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Effects of zeolite and organic fertilizers on soil quality and yield of sugarcane

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Abstract

Maintaining or improving the soil quality is crucial for agricultural productivity. This study was undertaken to evaluate the effect of zeolite and its combination with chemical fertilizer and organic fertilizers on soil quality and sugarcane yield in the north coast of Cuba, Villa Clara province. The organic fertilizer (sugarcane filter cake-SFC), and natural mineral (zeolite-Z) and chemical fertilization (nitrogen-phosphorus-potassium-NPK) were applied as treatments. The experiment was laid out in a randomised complete block design with nine treatments and four replicates. The soil samples were taken at a depth of 0-20 cm to determine soil properties such as degree of soil aggregation, water-stable aggregates, permeability, lower plastic limit, pH in water, pH in KCl, organic matter, assimilable P_2O_5 and K_2O. The sugarcane yield components such as cane yield (t ha^{-1}) and sucrose yield (t ha^{-1}) were evaluated. Principal components analysis (PCA) and simple regression analysis were also performed. The best results on cane yield were obtained with the treatment Z 7.5 t ha^{-1} + SFC 22.5 t ha^{-1}, which represent a relative increase of 200% vs control (without fertilization). Relations between soil properties and principal component analysis confirmed the good response of zeolite application on soil quality and sugarcane yield.

Keywords: Zeolite; organic fertilizer; sustainability; yield; Vertisol.
Abbreviations: OM_Organic matter; WSA_Water stable aggregates; DSA_Degree of soil aggregation; Z_Zeolite; SFC_Sugarcane filter cake; NPK_Nitrogen phosphorus potassium; SP_Soil permeability

Introduction

Soil is one of the most important environmental factors and is considered the main source in providing essential plant nutries, water reserves and a medium for plant growth (Ghaemi et al., 2014). Maintaining or improving soil quality is crucial for agricultural productivity and environmental safety which are to be preserved for future generations (Reeves, 1997; Lal, 2015). Because of its low cost and great versatility, zeolite also plays an important role in agriculture. Ghanbari and Ariafar, (2013) indicates that natural zeolite may represent an important alternative to reduce the effects of drought in arid and semi-arid regions. It can be used to improve the soils, boost the effects of chemical and organic fertilizers-alike, and as a component of substratum for the development of different crops (Najafi-Ghiri, 2014). In 2013, world production of natural zeolite was estimated to be 2.7 million to 3.2 million metric tons, with China accounting for more than 70 percent of production (Virta, 2013).

Zeolite is a naturally volcanogenic sedimentary mineral composed primarily of aluminosilicates (Pan et al., 1991). The mineral has a threedimensional crystal lattice, with loosely bound cations, capable of hydrating and dehydrating without altering the crystal structure (Ramesh and Damodar, 2011). About 40 natural zeolites and 100 synthetic zeolites exist (Szerment et al., 2014). In Cuba there are deposits of zeolites located in almost all provinces and geographical regions (Orozco y Rizo, 1998).

Mirzaei et al. (2015) showed the effects of application of nanozeolite and zeolite on MWDw as an index of aggregation stability and strength, and organic carbon aggregate size fractions in a soil treated with some plant residues during the incubation period. Aggregation process in the soil is important. It plays a considerable role in improving the soil physical characteristics such as hydraulic conductivity, infiltration, ventilation, etc. Also, the aggregation process is important in improving the carbon sequestration in soil (Lal, 2015). Zeolite assists water infiltration and retention in the soil due to its very porous properties and the capillary suction. Acting as a natural wetting agent, it is an excellent amendment for non-wetting sands and to assist water distribution through soils (Ghazavi, 2015; Szerment et al., 2014). Zeolite can hold nutrients in the root zone of plants until required. This leads to more efficient use of N and K fertilizers, using less fertilizer for the same yield or application of same amount of fertilizer for longer lasting and producing higher yields (Gamze, 2007; Khodaei-Joghan and Asilan, 2012).

