International Journal of Recycling of Organic Waste in Agriculture (2019) 8:309–315
https://doi.org/10.1007/s40093-019-0248-8

ORIGINAL RESEARCH

Nutrient content of fermented fertilizers and its efficacy in combination with hydrogel in *Zea mays* L.

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Received: 13 April 2018 / Accepted: 17 February 2019 / Published online: 1 March 2019

Abstract

Purpose The nutritional content of fermented fertilizers was determined, and the effect of its application in combination with hydrogel was evaluated in a bioassay with maize plants.

Methods The fertilizers were produced in artisanal biodigesters and the bioassay was carried out in pots with CP-569 maize. The nutritional content of the fermented fertilizers was evaluated, and in maize plants growth variables were measured, along with N–P–K contents in the aerial and root biomass.

Results The types of biol show different characteristics for organic matter, N, N–NH_4, N–NO_3, P, K, Ca, Mg, Fe, Cu, Zn, Mn and B, as well as physical characteristics. The terms of the bioassay, the treatments with super absorbent polymer (SAP), biol and biol + SAP, showed significant statistical differences in terms of plant height, stem diameter and number of leaves 30 days after emergence. In the dry weight of aerial and root biomass, no statistical differences were found. In terms of the contents of N–P–K in biomass, statistical differences were found for P in aerial biomass and K in both aerial and root biomass.

Conclusion Due to their physical and chemical properties, biols are an alternative to fertilizers. With the application of biol and SAP, maize plants undergo significant increases in height, stem diameter and number of leaves. By applying biol and SAP, the contents of N–P–K were not increased significantly in the aerial and root biomasses in comparison to the control.

Keywords Fermented fertilizer · Agroecology · Hydrogel · *Zea mays* L. · Nutrition

Introduction

To produce high-quality crops (Fathy et al. 2018), an alternative to organic fertilizer is fermented fertilizer, which is the name given to the effluents produced in the fermentation or digestion of organic wastes from biodigesters (Ndubuaku et al. 2013). Biogas production through anaerobic digestion leaves organic residues (digestates), which are rich in nutrients, the use of which can replace or at least reduce the use of mineral fertilizers in crop production (Sogn et al. 2018).

Digestate or effluent is composed of a liquid fraction known as biol and the solid fraction biosol, the biol being the most widely used and which accounts for 90% of the effluent (Rivero 2012). The liquid phase of digestates is rich in nutrients, such as ammonium (NH_4^+), phosphorus (P), potassium (K) and nitrogen (N) available to the plant by microbial decomposition and mineralization of the solid phase of the digestates (Sogn et al. 2018). Biol is an alternative for the fertilization of crops due to its nutrient content (Kaparaju and Rintala 2011; Masse et al. 2013; Ndubuaku et al. 2013; Osorio 2005).

The quality of the biol, taking into account the process of fermentation in terms of the composition of nutrients and physical properties, depends on the materials (inputs) used during fermentation (Ndubuaku et al. 2013). Biol is obtained with the use of inputs such as animal manure, mainly bovines (Bustamante et al. 2012; Holm-Nielsen

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et al. 2009), as well as flours, molasses and plants (de Oliveira et al. 2014). Farmers can modify the content of nutrients in the liquid fertilizer and add different sub-products such as fish guts, seaweed or human urine (Osorio 2005), mineral salts (Agbulu and Idu 2008) and milk whey (Rivera and Hensel 2013), enhancing the efficiency of materials used to obtain quality fertilizer (Preston 2005). Sometimes, a pre-digestion of the inputs used is performed, for example in a study by Kataki et al. (2017) similar to this study, initially crushed rice husk and green stubble were hydrolyzed for 30 days as pretreatment prior to anaerobic digestion. Green leaves of *Ipomoea* were cut before digestion and cow manure was used without any previous treatment, both for simple digestion and for co-digestion.

The relevance of the production of biol lies in the capability of use and accessibility to local inputs by farmers (Agbulu and Idu 2008). A small-scale biodigester is enough to produce biol and most farmers have manure available in their production units to use this technique; therefore, the construction and use of biodigesters is expected to have a low cost and that the materials used are available locally (Osorio 2005). The use of biol as an agricultural fertilizer boosts the use of organic residues to reduce the environmental impact of agriculture, reducing the amount of inorganic fertilizers (Walsh et al. 2012) and satisfying the need for alternative, cheaper and more efficient fertilizers (Soria Fregoso et al. 2001). It has been used with fertilizers for *Zea mays* L. (Leblanc et al. 2007; Morris and Lathwell 2004), *Abelmoschus esculentus* (Ndubuaku et al. 2013) and *Carica papaya* (Barrientos et al. 2007), mainly to contribute to the nutritional needs for their growth.

