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Scientific article

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Efecto de biofertilizantes en el crecimiento de sábila (Aloe barbadensis Miller) y calidad de gel en diferentes contenidos de humedad del suelo

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Abstract: Aloe (*Aloe barbadensis* Miller) is a water deficit-tolerant plant. Products obtained from the leaf have a high commercial value in the medical, food and cosmetological industries. The aim of this study was to evaluate the growth and development of aloe (*Aloe barbadensis* M.) plants and the quality of its gel when applying bat guano extract (BGE) and seaweed extract (SE) in different soil moisture contents. A split-plot randomized block design was used with three replicates. The large plots were soil moisture contents: low (13 to 17 %), medium (18 to 22 %) and high (23 to 27 %); the medium plots were the BGE doses (0 and 20 L·ha^{-1}·year^{-1}), and the small plots the SE doses (0 and 20 L·ha^{-1}·year^{-1}). At 152, 238 and 458 days after the first application of the biofertilizers (DAFAB), plant height (cm), leaf length, width and thickness (cm), gel weight (g) and concentration of total soluble solids (TSS, %) in the gel were measured. Leaf width and thickness were higher when the soil moisture content was close to field capacity (23 to 27 %), while leaf length and width were higher in the first two evaluations when the moisture content was medium (18-22 %). The TSS concentration did not show significant statistical differences ($P \leq 0.05$) in any treatment. At the end of the evaluation cycle (458 DAFAB), BGE increased leaf width and thickness.

Keywords: plant nutrition, arid zones, added value, water stress.

Resumen: La sábila (*Aloe barbadensis* Miller) es una planta tolerante al déficit hídrico. Los productos obtenidos de la hoja tienen un valor comercial alto en las industrias médica, alimenticia y cosmetológica. El objetivo del estudio fue evaluar el crecimiento y desarrollo de plantas de sábila (Aloe barbadensis M.) y la calidad de su gel al aplicar extracto de guano de murciélago (EGM) y extracto de algas marinas (EAM) en diferentes contenidos de humedad del suelo. Se usó un diseño de bloques al azar en parcelas subdivididas con tres repeticiones. Las parcelas grandes fueron los contenidos de humedad del suelo: bajo (13 a 17 %), medio (18 a 22 %) y alto (23 a 27 %); las parcelas medianas las dosis de EGM (0 y 20 L·ha-1·año-1), y las parcelas chicas las dosis de EAM (0 y 20 L·ha-1·año-1). A los 152, 238 y 458 días después de la primera aplicación de los biofertilizantes (DDPAB), se midió la altura de planta (cm), longitud, ancho y grosor de hoja (cm), peso del gel (g) y concentración de sólidos solubles totales (SST, %) en el gel. El ancho y grosor de hojas fueron mayores cuando el contenido de humedad del suelo estuvo próximo a capacidad de campo (23 a 27 %); en tanto que, la longitud y ancho de hoja fueron mayores en las dos primeras evaluaciones cuando el contenido de humedad fue medio (18-22 %). La concentración de SST no mostró diferencias estadísticas significativas (P ≤ 0.05) en ningún tratamiento. Al final del ciclo de evaluación (458 DDPAB), el EGM incrementó el ancho y grosor de la hoja.

Palabras clave: nutrición vegetal, zonas áridas, valor agregado, estrés hídrico.

Introduction

The aloe (*Aloe barbadensis* M.) has a crassulacean acid metabolism (CAM), which makes it tolerant to water deficit. Due to its characteristics, it is a crop that adapts to different environments, from arid to tropical and subtropical climates (Borland, Griffiths, Hartwell, & Smith, 2009; Nobel & Zhang, 2006; Winter, Aranda, & Holtum, 2005); therefore, it is considered as a viable production alternative for marginal agricultural areas characterized by low water availability, surface soils with low organic matter content and other limiting factors common to Mexico's arid zones.

