Colegio de Postgraduados

Response of sugarcane (*Saccharum officinarum*) to organic fertilizer in northern Belize

Tun, Sergio J.[1]**; Interián-Ku, Victor M.**[1]**; Cázares-Sánchez, Esmeralda**[2]**; Sosa-Madariaga, Jaime D.**[2]**; Hernández-Rodríguez, Gustavo**[1*]

[1] Tecnológico Nacional de México, Campus Instituto Tecnológico de la Zona Maya, Carretera Chetumal-Escárcega, Km 21.5, Ejido Juan Sarabia, Othón P. Blanco, Quintana Roo, México, C.P. 77965.

* Correspondence: interku2002@yahoo.com.mx

Citation: Tun, S. J., Interián-Ku, V. M., Cázares-Sánchez, E., Sosa-Madariaga, J. D., & Hernández-Rodríguez, G. (2023). Response of sugarcane (*Saccharum officinarum*) to organic fertilizer in northern Belize. *Agro Productividad*. https://doi.org/10.32854/agrop.v16i7.2468

Academic Editors: Jorge Cadena Iñiguez and Lucero del Mar Ruiz Posadas

Received: January 08, 2023.
Accepted: June 28, 2023.
Published on-line: October 17, 2023.

Agro Productividad, 16(8). August. 2023. pp: 99-107.

ABSTRACT

Objective: To provide an ecological alternative for sugarcane producers in northern Belize evaluating the response of the crop to organic fertilizer (bovine biol and bokashi).

Design/Methodology/Approach: Ten treatments with different doses and combinations of bokashi and bovine manure-based biol were applied in a crop of the sugarcane variety B79-474 in the northern region of Belize.

Results: The combination of 3 t ha^{-1} of bokashi applied to the soil and 2% biol applied to the leaves recorded the best sugarcane yields, with an average weight of 2.0 kg per processable stalk.

Study Limitations/Implications: Bokashi production involves the use of large amounts of manure, which are difficult to transport and handle with simple tools.

Findings/Conclusions: The sugarcane variety B79-474 had a positive response to organic fertilizer (average yield: 2.0 kg per stalk and 330 t ha^{-1} of cane), applying 3 t ha^{-1} of bokashi to the soil and 2% biol to the leaves.

Keywords: Sugarcane, organic agriculture, organic fertilizers, sustainable development.

INTRODUCTION

The production of sugarcane is of great importance in the world. Sugarcane is grown on 25.4 million hectares, distributed in more than 130 countries, with an average yield of 80 t ha^{-1} (FAOSTAT, 2013). The stalk of this crop is considered an agricultural fruit since it distributes and stores sugar. It consists approximately of 75% water and is made up of nodes and internodes, whose length, diameter, shape, and color differ, depending on the variety (SAGARPA, 2017).

Image by Albrecht Fietz at Pixabay

Sugarcane production is the main agricultural industry of Belize, making an important contribution to the agricultural sector, national income, and foreign exchange. It accounts for 7.8% of the gross domestic product (GDP), 10% of employment, and 6% of the currency income (Statistical Institute of Belize, 2015). However, the sugarcane production system is unsustainable, as a result of the environmental deterioration caused by the inefficient application of fertilizers and herbicides that have directly affected soil and water quality and caused a nutritional imbalance in plants (Chi *et al.*, 2017, 2020).

Other factors that affect this activity in Belize are the decrease in world demand for sugar and the competition from larger producers. Therefore, other markets have been explored, such as the United States of America, the Caribbean Community (CARICOM), and the fair trade market (Morris *et al.*, 2017).

Within the agronomic field, one of the alternatives to solve the nutritional problem and contain the rise in the prices of synthetic fertilizers is the use of organic fertilizers, which can be produced locally with vegetable and animal by-products. In addition, they have shown a positive impact on crop yield, because they enrich the soil with microorganisms and nutrients and likewise contribute to environmental conservation (Velasco-Velasco, 2018).