The application of different soil treatments, which may include sources of organic matter and natural mineral such as zeolite, can alter the properties which manifest the biggest changes over time and are closely related with cane yield as soil quality indicators (Cairo et al., 2010). In the case of natural minerals, zeolites are crystalline microporous aluminosilicates which are built from corner-sharing SiO_4- and AlO_4-tetrahedra. These porous materials are formed in nature in association with volcanic activity (Weckhuysen and Yu, 2015). Sugarcane is widely cultivated in Vertisols of north coast of Villa Clara province, Cuba. Serious natural constraints are occurred for plant production in Vertisols due to undesirable physical properties such as extreme plasticity (Vidal et al., 2006). Limitations of Vertisols are impeded root development in the topsoil and decreased crop yields (Cairo et al., 2012). Because of their poor physical conditions, Vertisols are very susceptible to degradation under sugarcane monoculture, leading to extreme quality limitation (Cairo et al., 2012). The aim of this research was to evaluate the effect of the zeolite and its combination with fertilizer and organic fertilizers on soil quality and yield of sugarcane.

Results and Discussion

Zeolite and organic fertilizer

Different zeolite levels and combinations with organic fertilizers were applied in Vertisols (Table 1). Significant effects on organic matter and structure, as well as on sugarcane yield (cane yield and sucrose yield) were observed. Zeolite levels increased both soil properties and sugarcane yield, but combinations of zeolite with nitrogen or organic fertilizers achieved the best results. The sugarcane yield is closely related to the increase of organic matter and indicators of soil structure. Treatment, Z 7.5 t ha^{-1} + SFC 22.5 t ha^{-1} (T6) showed the best result, where 3 of the indicators (organic matter, water-stable aggregates and degree of soil aggregation) reached the highest values of all treatments and sugarcane yield, with average assessment category, middle, excellent and good respectively. In this case the yield of sugarcane is almost doubled compared to the control (86 t ha^{-1} vs 162 t ha^{-1} cane yield). These results are agreed with those obtained by Diaz et al. (2010) and Rodriguez et al., (2012). Leggo et al. (2000) and Najafi-Ghiri (2014) have demonstrated the effect of Zeolite combined with organic fertilizers on soil properties and yield of crops under extreme soil degradation conditions.

Fig. 1. shows the soil water regime by comparing the control treatment (T1) with the soil treated with Z 7.5 t ha^{-1} + SFC 22.5 t ha^{-1} (T6), when sampling moisture is carried up from a meter deep after 25 mm of rainfall. In control treatment, water accumulated on the surface, remaining much drier in depth, due to the limited speed of water infiltration. However, treatment of soil with zeolite guarantees the uptake of rainwater in depth, due to the structural changes (Table 1), which is synonymous with a better use of rainwater and subsequent supply of assimilable water to plants. In the natural soils, all the detained superfluous water is lost by evaporation surface area which may be decisive in cane yield. The results show that the effect of the zeolite and its combination with organic fertilizer not only has its influence on the topsoil but also in depth. Xiubin and Zhanbin, (2001); Ozbahce et al., (2014); Ghazavi, (2015); Mirzaei et al., (2015) showed similar results highlighting the effects of zeolite on the aggregation and soil water retention. The dynamic characteristics of Vertisol under wet and dry conditions and the formation of deep cracks produced transfer of substrates from surface to depth which consequently caused a change in the structural diagram of the soil profile (Vidal et al., 2006; Cairo et al., 2012).

Soil quality analysis

In today's agricultural world much value has been given to organic matters and their relations with the structure and stability (Ghaemi et al., 2014), as these have direct influence on the quality of soil and its management under general degradation condition (Lal, 2015). Fig 2 and 3 show a close relationship and dependence (r> 0.80) between organic matter and water stable aggregation and soil permeability. The agroecological soil management alternatives determine the level of relations between organic matter and structural properties. These properties are sensitive to change by anthropogenic action but recovery may have residual effect over time as a result of the formation of organo-mineral complexes and in this case even more favored by the presence of the zeolite. Mirzaei et al. (2015) studied effects of natural zeolite and nano-zeolite on plant residues and obsereved significant results in the increment of organic carbon and soil aggregation. Lopes et al. (2016) reported close relations among organic matter with stable aggregates and the degree of soil aggregation that confirms the importance of these properties as indicators of the soil quality management.