Products obtained from the aloe leaf, such as juice, gel or powder, have high commercial value in the medical, food and cosmetological industries (Eshun & He, 2004; Ni, Turner, Yates, & Tigard, 2004). This is because it strengthens the immune system, aids in the treatment of burns, and restores the digestive system, among other benefits (Pedroza-Sandoval & Gómez-Lorence, 2006).

The water content in plant tissues determines the turgor state of the cells and the volume of the leaves. In the case of succulent plants such as aloe, this parameter affects the quantity and quality of gel (Delatorre-Herrera, Delfino, Salinas, Silva, & Cardemil, 2010; Murillo-Amador et al., 2015). It has been reported that moderate water stress can favor the concentration of total soluble solids (TSS) in the gel, a fact that gives it greater market value (Delatorre-Herrera et al., 2010).

Currently, agronomic techniques continue to be explored to improve the quantity and quality of aloe leaves (Cardarelli et al., 2013; Murillo-Amador et al., 2015; Pedroza-Sandoval et al., 2015) to meet domestic and international market demand. In particular, the Asian and European markets request organic aloe gel, powder and juice (Pedroza-Sandoval & Gómez-Lorence, 2006). However, when aloe is produced organically, its derivatives have a price premium of up to 30 % on the market (Gómez-Tovar, Gómez-Cruz, & Schwententesius-Rindermann, 1999).

For this reason, different sources of organic fertilization have been studied, such as the use of manure (Quiroga-Garza, Cueto-Wong, & Figueroa-Viramontes, 2011), organic extracts (Organización de las Naciones Unidas para la Alimentación y la Agricultura [FAO], 2013), compost produced from organic waste bioprocessed by the action of the red California earthworm (*Eisenia foetida* Savigny, 1826) (Calzada-

Rivera & Pedroza-Sandoval, 2005; Pedroza-Sandoval et al., 2015), algae extract (Aba-Guevara et al., 2016; Canales-López, 1999), humic acids (Aba-Guevara et al., 2016; Pedroza-Sandoval & Durán-Berdejo, 2005) and bat guano extract (Narro, 1985). However, these products have not been evaluated in contrast to soil moisture, which is important considering the fact that at certain levels of water stress the plants tend to increase the concentration of TSS in the juice or gel (Borland et al., 2009; Nobel & Zhang, 2006; Pedroza-Sandoval & Gómez-Lorence, 2006; Pedroza-Sandoval, 1995), which is one of the most valued quality features in the market. Therefore, it is important to evaluate different organic fertilizers under different soil moisture contents.

Bat guano extracts (BGE) have been used to recover nutrients and physico-chemical characteristics in arid soils affected by intensive production practices (Justin & Allison, 2007). Seaweed extracts (SE) are reported to have better properties than chemical fertilizers, because they more slowly release some elements such as nitrogen, in addition to being rich in micronutrients (Pedroza-Sandoval et al., 2015).

Therefore, the objective of this study was to evaluate the growth and development of aloe plants and the quality of their gel when applying bat guano extract and seaweed extract to different soil moisture contents.

Materials and methods

Geographic location

The study was carried out in the experimental field of the Arid Zone Regional University Unit of the *Universidad Autónoma Chapingo* in Bermejillo, Durango, Mexico (23° 54' North latitude and 103° 37' West longitude, at 1,130 masl). This area has a desert climate, with average rainfall of 250 mm per year and annual potential evaporation of 2,600 mm. The annual average temperature is 20 °C, which fluctuates from 28 to 40 °C. The coldest period is from December to January, with an average of 4.9 °C (Comisión Nacional del Agua [CNA], 2006).