These fertilizers include bokashi ("fermented organic matter"), which was developed by Japanese scientists. Its use activates and increases the number of microorganisms in the soil; it also improves its physical properties, chemical characteristics, and organic matter (Ramos-Agüero and Terry-Alfonso, 2014). For its part, biol is one of the products obtained from the anaerobic fermentation of organic matter (*e.g.*, animal manure); its production dates back to the year 1900, when the first biodigester for the production of biogas was built in India (Aguilar and Botero-Botero, 2016). It is currently used to fertilize the leaves of crops, due to its mineral and organic molecule content which favors plant development. Cowo-Cruz (2022) recommends the use of agricultural organic fertilizers in northern Belize. Currently, the use of this type of fertilizer is non-existent in that region of the country. This recommendation is particularly pressing, given the well-known risks to human health involved in the use of agrochemicals.

In this context, the objective of the present work was to evaluate the response of sugarcane cultivation to the application of organic fertilizer to the soil and the leaves, as an economic and ecological production alternative for sugarcane producers in northern Belize.

MATERIALS AND METHODS

The study was carried out in the village of Louisville, Corozal district, in northern Belize. The region is located at 5 m.a.s.l, has Vertisols and Inceptisols, its climate is tropical with summer rainfall, and has an annual rainfall of 1,500 mm. The average temperature is 25.9 °C (National Meteorological Service of Belize, 2014).

Manure production

To produce biol, the following ingredients were used: 53 kg of fresh bovine manure, 110 L of chlorine-free water, 7 L of molasses, 1.3 L of whole milk, and 267 g of yeast. These ingredients were mixed in a 200-L dark plastic container, which was hermetically sealed. Previously, a gas outlet was adapted on the lid, using a 1.5-m long and ½" diameter plastic hose. The other end of the hose was fitted in a 2-L plastic bottle filled with water, which served as a seal to prevent the entry of air into the container and guarantee the anaerobic fermentation process. The biol was applied to the crop two and a half months after it was manufactured.

To produce bokashi, 425 kg of bovine manure, 25 kg of green leaves, 25 kg of dry leaves, 2.5 kg of powdered charcoal, and 2.5 kg of stove ash were first mixed. Afterward, that mix was hydrated with a solution made with 2.5 kg of molasses, 300 g of yeast, and 100 liters of lukewarm water. The entire mixture was turned over every three days and the process ended after approximately 45 days when the temperature of the fertilizer equaled the environmental temperature (35°C on average). This fertilizer was used two months after its manufacture, to enable the mineralization process to conclude properly.

Land preparation

First, the weeds were manually eliminated with a machete, then the land was leveled plowing once with a tractor, followed by subsoiling to loosen the soil, and a harrowing pass to break clods or large soil particles. To establish the experimental plot, furrowing was done every 1.5 m × 30 m. In total, a treatment was established in each of the 10 furrows.

Cane variety used and sown

The Sugar Industry Research and Development Institute (SIRDI) recommends the use of the B79-474 variety for this area of Belize. Segments of 1 m in length, 1 to 2 cm in diameter, 7 to 8 months old, and with good vigor and development were used for planting. The sowing was carried out in February 2021.

Weed, pest, and disease control

The weeds were removed manually with a machete when their size exceeded 10 cm, to control them without the use of herbicides. Regarding pests, there are two major animals that have a negative impact on sugarcane production in northern Belize: the froghopper (*Aeneolamia* spp.) and the stem borer (*Diatraea* spp.) (Chaves Solera, 2012). However, they were completely eradicated with three applications of biol (with doses according to the analyzed treatments) and 227 grams of the biological control (*Metarhizium anisopliae*) plus 20 mL of *Dipax per* L.

Treatments

Ten treatments were evaluated in this research, applying bokashi organic fertilizers to the soil and bovine manure biol to the leaves. In addition, the synthetic chemical fertilizer most frequently used in the area (15-4-28 + 2Ca and 1.36Mg) was used as a control (Table 1).