Table 2 shows the trends of the properties studied when applying statistical tools and sensitivity to category change. Ghaemi et al. (2014) stated that the use of principal components can contribute to the assessment of soil quality and the sustainable management of an agricultural system. The properties that best demonstrate the qualities of indicators of soil quality are organic matter, stable aggregates, degree of soil aggregation, permeability log 10K and lower plastic limit. In this case, they observed statistical significance of 60 and 90% with high sensitivity to change of category among the first component (Table 2). The maximum and minimum values of the properties and their evaluation are shown in Table 2. All other properties did not meet all of these requirements. On the other hand, it is very favorable that the cane yield shows similar results which can be considered as biological indicators of soil quality (Adeyolanu et al., 2013; D'Hose et al., 2014). Crop yield considered in these studies, had an extraordinary value for selecting quality indicators and determining soil quality. Hence, integration of natural minerals and organic amendments is suitable for Vertisols with high clay contents and improves physical soil properties. In similar studies, an improvement in the structural state of an inceptisol was observed with the application of organic and organic-mineral treatments, resulting in an increase of water-stable aggregates, degree of soil aggregation and permeability (Diaz et al., 2008, Mollinedo et al., 2015). There was also a proportional relationship between soil quality and sugarcane yield (Diaz et al., 2010; Kumar and Chand 2013; Jeevika et al., 2015).

A balanced use of organic, inorganic and biofertilizers is essential to maintain a good soil physical and chemical environment and also serves as an energy source for the soil microbial biomass (Rajesh et al., 2003; Gopalasundaram et al., 2012).

Materials and Methods

Site description

The study was plotted in the sugarcane growing areas of the northern coast of Villa Clara province (Fig. 4) in the municipality of Sagua La Grande, the Experimental Station of Sugarcane "Jesus Menendez" is localised at 22º81′19″ N

Table 1. Influence of zeolite and sugarcane filter cake on organic matter, soil structure and sugarcane yield.

Treatments	OM%	WSA%	DSA%	log 10k	Cane yield ($t\ ha^{-1}$)	Sucrose yield ($t\ ha^{-1}$)
Control	2.29 g	64.18 e	54.03 e	1.84 f	86.37 i	14.99 i
Z 7.5 $t\ ha^{-1}$	3.43 cd	68.58 d	57.24 d	2.01 de	89.41 h	15.31 h
Z 15 $t\ ha^{-1}$	3.57 b	69.38 c	60.65 c	2.05 c	114.40 f	19.48 f
Z 7.5 $t\ ha^{-1}$+ N(100 $kg\ ha^{-1}$)	3.46 c	68.58 d	57.24 d	2.13 a	154.84 b	26.14 a
Z 15 $t\ ha^{-1}$+ N(100 $kg\ ha^{-1}$)	3.52 b	69.38 c	60.65 c	2.05 c	142.30 c	23.84 c
Z 7.5 $t\ ha^{-1}$+SFC(22.5 $t\ ha^{-1}$)	3.71 a	69.67 b	65.57 a	2.09 b	162.00 a	24.42 b
Z 3 $t\ ha^{-1}$+SFC(18 $t\ ha^{-1}$)	3.40 de	71.04 a	62.62 b	2.14 a	137.66 d	22.95 d
Z 7.5 $t\ ha^{-1}$+NPK(100-60-200 $kg\ ha^{-1}$)	3.37 e	68.58 d	57.24 d	2.00 e	135.79 e	22.19 e
Z 15 $t\ ha^{-1}$+NPK(100-60-200 $kg\ ha^{-1}$)	3.24 f	69.38 c	60. 65 c	2.04cd	106.93 g	17.29 g
EE = ±	0.06	0.27	0.49	0.01	3.90	0.58

(a, b, c, d, e, f, g) means with common letters do not differ in the same column by Tukey HSD at $p\leq0.05$. T Control without fertilization; Zeolite Z; N nitrogen; SFC (sugarcane filter cake); NPK (nitrogen-phosphorus-potassium); OM(Organic matter); WSA(Water stable aggregates); DSA (Degree of soil aggregation); Log 10k (Permeability).