Study factors

Soil moisture levels

Three soil moisture levels were tested: low (13 to 17 %, equivalent of -1.5 to -0.3 MPa), medium (18 to 22 %, equivalent of -0.18 to -0.07 MPa) and high (23 to 27 %, equivalent of -0.06 to -0.03 MPa), where the permanent wilting point (PWP) and field capacity (FC) are 13 and 27 %, respectively. The irrigation-drought method was used to maintain treatments with a favorable soil moisture level (near FC) and an unfavorable one (near PWP), by means of controlled water supply (Jiménez-Galindo & Acosta-Gallegos, 2013) using a tape-type drip irrigation system, with which different soil moisture level treatments were provided. The soil characteristics were: bulk density of 1.2 $g{\cdot}cm^{-3}$, capillarity of $L = 2.3669T^{0.4215}$ (L in cm and T in min), infiltration rate of 1.3 $cm{\cdot}h^{-1}$, mean daily evapotranspiration of 11 mm and experimental evaporation coefficient of 70 %.

The irrigations were applied according to the soil moisture level, which was verified with a digital meter (Soil Tester model HB-2) with real-time reading. The soil moisture supply calibration curve based on water potential (MPa) was determined with a pressure plate extractor (Soil Moisture Equipment Co Model 1500F1). After the initial irrigation standardized to field capacity, the soil moisture was allowed to fall according to the soil moisture treatments indicated above, proceeding to the recovery irrigations when a 4 % depletion was detected in each treatment.

Bat guano extract

The chemical composition of the BGE is 9.6 % phosphorus oxide (P_2O_5), 2.5 % N, 2.32 % potassium oxide (K_2O), 14.1 % calcium oxide (CaO), 6.29 % magnesium oxide (MgO), 0.49 % Fe, 0.0162 % Cu, 0.0715 % Zn, 0.00021 % Co, 0.002 % Mo, 0.00418 % Bo and 11.5 % organic matter (Justin & Allison, 2007). The dose used was 20 $L{\cdot}ha^{-1}{\cdot}year^{-1}$ BGE and the control was without application.

Seaweed extract

The SE are produced by a regional company called *Sanialga Mex, S.A. de C.V*. Its chemical composition is 14800, 14500, 13600, 1320, 750, 62, 505, 404 and 147 $mg{\cdot}L^{-1}$ of P, N, Na, Mg, P, Ca, Zn, Fe and Cu, respectively (Frikha et al., 2011). A dose of 20 $L{\cdot}ha^{-1}{\cdot}year^{-1}$ SE was used, and the control was without application.

The combination of the three soil moisture levels and the two doses (0 and 20 $L{\cdot}ha^{-1}{\cdot}year^{-1}$) of each type of extract resulted in a total of 12 treatments. The BGE and SE applications were carried out in May, August and November 2014, with one third of the total dose being applied per application date. The same procedure was repeated in February, May and August of 2015. Both biofertilizers were applied in liquid form with a manual backpack sprayer adapted with a steel tube at the height of the nozzle so that it could be inserted in the soil to 10 cm deep in the plant's rhizosphere area.

Experimental and treatment design

A split-plot randomized block design was used with three replicates. The large plots were the usable moisture levels (from 13 to 17, 18 to 22 and 23 to 27 %), the medium plots were the BGE doses (0 and 20 $L{\cdot}ha^{-1}{\cdot}year^{-1}$) and the small plots the SE doses (0 and 20 $L{\cdot}ha^{-1}{\cdot}year^{-1}$).

When both products were to be applied, only 10 L·ha^{-1}·year^{-1} of each were supplied. The experimental unit was three furrows 8 m long and 1 m wide between each furrow. The useful plot was the middle furrow of each treatment, from which four plants were selected at random to perform the measurements of the respective variables.

Variables evaluated

At 152, 238 and 458 days after the first application of the biofertilizers (DAFAB), the gel weight (g) was measured using a manual procedure for removing the cuticle from the leaf to obtain the gel fillet, TSS concentration in the gel (%), leaf length (cm), leaf width (cm), leaf thickness (cm) and plant height (cm). Leaf length, width and thickness were measured with a Vernier caliper, while for plant height a 2-m ruler was used. TSS content was determined with the Calzada-Rivera & Pedroza-Sandoval (2005) method, using a porcelain crucible at constant weight in which 1 g of the gel was deposited and dried in a Binder BD oven at 105 °C for 24 h. An analytical balance (model SHIMADZU AY220) was used for determining the weights.