Three months after the sugarcane sowing, the bokashi was applied as follows: a) 50% to the soil in the form of a stream, opening a channel in the furrow 10 cm away from the stalk, at a 5-cm deep, which was later covered with earth; and b) the remaining 50% was

Table 1. Treatments evaluated in sugarcane cultivation in northern Belize.

Treatment	Bocashi		Biol in water (%)	Fertilizer kg ha^{-1}
	t ha^{-1}	kg tra^{-1}		
T1	0	0	0	Control without fertilization
T2	0	0	0	250
T3	2	9.1	0	
T4	3	13.6	0	
T5	4	18.2	0	
T6	0	0	1	
T7	0	0	2	
T8	0	0	3	
T9	2	9.1	1	
T10	3	13.6	2	

applied 30 days after the first application. The amount applied per 30-m furrow (Table 1) was calculated as follows: ((Dose per ha in kg/66 furrows) /100 m per furrow) * 30 m of one furrow.

Based on the dose indicated for each treatment, biol was applied to the leaves every 30 days, before 9:00 a.m. (Table 1). A 20-L backpack sprayer was used and the nozzle was directed towards the underside of the leaves. The first application was carried out when the first leaves reached 30 to 40 cm long. In total, three applications were made.

Variables evaluated in stalks

Once the crop cycle was over (11 months after sowing), 20 processable stalks were randomly selected from the planting furrow. The green tip (between sections 8 and 10) and the dry leaves were removed from each stalk and the following elements were recorded: the diameter in the middle part (with a digital vernier), the length (with a tape measure), and the weight of the stalk (with a digital scale), as well as the weight of the dry leaves and the tip (with a digital scale). Additionally, 20 non-processable stalks were randomly selected and their total length and weight were also recorded.

Maturity index in processable stalks

A portable refractometer was used to measure °Brix in the first and last third of the stalk. Based on these data, the maturity index (MI) was calculated according to the methodology proposed by Viswa-Nath and Kasinath (1935), with the following formula:

$$\textit{Maturity Index}\ (MI)\ \frac{°\mathrm{Bx}\ \textit{of the upper internode of the stalk}}{°\mathrm{Bx}\ \textit{of the lower internode of the stalk}}$$

Values close to 1 show greater maturity and values close to zero show less maturity.

Yield estimation and ratio of processable/non-processable stalks

To determine the number of processable and non-processable stalks, a 2-m border was left at the beginning of each row and three 1-m long sampling plots were established 5 m apart from each other. To estimate the yield, the average weight of the processable stalks was determined (eliminating dry leaves and the tip) and multiplied by the average number of stalks per linear meter, per 100 meters, and per 66 rows. To determine the processable:non-processable stalks ratio, the number of processable stalks was divided by the number of non-processable stalks.

Experimental design and statistical analysis

The experimental design was completely randomized, with 10 treatments and 20 repetitions, considering one plant as the experimental unit. The resulting data was subjected to an analysis of variance and a means comparison, using Tukey's test and the SAS version 9.0 statistical package (Statistical Analysis System).

RESULTS AND DISCUSSION

The measured variables recorded highly significant differences ($P \leq 0.001$) among the treatments, with the exception of stalk length which only registered significant differences ($P \leq 0.005$), as indicated in Table 2.

The stalk diameter, stalk weight, maturity index, and weight of dry leaves in processable stalks variables had a positive effect in combination with the application of bokashi and biol to the soil and the leaves, respectively. Treatment 10 (3 t of bokashi and 2% of biol) showed the highest average values (Tukey, $P \leq 0.05$). It is important to highlight that the separate use of these fertilizers did not have an obvious effect on the crop (T3-T8).

With respect to the weight of the stalk tip, the T10 recorded a lower average value, indicating that this treatment tends to increase the quality of the stalk (length, diameter, and °Brix) and to reduce the number of stalks that do not meet the grinding requirements, although all treatments had similar lengths (Table 3). Specifically, the stalk length has a statistically equal behavior, although the stalk diameter and maturity index variables are separated —with T10 recording the highest average values. According to Table 3, it is possible to distinguish the effect of the fertilizers: on the one hand, by themselves, bokashi and biol do not increase the average value of the variables in the plant, but, on the other hand, at high doses, their combination potentiates the effect (3 t of bokashi and 2% of biol per hectare).