As a complement to the fertilization of crops, hydrogels or superabsorbent polymers (SAP) are used to immobilize, encapsulate and release, in a controlled manner, water and organic fertilizers. The polymers absorb and retain large amounts of water and soil nutrients and keep them available for the plant. They can absorb up to 150 times their own volume, with a retention capacity of 980 mL of water mL^{-1} g^{-1} (Pedroza-Sandoval et al. 2015). With this, soils improve their moisture release and retention properties, which translate into a higher production and resistance of plants to conditions of drought (Dabhi et al. 2013; Koupai et al. 2008). Some authors have reported the use of SAP in crops such as maize, *Capsicum nahum* L., *Lactuca sativa* L. and Anaheim chilies (*Capsicum annuum* L.), which have resulted in greater plant height, foliar area, grain yield, accumulation of biomass in maize and greater root development (Egrinya Eneji et al. 2013; López-Elías et al. 2013; Torres et al. 2008). In the case of maize, SAP doses of 60 kg ha^{-1} have been used (Islam et al. 2011; Najafinezhad et al. 2015), producing important effects on the growth of maize (Pedroza-Sandoval et al. 2015).

The objective of the research was to evaluate the effect of the application of fermented liquid fertilizer and superabsorbent polymers on the growth and absorption of N–P–K in maize plants through a bioassay.

Materials and methods

Location

The investigation was carried out in the Colegio de Postgraduados, Campus Veracruz, in the land named Tepetates, in the municipal area of Manlio Fabio Altamirano, Veracruz, México, 19.27°N, 96.27°W at a height of 36 m above sea level, in the months of May 2015 and January 2016.

Fermented fertilizer production

Type batch biodigesters were created by hand and at low cost between March and July, the "dry season". For this, we used buckets with lids, with a capacity of 19 L each. They were connected to a hose to condition the exit of gas and sealed using insulating tape at the exit to avoid leaks. The hose was finally led to the escape valve using a 0.6 L PET bottle, filled halfway with water (Fig. 1). A low-cost stationary digester does not suggest a sophisticated design. Perfect sealing of the gas outlet is necessary, as well as the monitoring of the exhaust valve, always taking care to contain in the water. In the exhaust valve with water, the gas is released safely when there is high pressure inside the digester.

Different plant and animal by-products were used and the procedure was carried out using the anaerobic digestion technique, according to the methodology described by Osorio (2005). The bucket was placed under the sun for a 60-day period. The bucket was shaken every week to achieve a uniform fermentation of all the materials. At the end of this period, the effluent was obtained. For this, three types of biols were produced (Table 1). Fresh bovine manure, sugarcane molasses, and *Mucuna pruriens var. utilis* paste, harvested in flowering, were used.

At the end of the fermentation process, the solid and liquid parts of the fertilizer were separated by filtration, using a plastic millimetric mesh for the types of biol. A 500 mL sample was taken using containers of that volume and they were not exposed to light. They were later taken to the laboratory. The following were established using the methodology established by the Official Mexican Norm NOM-021-RECNAT-2000 (SEMARNAT 2002): pH, electric conductivity, organic matter, total nitrogen, ammonium, nitrates, phosphorus, calcium, magnesium, iron, copper, zinc, manganese and boron.

