011).Phosphorous is another nutrient important for plants, non-available on the soil (Raghothama, 1999; Hammond and White, 2008). However, it seems in sufficient quantities in the Xerosols soils.

TABLE 4
EFFECT OF THE SOILS ON THE VARIABLES MEASURED

Soils	Variables					
	X1	X2	X3	X4	X10	X11
Xerosol	90.5000a	74.2500a	119.7100a	115.1700a	2.9496a	1.2725a
Lithosols	63.0000b	42.5420b	93.4200b	90.1300b	2.1550b	0.9321b

X1= plant height (cm), X2= number of branches, X3= leaf area (cm^2), X4= the number of leaves,X10= leaves fresh weight (g), X11= leaves dry weight (g).
Means with the same letter within the same column are statistically equal (Tukey, $p \leq 0.05$).

3.4 Effect of the mycorrhiza

The inoculation with *Glomus sp*. promoted higher root and shoot growth in the mesquite plants (Table 5). Gardezi *et al.*, (2008) showed similar results with the inoculation of *Glomus intrarradices* in the same trees. They showed that high absorption of mineral nutrients caused an improvement in the growth of the plants. Adding *Glomus sp*. increase the growth of the trees in soils with lower P content, such as the case of the arboreous legume *Acacia farnesiana* (Gardezi *et al*., 1990).

Glomus sp. can stimulate the growth of plants in a better way than phosphorous fertilization (Gardezi and Ferrera-Cerrato, 1992).

TABLE 5
EFFECT OF THE INOCULATION WITH *GLOMUS SP.* ON THE VARIABLES MEASURED

Glomus sp.	Variables											
	X1	**X2**	**X3**	**X4**	**X5**	**X6**	**X8**	**X9**	**X10**	**X11**	**X12**	**X13**
Inoculated	100.1250a	80.1250a	137.2900a	129.1700a	26.2920a	25.2917a	1.4208a	3.8500a	3.1971a	1.4421a	4.0175a	1.7858a
Non inoculated	53.3750b	36.6670b	75.8300b	76.1300b	20.5000b	18.5833b	0.8396b	2.5167b	1.9075b	0.7625b	2.1738b	0.8963b

X1= plant height (cm), X2= number of branches, X3= leaf area (cm^2), X4= leaves number, X5= root length (cm), X6= root volume (cm^3), X8= root dry weight (g), X9= stem diameter, X10= leaves fresh weight (g), X11= leaves dry weight (g), X12= shoot fresh weight (g), and X13= shoot dry weight (g).

Means with the same letter within the same column are statistically equal (Tukey, $p \leq 0.05$).

IV. CONCLUSION

In this study, the inoculation of *Prosopis laevigata* with *Glomus* sp. favored the growth of mesquite seedlings under greenhouse conditions, shoot, and root growth increased. The Xerosols soils from the northern central highlands provided better conditions for the shoot parts. The highest quantity of organic matter applied gave the largest increase in growth. Therefore, we recommend the use of *Glomus* sp. in Xerosols soils with high quantities of organic matter for the production of mesquite plants.

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