Table 2. Mean squares of the analysis of variance for the variables measured in sugarcane to which organic fertilizers were applied in northern Belize.

SV	DF	SD	SL	SW	MI	NDL	WDL	TW	PW	PL
		Processable stems							Unprocessable stems	
Tre	9	120***	0.2885*	2.4***	128.9***	50.4**	9214***	0.0152**	0.3849***	0.7403***
Error	190	14.9	0.1280	0.3200	17.9	19	1753	0.0056	0.1108	0.2057

SV=Source of variation; Tre=Treatment; DF=Degrees of freedom; *=≤0.05; **≤0.01; ***=≤0.001; ns=not significant; SD=Stalk diameter; SL=Stalk length; SW=Stalk weight; MI=Maturity Index; NDL=Number of dry leaves; WDL=Weight of dry leaves; TW=tip weight; PW=Plant Weight; PL=Plant length.

Table 3. Average treatment values and the response variables of sugarcane to organic fertilizers in northern Belize.

T	N	SD (mm)	SL (m)	SW (kg)	MI (%)	NDL	WDL (g)	TW (kg)	PW (g)	PL (m)
T1	20	27.2 bcd	1.77 a	1.66 abc	81.3 c	14.4 ab	93.5 bc	0.1805 ab	0.31 ab	1.23 abc
T2	20	24.4 d	1.73 a	1.23 bcd	87.1 ab	14.7 ab	111 ab	0.2504 a	0.18 b	1.25 abc
T3	20	23.8 d	1.70 a	0.99 d	85.2 bc	11.4 b	65.6 c	0.2121 ab	0.64 a	1.09 bc
T4	20	24.3 d	1.71 a	1.18 bcd	87.7 ab	10.8 b	62 c	0.2117 ab	0.15 b	1.05 bc
T5	20	28.9 ab	1.90 a	1.73 ab	88.0 ab	12.3 ab	89.9 bc	0.1736 b	0.30 b	1.47 ab
T6	20	26.6 bcd	1.78 a	1.27 bcd	89.0 ab	12.4 ab	97.7 abc	0.1894 ab	0.34 ab	1.23 abc
T7	20	28.8 abc	2.02 a	1.43 bcd	89.4 ab	13.2 ab	92.3 bc	0.2044 ab	0.38 ab	0.91 c
T8	20	24.9 cd	1.98 a	1.55 bcd	88.9 ab	12.9 ab	93.5 bc	0.1879 ab	0.41 ab	1.57 a
T9	20	25.5 bcd	1.88 a	1.12 cd	88.2 ab	12.9 ab	78.9 bc	0.1589 b	0.33 ab	1.15 abc
T10	20	31.2 a	1.98 a	2.14 a	89.9 a	16.2 a	136.4 a	0.1617 b	0.23 b	1.17 abc
HSD		3.91	0.3623	0.5728	4.2946	4.4434	42.4	0.0758	0.337	0.4592

T=Treatment; N=Number of repetitions after treatment; SD=Stalk diameter; SL=Stalk length; SW=Stalk weight; MI=Maturity Index; NDL=Number of dry leaves; WDL=Weight of dry leaves; TW=Tip Weight; PW=Plant weight; PL=Plant length; HSD=Honestly significant difference. Values with the same letters between rows are not statistically different (Tukey, $P \leq 0.05$).