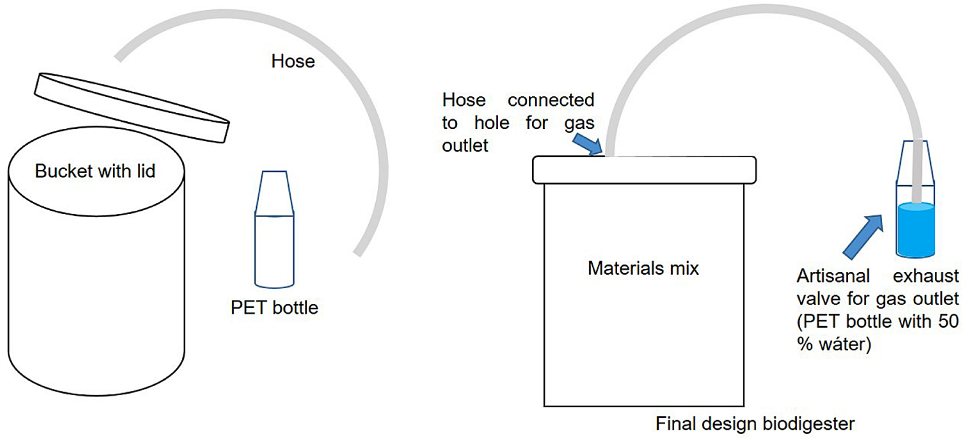

Fig. 1 Design of the biodigester used

Table 1 Materials used for the preparation of the three types of biol

Type of biol	Composition[a]
Biol 1	Water (58%), manure (22%), molasses (10%) and soy paste (10%)
Biol 2	Water (58%), manure (22%), molasses (5%), soy paste (5%) and *Mucuna pruriens var. utilis* (10%)
Biol 3	Water (58%), manure (22%), molasses (5%) and *Mucuna pruriens var. utilis* (15%)

[a]All the inputs were mixed and later incorporated in the biodigester

Bioassay

For the sowing of maize with the application of biol and superabsorbent polymers, soil, which displayed the following characteristics, was collected: pH 7.5, N total 0.33%, electric conductivity 1.04 dS m^{-1}, organic matter 7.73%, inorganic nitrogen 98.3 mg kg^{-1}, P 33.81 mg kg^{-1}, K 684 mg kg^{-1}, cationic exchange capacity 31.8 Cmol (+) kg^{-1}, apparent density 1.07 mg m^{-3}, field capacity 28.53% and saturation point 54.11%.

The study evaluated four treatments: (1) application of superabsorbent polymers (SAP), (2) application of fermented fertilizer (biol) + SAP, (3) application of biol only and (4) a control (no application). The experiment used a randomized complete block design with five repetitions. Three CP-569 maize seeds were sown in pots at a depth of 3 cm; at germination, only one plant was chosen and the rest were discarded. The experimental unit consisted of each pot with an average of 5.3 kg of soil with one plant, with 20 plants in the experiment.

Each plant was added 1 g of the Silos de Agua® super absorbent polymer (SAP) at the time of planting, using 62.5 kg ha^{-1}. A similar dose to that used by Islam et al. (2011) and Najafinezhad et al. (2015) (60 kg ha^{-1}) was deposited by making a hole in the soil, 5 cm deep, and at a distance of 10 cm from the plant. For the case of corn, Biol 1 was the used in the bioassay. The biol was applied at the emergence of the plants and 15 after day, 10 mL per plant, diluted at 50% volume per volume of water (v/v), 20 mL per plant of the solution. The amounts of nitrogen, phosphorus and potassium applied in the solution were 22.23, 0.26 and 1.2 mg L^{-1}, respectively, for each application. The contribution of the application of biol per hectare is 2.7 kg of nitrogen, 0.03 kg of phosphorus and 0.1 kg of potassium. The plants were irrigated with tap water and kept free of weeds.

Plant height was measured using a ruler and read from the base of the stem up to the maximum length of the leaves, picking them up upward. The stem diameter was measured using a digital caliper, measuring at a height of 5 cm from the base of the stem, and the leaves of each plant were counted. This was carried out 30 days after emergency (DAE) of the plants. Plant tissue samples were taken 35 days after planting (DAP), and the aerial biomass (leaves and stem) and root biomass of the plants were separated and placed in paper bags by treatment and repetition. The roots were washed to remove leftover soil using tap water.

The samples were dried in a forced air oven at a temperature of 60 °C, until it reached a constant weight, which represents the dry matter in grams. A chemical analysis was performed on the plant tissue of the aerial biomass and root biomass of the plant, determining nitrogen by the Kjeldahl method, phosphorus digested with a diacid mixture and determined by photocolorimetry by reduction with molybdenum vanadate and potassium digested with a diacidic mixture and determined by flame spectrophotometry. The statistical analyses of the study variables were carried out using the SAS statistical package version 9.4 for Windows (SAS 2014), with average tests using Tukey $\alpha = 0.05$.