Statistical analysis of data

Analysis of variance and Tukey's range test ($P \leq 0.05$) were performed using Statistical Analysis System software (SAS, 2002).

Results and discussion

Moisture content

In Table 1 it can be seen that the height of the plant did not show significant statistical differences ($P \leq 0.05$) due to soil moisture at any of the three evaluation dates. On the other hand, leaf length and width were greater at 152 and 238 DAFAB with the medium soil moisture content (18 to 22 %). Leaf thickness showed statistical differences ($P \leq 0.05$) among the different moisture treatments, with the high content (23 to 27 %) obtaining the greatest thickness at the first two evaluation dates. At 458 DAFAB there was no difference between the three soil moisture levels for any of the variables evaluated, which could be indicative of aloe's tolerance to water stress.

Table 1
Plant height and leaf length, width and thickness at different sampling dates and three soil moisture contents in the cultivation of aloe (*Aloe barbadensis* Miller).

Soil moisture/ Humedad del suelo	DAFAB[1]/DDPAB[1]					
	152		238		458	
	Plant height (cm)/ Altura de planta (cm)	Leaf length (cm)/ Longitud de hoja (cm)	Plant height (cm)/ Altura de planta (cm)	Leaf length (cm)/ Longitud de hoja (cm)	Plant height (cm)/ Altura de planta (cm)	Leaf length (cm)/ Longitud de hoja (cm)
Low (13-17 %)/ Bajo (13-17 %)	61.7 a[z]	44.4 b	64.9 a	48.5 ab	51.1 a	33.5 a
Medium (18-22 %)/ Medio (18-22 %)	65.3 a	47.4 a	66.5 a	49.0 a	49.2 a	32.1 a
High (23-27 %)/ Alto (23-27 %)	63.9 a	44.4 b	64.5 a	46.9 b	50 a	32.2 a
HSD/DMSH	6.12	2.39	2.72	1.75	3.64	3.32
	Leaf width (cm)/ Ancho de hoja (cm)	Leaf thickness (cm)/ Grosor de hoja (cm)	Leaf width (cm)/ Ancho de hoja (cm)	Leaf thickness (cm)/ Grosor de hoja (cm)	Leaf width (cm)/ Ancho de hoja (cm)	Leaf thickness (cm)/ Grosor de hoja (cm)
Low (13-17 %)/ Bajo (13-17 %)	6.2 b	0.72 c	8.0 b	1.84 b	6.6 a	1.5 a
Medium (18-22 %)/ Medio (18-22 %)	6.9 a	0.96 b	8.6 a	1.86 b	6.4 a	1.5 a
High (23-27 %)/ Alto (23-27 %)	7.0 a	1.71 a	8.3 ab	2.03 a	6.1 a	1.4 a
HSD/DMSH	0.40	0.12	0.48	0.10	0.62	0.10

The results indicate that aloe, because of its succulent nature, is capable of conserving high water potentials within certain limits, even under water stress conditions, allowing it to continue its growth (Granados-Sánchez, López-Ríos, & Gama-Flores, 1998) without affecting cell multiplication and division in tissues (Hsiao & Bradford, 1983). This is important since it means that in the early stages of leaf development (152 and 238 DAFAB, for this study) there is growth under different soil moisture conditions, with the variants already specified for leaf length, width and thickness; however, these effects are lost at 458 DAFAB, possibly associated with physiological drought tolerance responses.

Aloe is a genus known for its CAM photosynthetic system, which makes it capable of adapting to water deficit conditions. These types of plants are also capable of assuming the C_3 photosynthetic process under favorable soil moisture conditions (Ehleringer, 1995). This could explain the greater leaf width and thickness response obtained in medium and high soil moisture levels. It has been recognized that tolerance to water deficit is detrimental to the capacity for growth and development (Ehleringer, 1994; Nobel & Zhang, 2006), even in plants with CAM.