According to the yield estimation, treatment 10 obtained the best results (330 t ha^{-1}), followed by 1 and 5, showing that the combination of high doses of organic fertilizers tends to achieve a higher yield (Table 4) than that reported by the sugar industry of Belize (54 to 64 t ha^{-1} on average). Meanwhile, during the 2020-2021 production cycle, Mexico reported 64 t ha^{-1} (Chaves Solera, 2012; Comité Nacional para el Desarrollo Sustentable de la Caña de Azúcar (CONADESUCA), 2022). For its part, the Inter-American Development Bank (2017) indicates that Belizean sugarcane has low quality and productivity (average yield: 42 t ha^{-1}) which is 50% lower than countries such as Guatemala and Nicaragua, which usually produce 100 t ha^{-1}. The ratio of processable:non-processable stalks indicates

Table 4. Estimated yield per hectare of sugarcane and processable:non-processable stalk ratio in northern Belize.

T	ASLM	AWS	ER (t ha^{-1})	PS	NPS	RP/NPS
T1	18	1.8	213	35	26	1.35
T2	17	1.5	168	33	20	1.65
T3	15	1.2	118	29	13	2.23
T4	16	1.6	169	30	13	2.31
T5	19	1.7	213	36	19	1.89
T6	17	1.7	190	33	17	1.94
T7	20	1.5	198	38	12	3.17
T8	18	1.5	178	35	19	1.84
T9	16	1.3	137	31	11	2.82
T10	25	2.0	330	49	29	1.69

T=Treatment; ASLM=Average stalks per linear meter; AWS=Average weight of stalks; ER=Estimated return; PS=processable stalks; NPS=non-processable stalks; RP/NPS=Ratio of processable: non-processable stalks.

that treatments 7, 9, 4, and 3 had a greater number of processable stalks for each non-processable stalks; however, their estimated yields are lower than those of T10, suggesting that these variables are independent from each other.

This work can demonstrate the high quality of organic fertilizers, since they even exceed the average yield of sugarcane harvest in Belize and they can replace synthetic chemical fertilizers and reduce production costs.

Similar studies confirm the findings of this work. For example, García-Peña *et al.* (2020) used bokashi and biol in *Cucurbita argyrosperma* and exceeded the average domestic yield by 50%, obtaining 4.48 t ha^{-1} of fresh fruit and 1.76 t ha^{-1} of dry seed. Likewise, Favorito *et al.* (2019) showed that the application of bokashi in corn cultivation increased grain yield by 20% compared to the other treatments. For their part, González *et al.* (2015) observed higher increases in stalk length, stalk diameter, and yield, applying 30% Supermagro (biol) to a watermelon crop. Meanwhile, Ferreira *et al.* (2013) recorded yields of 10 t ha^{-1} as a result of the application of 1,000 g m^{-2} of bokashi to broccoli cultivation. Finally, Diniz *et al.* (2008) recorded 12.5 t in the same species with the application of 25 t ha^{-1} of this fertilizer. All of this proves the importance, and above all the effect, of these organic fertilizers for the productivity of cultivated species.

Other studies show that the use of organic fertilizers in crops improves the physical, chemical, and biological properties of the soil. For example, Matos-Pech *et al.* (2022) used cover crops with the *Vigna unguiculata* L., *Phaseolus lunatus* L., and *Mucuna pruriens* L. species and registered a positive improvement in organic matter (3.6-3.9%), electrical conductivity, pH, macronutrient content (N, P, K, Ca, Mg, and Na), micronutrient content (B, Fe, Mn, Cu, Zn), and C:N ratio, as well as the sum of exchangeable bases (meq/100 g). For their part, Cervantes-Vázquez *et al.* (2022) found the same improvements in soil where watermelon was grown, as a result of the application of 6 to 9 t ha^{-1} of vermicompost combined with bovine manure as fertilizer. Similarly, Orozco Corral *et al.* (2016) record that applying 6 t ha^{-1} of vermicompost lead to an increase of $>$10% in water storage capacity, 83% in cation exchange capacity, $>$24% in organic matter, and $>$113% in microbial biomass. Likewise, Gashua *et al.* (2022) and Pérez *et al.* (2008) carried out a chemical characterization of the bokashi fertilizer and found the following mineral elements: Mo, N, P, K, Ca, Mg, Mn, Fe, Zn, Na, Cd, Cr, Cu, Ni, and Pb.