Results and discussion

Fermented fertilizer production

The nutrient concentrations show differences among the three types of biol (Table 2), since the fertilizer quality depends on the inputs with different physical and chemical characteristics (Herrán et al. 2008). Another indicator of quality is fermentation; an optimal period can be 40 days according to de Oliveira Neto et al. (2017), who mention that the greatest availability of nutrients in biofertilizer occurs with a longer fermentation period, because in a short period sufficient decomposition of biofertilizer does not occur to release nutrients. In our study, fermentation was carried out for 60 days, so it is considered that a quality fertilizer was produced. Also, bad odors are eliminated, which is an indicator that the fermentation has been carried out successfully, as it happened in this study. The above favors the elimination of coliforms (Arslan Topal et al. 2016; Hernández-Chontal et al. 2016).

Table 2 The nutritional characteristics of the three types of biol

Characteristic	Biol 1	Biol 2	Biol 3
pH	3.82	3.83	3.74
EC (dS m^{-1})	15.64	10.38	10.83
OM (%)	11.56	4.27	3.77
N total (mg L^{-1})	2223	812	974
N–NH_4 (mg L^{-1})	8.2	80.3	40.3
N–NO_3 (mg L^{-1})	1075.3	500.3	233.2
P (mg L^{-1})	26.11	9.48	12.93
K (mg L^{-1})	120	39.7	36.9
Ca (mg L^{-1})	831.9	311.65	481.6
Mg (mg L^{-1})	526.6	331.35	432.5
Fe (mg L^{-1})	215.0	191.9	115.4
Cu (mg L^{-1})	2.3	1.1	0.5
Zn (mg L^{-1})	16.4	14.6	13.1
Mn (mg L^{-1})	28.9	22.2	16.5
B (mg L^{-1})	39.54	9.58	19.41

EC electric conductivity, *MO* organic matter, *N total* total nitrogen, *N–NH₄* ammonium, *N–NO₃* nitrates, *P* phosphorus, *K* potassium, *Ca* calcium, *Mg* magnesium, *Fe* iron, *Cu* copper, *Zn* zinc, *Mn* manganese, *B* boron

Bioassay

The plant height variable showed significant differences ($p = 0.0068$ and HSD of 7.99 cm, Table 3). SAP and biol treatments reached the greatest level, surpassing the control treatment. The stem diameter displayed significant differences among different treatments ($p = 0.0134$ and HSD of 0.21 cm). Greater stem diameters were obtained in SAP and biol treatments, showing differences with regard to the control. The number of leaf variable showed no statistical differences ($p = 0.2828$ and HSD of 1.3 cm).

Biol is an organic amendment that adds nutrients and organic matter and offers many opportunities to improve the physical, chemical and biological properties of soil, important for the success of soil recovery initiatives (Larney and Angers 2012). Ndubuaku et al. (2013) applied biol in okra and, 6 weeks later, obtained significant differences in the height of plants, number of leaves and stem circumference, in comparison with treatments in which biol was not used. This can be evidenced by the presence of organic matter in the biofertilizer, because it intervenes in the supply of nutrients by mineralization, in particular, the release of N, P, sulfur and micronutrients available to plants.

Morris and Lathwell (2004) indicate that fermented liquid fertilizers, such as biol, stimulate greater maize growth in the early stages of plant development, even more than sources of inorganic fertilizers, if applied to an acid soil, as in this study. In this sense, the organic matter improves the infiltration of water and reduces its loss by evaporation. It improves the drainage of the soil with a fine texture and therefore helps to better distribute the water in the soil profile (Cepeda Dovala 2016).

Table 3 Comparison of the means of plant height, stem diameter, number of leaves, accumulation of dry matter and content of nutrients in the maize plants

Treatments	Plant height (cm)	Stem diameter (cm)	Number of leaves	Aerial biomass				Root biomass			
				DM (g)	N (g)	P (g)	K (g)	DM (g)	N (g)	P (g)	K (g)
SAP	[A]127.4a	1.5a	[B]8.8a	11.09a	0.78a	0.36c	1.15b	5.1a	0.70a	0.28a	0.92b
Biol + SAP	120.4ab	1.39ab	9.2a	11.2a	0.76a	0.42ab	1.04a	5.1a	0.66a	0.32a	1.07a
Biol	127.8a	1.31ab	8.6a	10.8a	0.79a	0.41b	1.10ab	6.1a	0.67a	0.28a	0.92b
Control	118.2b	1.26b	8.8a	10.3a	0.80a	0.43a	1.13ab	5.2a	0.75a	0.32a	0.88b