Bat guano extract

When BGE was applied, leaf length, width and thickness were greater than the control only at the last evaluation date (458 DAFAB), indicating that this biofertilizer is slow in its process of incorporation into the plant and in showing its benefits (Table 2).

Table 2

Plant height and leaf length, width and thickness at different sampling dates when applying and not applying bat guano extract (BGE) in the cultivation of aloe (*Aloe barbadensis* Miller).

BGE dose (L·ha^{-1}·year^{-1})/ Dosis de EGM (L·ha^{-1}·año^{-1})	DAFAB[1] / DDPAB[1]					
	152		238		458	
	Plant height (cm)/ Altura de planta (cm)	Leaf length (cm)/ Longitud de hoja (cm)	Plant height (cm)/ Altura de planta (cm)	Leaf length (cm)/ Longitud de hoja (cm)	Plant height (cm)/ Altura de planta (cm)	Leaf length (cm)/ Longitud de hoja (cm)
0	63.3 a[z]	44.8 a	65.7 a	47.5 a	50.8 a	31.8 b
20	64.0 a	46.1 a	65.0 a	48.8 a	49.5 a	34.1 a
HSD/DMSH	4.17	1.63	1.85	1.19	2.48	2.26
	Leaf width (cm)/ Ancho de hoja (cm)	Leaf thickness (cm)/ Grosor de hoja (cm)	Leaf width (cm)/ Ancho de hoja (cm)	Leaf thickness (cm)/ Grosor de hoja (cm)	Leaf width (cm) / Ancho de hoja (cm)	Leaf thickness (cm)/ Grosor de hoja (cm)
0	6.6 a	1.1 a	8.4 a	1.9 a	6.1 b	1.4 b
20	6.8 a	1.1 a	8.2 a	1.9 a	6.6 a	1.5 a
HSD/DMSH	0.27	0.08	0.33	0.07	0.42	0.07

Seaweed extract

Applying 20 L·ha^{-1}·year^{-1} of SE favored plant growth and leaf thickness at 458 DAFAB. Leaf length increased at both 238 and 458 DAFAB (Table 3). This means that the release of SE's active compounds is slow and gradual, and that their effects are not shown until 15 months after first application. This is consistent with the findings reported by Aba-Guevara et al. (2016) and Pedroza-Sandoval et al. (2015), who mention that the best time for cutting the leaf, due to its degree of development and therefore gel content, is from June to September of each year. In addition, they recommend to stop cutting from October to April which is when, due to the cold, the leaf's dimensions are negatively affected.

Table 3

Plant height and leaf length, width and thickness at different sampling dates when applying and not applying seaweed extract (SE) in the cultivation of aloe (*Aloe barbadensis* Miller).

SE dose (L·ha^{-1}·year^{-1})/ Dosis de EAM (L·ha^{-1}·año^{-1})	DAFAB[1]/DDPAB[1]					
	152		238		458	
	Plant height (cm)/ Altura de planta (cm)	Leaf length (cm)/ Longitud de hoja (cm)	Plant height (cm)/ Altura de planta (cm)	Leaf length (cm)/ Longitud de hoja (cm)	Plant height (cm)/ Altura de planta (cm)	Leaf length (cm)/ Longitud de hoja (cm)
0	61.8 a[z]	43.0 a	63.6 a	47.0 b	48.1 b	32.1 b
20	65.4 a	45.6 a	67.0 a	49.3 a	52.2 a	33.8 a
HSD/DMSH	4.17	1.63	1.85	1.19	2.48	2.26
	Leaf width (cm)/ Ancho de hoja (cm)	Leaf thickness (cm)/ Grosor de hoja (cm)	Leaf width (cm)/ Ancho de hoja (cm)	Leaf thickness (cm)/ Grosor de hoja (cm)	Leaf width (cm)/ Ancho de hoja (cm)	Leaf thickness (cm)/ Grosor de hoja (cm)
0	6.6 a	1.1 a	8.1 a	1.8 a	6.2 a	1.4 b
20	6.8 a	1.1 a	8.4 a	1.9 a	6.1 a	1.5 a
HSD/DMSH	0.27	0.08	0.33	0.07	0.42	0.07