The chemical and nutritional improvements of the soil and crop yields are mainly based on the solubilizing action of microorganisms present in organic fertilizers on mineral elements. A few examples follow:

1) the biological fixation of N is caused by the action of free-living organisms or in symbiosis with the roots, as is the case of bacteria of the following genera: *Azospirillum*, *Enterobacter*, *Klebsiella*, *Pseudomonas*, *Burkholderia*, *Rhizobium*, *Ensifer*, *Bradyrhizobium*, *Azorhizobium*, and *Mesorhizobium* (Berrada and Fikri-Benbrahim, 2014; Dhayalan and Karuppasamy, 2021; Estrada-de los Santos *et al.*, 2001; Jarvis *et al.*, 1997).
2) P fixation is the result of the action of several bacteria and fungi. The bacteria include: *Erwinia*, *Pseudomonas*, *Bacillus*, *Rhizobium*, *Klebsiella*, *Burkholderia*, *Serratia*,

Achromobacter, *Agrobacterium*, *Microccocus*, *Aerobacter*, *Flavobacterium*, *Enterobacter*, *Arthrobacter*, *Rhodobacter*, and *Pantotea*. For their part, fungi include: *Aspergillus*, *Penicillium*, *Trichoderma*, and *Fusarium* (Awasthi *et al*., 2011; Jones and Oburger, 2011; Khan *et al*., 2010).

3) Finally, K fixation is also carried out by both bacteria and fungi. The former includes *Bacillus mucilaginosus*, *B. Edaphicus*, *B. Circum*, *Arthrobacter* spp., *Burkholderia*, *Acidithiobacillus ferrooxidans*, *Enterobacter homaechei*, *Paenibacillus glucanolyticus*, *Paenibacillus frequentans*, *Cladosporium*, and *Aminobacter*. The latter includes: *Aspergillus terreus*, *Aspergillus niger*, *Rhizobium*, and *Pseudomonas* (Meena *et al*., 2014; Pattnaik *et al*., 2021; Prabina *et al*., 2022; Upadhyay *et al*., 2022).

CONCLUSIONS

T10 (3 tons per hectare of bokashi applied to the soil + 2% bovine biol diluted in water applied to the leaves) was the best treatment, with an average weight of 2.0 kg per stalk, a total weight of 330 t ha^{-1}, and a maturity index of 89, which exceeds all treatments. In addition, the use of bovine biol as a spotted fly (*Aeneolamia varia*) repellent decreases the population of this pest in the plantation, although it does not eradicate it.

REFERENCES

Aguilar, F. X., & Botero Botero, R. (2016). Los beneficios económicos totales de la producción de biogás utilizando un biodigestor de polietileno de bajo costo. *Tierra Tropical, 2*(1), 15–25.

Awasthi, R., Tewari, R., & Nayyar, H. (2011). Synergy between plants and P-solubilizing microbes in soils: effects on growth and physiology of crops. *International Research Journal of Microbiology, 2*(12), 484–503.

Banco Interamericano de Desarrollo. (2017). *Creación de una industria sostenible de caña de azúcar en el norte de Belize*. (Banco Interamericano de Desarrollo, Ed.; 1st ed., Vol. 1).

Berrada, H., & Fikri-Benbrahim, K. (2014). Taxonomy of the Rhizobia: Current Perspectives. *British Microbiology Research Journal, 4*(6), 616–639.

Cervantes-Vázquez, T. J. Á., Preciado-Rangel, P., Fortis-Hernández, M., Valenzuela-García, A. A., García-Hernández, J. L., & Cervantes-Vázquez, M. G. (2022). Efectos en el suelo por la aplicación de estiércol bovino y vermicompost, en el cultivo de sandía (*Citrullus lanatus*). *Terra Latinoamericana, 10*(e835), 1–13.