[A]Values with same letters in each column are statistically similar (Tukey $\alpha = 0.05$)

[B]Original mean, data transformed according to $\sqrt{X}$

*$p \leq 0.05$

However, polymers have the capacity to absorb 400–1500 g of water per dry gram (Koupai et al. 2008), retain it and make it available for plant growth (Akhter et al. 2004). Islam et al. (2011) mention that the application of 60 kg ha^{-1} of SAP (a dose similar to that used in this study) increases the height of maize plants by 14.1%, compared to treatments without applications. When applying SAP in *Pennisetum americanum* L., an increase in height is achieved (Keshavars et al. 2012).

It has been shown that with this polymer, the accumulation of biomass is correlated with N and K amounts in shoots of *Lolium perenne* L. cv. Victoriana and can also improve the growth of plants even in soils contaminated by heavy metals (Qu et al. 2010). In very serious cases with high amounts, its concentration has a close relationship with the biological activity of the soil; a high concentration of heavy metals inhibits this activity (Puoci et al. 2008). Studies carried out by Linares-Gabriel et al. (2016) have found favorable results in agronomic variables in flowers of heliconias, with the combination of agricultural amendments (biol and superabsorbent polymers). In the same way, Linares Gabriel et al. (2018) evaluated these agricultural amendments and found significant results for a variable number of leaves.

With respect to the dry matter (DM) accumulated at 35 DAP (days after sowing) of corn, the analysis of variance did not present significant differences for the aerial biomass ($p=0.6273$ and HSD of 4.05 g) and biomass of the root ($p=0.4828$ and HSD of 2.13 g, Table 3). Regarding the contents of N–P–K in aerial biomass, the following results were found. The variable P ($p=0.1869$ and HSD of 0.062 g) and K ($p=0.0195$ and HSD of 0.0798 g) showed significant differences. The variable N did not show statistical differences ($p=0.4137$ and HSD of 0.0637 g). For the contents of N–P–K in radical biomass, the following results were found. The K variable showed significant differences ($p=0.0341$ and HSD of 0.1782 g). The variable N ($p=0.1668$ and HSD of 0.1118 g) and P ($p=0.6211$ and HSD of 0.1193 g) did not show statistical differences.

Based on the Tukey test for comparison of means ($\alpha=0.05$), the treatments with biol application displayed the highest values for P and K contents in the aerial biomass in comparison with the control, as well as the K contents in root biomass, in which the treatment with biol application was also significant (Table 3). Regarding N, the soil managed to provide the largest amount of N, and this is explained by the fact that the N availability in the soil is produced by the high percentages of organic matter (Rodríguez and De León 2008) as occurred in this study. In terms of P, an acidic pH reduces the amount of phosphorus available, although the favorable application of SAP, due to water disposition, helped the roots to concentrate phosphorus by diffusion in the aerial biomass, related to the application of biol. Khadem et al. (2010) mention that the highest amounts of K absorption are due to the presence of enough organic matter in the soil and the moisture in the presence of SAP. In general terms, the same authors point out that the combined effects of organic fertilizer and super absorbent polymers increase the absorption of nutrients (N–P–K) and the supply of soil moisture.

No statistical differences were found in the variables on application of the fermented fertilizer, because the effect of organic fertilizers is long term. The fermented fertilizers or digestates can contribute with an additional supply of N by the mineralization of the organic matter, having impact on more advanced stages of the plants and therefore in the production of biomass (Sogn et al. 2018). It is important to consider that the absorption of plant nutrients depends largely on the release of nutrients from the solid phase of the soil in the form of mineral and organic materials to the soil solution (Fathy et al. 2018; Nurhidayati et al. 2018).

Conclusion

The effect seen in this bioassay was significantly reflected in the variables height and plant diameter, phosphorus for aerial biomass and potassium in root biomass. This effect was seen with the application of biol, SAP, and the combination of both treatments. Although for the biomass the treatments did not show significant effects, the same happened for nitrogen.

Acknowledgements The funding was provided by Colegio de Postgraduados.

Compliance with ethical standards

Conflict of interest The authors declare no conflict of interest.

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