Effect of double interaction: BGE-SE

There was no significant effect in the BGE-SE interaction for any of the variables evaluated (data not shown); it is thus considered that these biofertilizers act independently.

In general, a clear effect of the applied biofertilizers is not shown, although it is by the soil moisture content with a trend towards a better effect under the medium soil moisture content (18-22 %) with or without BGE or in combination with SE. The rest of the treatments had a slight effect on plant height at the different sampling dates (Tables 4 and 5). These results partially coincide with those of Pedroza-Sandoval et al. (2015), who point out that applying compost in combination with humic acids has no effect on aloe growth, but higher plant height does occur when applying 14 L·ha^{-1}·year^{-1} algae extract.

Table 4

Morphometric characteristics in the first and second evaluation using bat guano extract (BGE), seaweed extract (SE) and three soil moisture contents in aloe (*Aloe barbadensis* Miller).

Treatment/ Tratamiento	DAFAB[1]/DDPAB[1]							
	152				238			
	PH (cm)/ AP (cm)	LL (cm)/ LH (cm)	LW (cm)/ AH (cm)	LT (cm)/ GH (cm)	PH (cm)/ AP (cm)	LL (cm)/ LH (cm)	LW (cm)/ AH (cm)	LT (cm)/ GH (cm)
LMC-NG-NS/ CHB-SG-SA	58.8 a[z]	45.1 ab	6.05 bc	0.72 c	63.6 bc	48.4 abcd	8.2 a	1.99 abc
LMC-NG-WS/ CHB-SG-CA	61.0 a	41.6 b	5.9 c	0.65 c	64.3 bc	48.1 abcd	7.8 a	1.73 c
LMC-WG-NS/ CHB-CG-SA	68.2 a	45.7 ab	6.7 abc	0.76 c	67.0 ab	49.1 abcd	8.2 a	1.78 bc
LMC-WG-WS/ CHB-CG-CA	64.8 a	45.2 ab	6.1 bc	0.76 c	64.7 bc	48.3 abcd	7.9 a	1.85 bc
MMC-NG-NS/ CHM-SG-SA	60.1 a	44.5 b	6.4 abc	0.85 bc	57.1 c	45.8 cd	8.1 a	1.75 bc
MMC-NG-WS/ CHM-SG-CA	70.3 a	47.3 ab	6.6 abc	0.93 bc	73.8 a	52.7 a	8.9 a	1.91 abc
MMC-WG-NS/ CHM-CG-SA	64.3 a	46.0 ab	7.1 ab	0.90 bc	62.8 bc	46.5 bcd	8.3 a	1.87 bc
MMC-WG-WS/ CHM-CG-CA	66.6 a	51.8 a	7.5 a	1.17 b	72.5 a	51.1 ab	9.1 a	1.90 abc
HMC-NG-NS/ CHA-SG-SA	67.4 a	46.4 ab	7.1 ab	1.69 a	67.6 ab	47.8 bcd	8.4 a	1.9 abc
HMC-NG-WS/ CHA-SG-CA	66.4 a	44.1 b	7.3 a	1.78 a	67.6 ab	50.0 abc	8.8 a	2.18 a
HMC-WG-NS/ CHA-CG-SA	58.5 a	44.3 b	6.4 abc	1.76 a	63.7 bc	44.4 d	7.8 a	2.0 abc
HMC-WG-WS/ CHA-CG-CA	63.6 a	43.8 b	7.1 ab	1.60 a	59.0 c	45.5 cd	8.2 a	2.04 ab
HSD/DMSH	17.18	6.72	1.14	0.33	7.65	4.91	1.36	0.30

Table 5
Morphometric characteristics in the third evaluation using bat guano extract (BGE), seaweed extract (SE) and three soil moisture contents in aloe (*Aloe barbadensis* Miller).