Chaves Solera, M. A. (2012). Diagnóstico de la agroindustria del azúcar de Belice para el desarrollo de un servicio de extensión e investigación y desarrollo de la industria del azúcar. https://www.sirdi.bz/

Chi, L., Huerta-Lwanga, E., Álvarez Solís, D., Kú-Quej, V. M., & Mendoza-Vega, J. (2020). Abundance and diversity of soil macroinvertebrates in sugarcane (*Saccharum* spp.) plantations under organic and chemical fertilization in Belize. *Acta Zoológica Mexicana, 36*(1), 1–19.

Chi, L., Mendoza-Vega, J., Huerta, E., & Álvarez.-Solís, J. M. (2017). Effect of long-term sugarcane (*Saccharum* spp.) cultivation of chemical properties of soil in Belize. *Communications in Soil Science and Plant Analysis, 48*(0), 741–755.

Comité Nacional para el Desarrollo Sustentable de la Caña de Azúcar (CONADESUCA). (2022). *Reporte final de producción de caña de azúcar de la zafra 2021-2022*.

Cowo Cruz, Elbert. (2022). Propuesta para la transición de un sistema productivo convencional de caña de azúcar a prácticas con enfoque agroecológico en la zona norte (orange walk y corozal) de Belice. CATIE.

Dhayalan, V., & Karuppasamy, S. (2021). Plant growth promoting rhizobacteria in promoting sustainable agriculture. *Global Journal of Environmental Science and Management, 7*(3), 1–18.

Diniz, E. R., Silva Santos, R. H., Urquiaga, S. S., Peternelli, L. A., Barrella, T. P., & de Freitas, G. B. (2008). Crescimento e produção de brócolis em sistema orgânico em função de doses de composto. *Ciência e Agrotecnologia , 32*(5), 1428–1434.

Estrada-de los Santos, P., Bustillos-Cristales, R., & Caballero-Mellado, J. (2001). Burkholderia, a genus rich in plant-associated nitrogen fixers with wide environmental and geographic distribution. *APPLIED AND ENVIRONMENTAL MICROBIOLOGY, 67*(6), 2790–2797.

FAOSTAT. (2013). *Estadísticas de producción de alimentos. Caña de azúcar*. (FAO, Ed.).

Favorito, A. C., Pereira Seidel, E., Kohler, T. R., Ribeiro de Carvalh, W., Pan, R., & Soares de Vasconcelos, E. (2019). Application of biofertilizers in cover of and its effects on organic maize. *Journal of Experimental Agriculture International, 39*(6), 1–7.

Ferreira, S., de Souza, R. J., & Gomes, A. L. A. (2013). Produtividade de brócolis de verão com diferentes doses de bokashi. *Agrogeoambiental, 1*(2), 31–38.

García-Peña, E., Interián-Ku, V. M., Ayil-Gutiérrez, B. A., Cázares-Sánchez, E., Sánchez-Azcorra, P. S., & Casanova-Villarreal, V. E. (2020). Yield of "Pipiana" squash (*Cucurbita argyrosperma* Huber) in Vertisol soil due to the effect of biostimulants . *Agroproductividad, 13*(10), 39–43.

Gashua, A. G., Sulaiman, Z., Yusoff, M. M., Samad, M. Y. A., Ramlan, M. F., & Salisu, M. A. (2022). Assessment of fertilizer quality in horse waste-based bokashi fertilizer formulations. *Agronomy, 12*(937), 1–19.

González, J. D., Mosquera, J. D., & Torrente Trujillo, A. (2015). Efectos e impactos ambientales en la producción y aplicación del abono supermagro en el cultivo de sandía. *Revista Ingeniería y Región, 13*(1), 103–111.

Jarvis, B. D. W., Berkum, P. van, Chen, W. X., Nour, S. M., Fernández, M. P., Cleyet-Marel, J.-C., & Gillis, M. (1997). Transfer of *Rhizobium loti*, *Rhizobium huakuii*, *Rhizobium ciceri*, *Rhizobium mediterraneum*, *Rhizobium tianshanense* to *Mesorhizobium* gen. Nov. *International Journal of Systematic Bacteriology, 47*(3), 895–898.

Jones, D. L., & Oburger, E. (2011). Solubilization of phosphorus by soil microorganisms. *In* E. Bünemann, A. Oberson, & E. Frossard (Eds.), *Phosphorus in Action* (1st ed., Vol. 26, pp. 169–198). Springer.

Khan, M. S., Zaidi, A., Ahemad, M., Oves, M., & Wani, P. A. (2010). Plant growth promotion by phosphate solubilizing fungi – current perspective. *Archives of Agronomy and Soil Science, 56*(1), 73–98.

Matos-Pech, G., Arcocha-Gómez, E., López-Hernández, M. B., Garma-Quen, P., González-Valdivia, N. A., & Echavarría-Góngora, E. de J. (2022). Efecto de abonos verdes inoculados en las propiedades químicas de un luvisol férrico de Campeche, México. *Terre Latinoamericana, 40*(e933), 1–9.

Meena, V. S., Maurya, B. R., & Verma, J. Prakash. (2014). Does a rhizospheric microorganism enhance K+ availability in agricultural soils? *Microbiological Research, 169*(5–6), 337–347.

Morris, E., Angel, A., & Hernández, N. (2017). *The impact of failing sugar prices on growth and rural livelihoods*. (Inter-American Development Bank, Ed.; Vol. 1). Inter-American Development Bank.

National Meteorological Service of Belize. (2014). *Climatology*.

Orozco Corral, A. L., Valverde Flores, M. I., Martínez Téllez, R., Chávez Bustillos, C., & Benavides Hernández, R. (2016). Propiedades físicas, químicas y biológicas de un suelo con biofertilización cultivado con manzano. *Terra Latinoamericana, 34*(0), 441–456.

Pattnaik, S., Mohapatra, B., & Gupta, A. (2021). Plant growth-promoting microbe mediated uptake of essential nutrients (Fe, P, K) for crop stress management: microbe–soil–plant continuum. *Frontiers in Agronomy, 3*(689972), 1–20.

Pérez, A., Cespedes, C., & Nunez, Pedro. (2008). Caracterización fisica-química y biológica de enmiendas orgánicas aplicadas en la producción de cultivos en República Dominicana. *Revista de La Ciencia Del Suelo y Nutrición Vegetal, 8*(3), 10–29.

Prabina, J., Baby, A. S., Thankappan, S., & Susan, A. (2022). Potassium releasing bacteria for unlocking soil potassium a way forward for judicious use of chemical fertilizers. *International Journal of Plant & Soil Science, 34*(19), 49–61.

Ramos Agüero, D., & Terry Alfonso, E. (2014). Generalidades de los abonos orgánicos: importancia del bocashi como alternativa nutricional para suelos y plantas. *Cultivos Tropicales, 35*(4), 52–59.

SAGARPA. (2017). *Planeación agrícola nacional 2017-2030*.

Statistical Institute of Belize. (2015). *Estimated mid-year population 2015 and merchandize trade, population and household* (Statistical Institute of Belize., Ed.; 1st ed., Vol. 1). Halcrow Group Limited.

Upadhyay, S. K., Srivastava, A. K., Rajput, V. D., Chauhan, P. K., Bhojiya, A. A., Jain, D., Chaubey, G., Dwivedi, P., Sharma, B., & Minkina, T. (2022). Root exudates: mechanistic insight of plant growth promoting rhizobacteria for sustainable crop production. *Frontiers in Microbiology, 13*(916488), 1–19.

Velasco-Velasco, J. (2018). Los biofertilizantes y la caña de azúcar (*Saccharum* spp.). *Agro Productividad, 7*(2), 60–64.

Viswa-Nath, B., & Kasinath, S. (1935). *The top/bottom ratio method for determining the maturity of sugar cane*. (International Society of Sugar Cane Technologist, Ed.; pp. 172–189). International Society of Sugar Cane Technologist.