Treatment/ Tratamiento	458 DAFAB[1]/458 DDPAB[1]			
	PH (cm)/AP (cm)	LL (cm)/LH (cm)	LW (cm)/AH (cm)	LT (cm)/GH (cm)
LMC-NG-NS/ CHB-SG-SA	47.5 b[z]	33.2 ab	6.6 abc	1.52 ab
LMC-NG-WS/ CHB-SG-CA	54.1 ab	35.6 ab	6.9 ab	1.6 ab
LMC-WG-NS/ CHB-CG-SA	51.5 ab	32.4 ab	6.6 abc	1.45 ab
LMC-WG-WS/ CHB-CG-CA	52.4 ab	32.9 ab	6.4 abc	1.58 ab
MMC-NG-NS/ CHM-SG-SA	45.1 b	31.8 ab	6.1 abc	1.45 ab
MMC-NG-WS/ CHM-SG-CA	50.5 ab	31.3 ab	6.3 ab	1.48 ab
MMC-WG-NS/ CHM-CG-SA	47.5 b	32.4 ab	5.9 abc	1.47 ab
MMC-WG-WS/ CHM-CG-CA	54.5 ab	33.0 ab	7.3 a	1.63 a
HMC-NG-NS/ CHA-SG-SA	50.3 ab	33.1 ab	6.3 abc	1.56 ab
HMC-NG-WS/ CHA-SG-CA	58.3 a	39.7 a	7.4 a	1.74 a
HMC-WG-NS/ CHA-CG-SA	46.9 b	29.8 b	5.6 bc	1.31 b
HMC-WG-WS/ CHA-CG-CA	44.5 b	30.3 b	5.1 c	1.33 b
HSD/DMSH	10.24	9.34	1.74	0.30

In general, it can be observed that the SE acts better in medium moisture contents. This may be related to the great diversity of microelements presented by SE, which favors better nutrient availability (Khan et al., 2009), without the soils being very dry or very saturated with water. In addition, organic fertilizers influence the soil structure, favoring an increase in beneficial biota, which leads to increasing the formation of aggregates that allow greater water retention and greater gas and nutrient exchange in the rhizosphere (Julca-Otiniano, Meneses-Florián, Blas-Sevillano, & Bello-Amez, 2006).

Leaf length was greater at 238 DAFAB, especially with medium soil moisture content (18 to 22 %) and SE. Plant height did not vary at the first evaluation date (152 DAFAB), but it did at 238 DAFAB, with slight variations among treatments, highlighted by the medium soil moisture contents with SE and BGE, both separately. Similarly, leaf length and width were the highest in the medium soil moisture content with BGE and SE during the first two evaluations (152 and 238 DAFAB, Table 4). By contrast, at 458 DAFAB, plant height and leaf length, width and thickness were the highest in the high moisture content and with SE, while at the same date the lowest values in all morphological variables were obtained by combining high moisture contents and BGE (Table 5).

The results obtained, considering the moisture content, suggest that this factor was the one that was most associated with leaf thickness. Pedroza-Sandoval et al. (2015) indicated that leaf thickness was greater when applying 5 $t \cdot ha^{-1}$ of compost, without effect when applying SE. This is important for aloe leaf gel production systems, where leaf thickness is the main morphological variable associated with this productive characteristic.

In general, plant height and leaf length, width and thickness were higher when applying SE, which may be related to the fact that this product promotes the reversible catalytic enzymatic hydrolysis reactions associated with plant growth (Khan et al., 2009). It has also been reported that applying organic products as biofertilizers improves photosynthetic activity, since there is a greater assimilation of CO_2 in the plant, which leads to greater growth (García-Delgado, Bustos-Vázquez, Cervantes-Martínez, & Compeán-Ramírez, 2010).

The lack of consistency in the response of aloe growth and development (plant height and leaf length, width and thickness), over time, may be associated with the development stage of the plant, since it has been reported that the difference in stress response is based on the phenological stage in which the plant is found (Pedroza-Sandoval & Gómez-Lorence, 2006) and the mineralization process that involves the contribution of some macro and microelements (Rosen & Bierman, 2005).

The absence of effect in the majority of the variables measured when using guano could be related to the dose used in this study. According to Cardarelli et al. (2013), when guano doses were doubled, from 4 to 8 $g \cdot L^{-1}$, it resulted in greater plant height, a higher number of leaves, and greater fresh and dry weight of aloe leaf (*A. barbadensis* and *A. arborescens*). The above could suggest that the doses evaluated in this study were below the level required by the plant.

The amount of gel produced was higher (417.7 g) in the high moisture content, without presenting significant statistical differences ($P \leq 0.05$) with the medium moisture content (394.9 g; Table 6). This is consistent with what was reported by Rodríguez-García, Jaso-de Rodríguez, Gil-Marín, Angulo-Sánchez, and Lira-Saldivar (2007), who obtained the highest yield when the plant had no water stress, with a soil moisture content of 27 %; in addition, they observed a significant decrease in drought conditions.

Table 6

Amount of gel and total soluble solids at different soil moisture contents and biofertilizer doses in aloe (*Aloe barbadensis* Miller) at 458 days after first application of biofertilizers.

Treatment/Tratamiento	Gel content (g)/Contenido de gel (g)	Total soluble solids (%)/ Sólidos solubles totales (%)
LMC-NG-NS[1]/CHB-SG-SA[1]	216.3 cd[z]	14.46 a
LMC-WG-NS/CHB-CG-SA	216.3 bcd	16.73 a
LMC-WG-WS/CHB-CG-CA	216.3 abcd	10.71 a
LMC-NG-WS/CHB-SG-CA	196.03 d	10.31 a
MMC-NG-NS/CHM-SG-SA	322.9 abcd	8.58 a
MMC-WG-NS/CHM-CG-SA	310.5 abcd	17.17 a
MMC-WG-WS/CHM-CG-CA	287.5 abcd	18.10 a
MMC-NG-WS/CHM-SG-CA	394.9 ab	15.78 a
HMC-NG-NS/CHA-SG-SA	411.2 a	22.25 a
HMC-WG-NS/CHA-CG-SA	417.7 a	18.87 a
HMC-WG-WS/CHA-CG-CA	356.5 abcd	14.61 a
HMC-NG-WS/CHA-SG-CA	375.0 abc	12.47 a
HSD/DMSH	177.2	20.16

The TSS showed no significant statistical difference ($P \leq 0.05$). The values ranged from 8.58 to 22.25 % (Table 6), regardless of soil moisture content and application or not of BGE and SE. It is possible that the water stress conditions applied in this study were not sufficient to show the expected benefit, or there was a lack of interaction between stress conditions and other environmental factors such as environmental temperature and soil types in marginal condition (superficial, infertile and low organic matter soils, among others).

Conclusions

The medium (18-22 %) and high (23-27 %) soil moisture contents, mainly the latter, were the ones that most affected the plant's morphology (leaf length, width and thickness). The effect of SE on plant growth occurred at 152 and 238 days after the first application. The combination of SE (20 $L \cdot ha^{-1} \cdot año^{-1}$) with the medium soil moisture content (18 to 22 %) gave the largest leaf length and width in the first two evaluations (152 and 238).

The water stress did not affect the concentration of total soluble solids in the gel, nor did applying the seaweed and bat guano extracts, while the amount of gel obtained was greater when the high moisture content and BGE were combined.

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