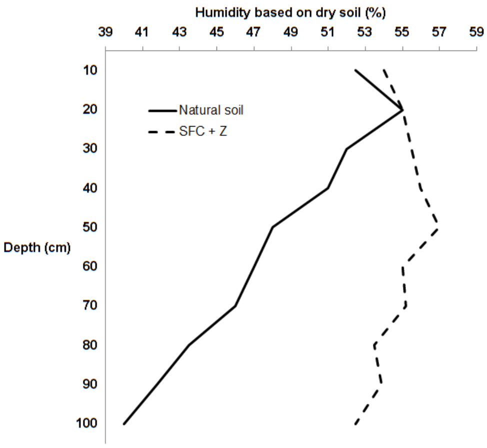

Fig 1. Soil moisture profile (25 mm of rain before sampling). ------ Average values of sampling of the soil moisture content (Z 7.5 $t\ ha^{-1}$ + SFC 22.5 $t\ ha^{-1}$)____Average values of sampling of the soil moisture content (Control without fertilization).

Table 2. Correlations, sensitivity to change of category and principal components.

Properties	Correlations (%) significant of Total	Range (degree of sensitivity)		Principal component
Water-stable aggregates (%)	80	64.00 *Good*	71.09 *Excellent*	1
Degree of soil aggregation (%)	80	54.00 *Bad*	66.64 *Good*	1
Permeability (log 10K)	80	1.82 *Adequate*	2.50 *Excellent*	1
Lower plastic limit (%Hbds)	90	30.07 *Plastic*	42.67 *Moderately plastic*	1
pH (in water)	50	5.69 *Slightly acid*	6.45 *Neutral*	1
pH (in KCl)	30	5.10 *Mildly acid*	5.90 *Slightly acid*	2
Organic matter (%)	60	2,25 *Low*	3.75 *Medium*	1
K_2O ($mg\ 100g^{-1}$)	30	10.48 *Medium*	17.67 *High*	1
P_2O_5 ($mg\ 100g^{-1}$)	40	3.58 *Low*	13.05 *High*	1
Cane yield ($t\ ha^{-1}$)	60	86.30	- 162.15	1
Sucrose yield ($t\ ha^{-1}$)	70	14.98	- 26.16	1

Hbds = Humidity in base dry soil.

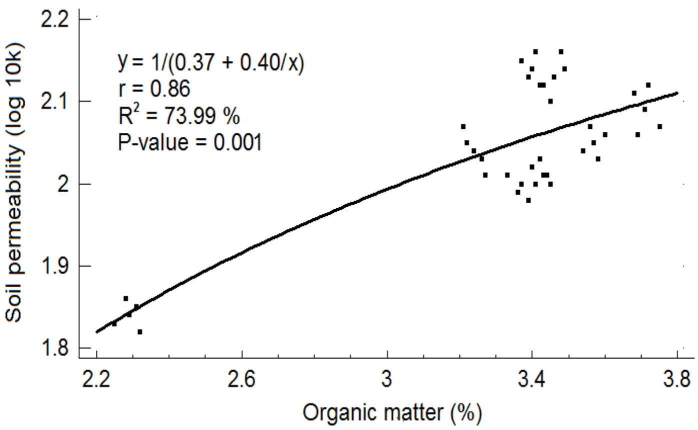

Fig 2. Relation between organic matter and soil permeability (simple regression equation, inverse double model, p≤0.05).

Table 3. Chemical composition of the materials used in the experiment.

Organic fertilizer Parameter	Sugarcane filter cake	Natural mineral Parameter	Zeolite
N (%)	2.85	SiO_2	63.00
P (%)	1.71	Al_2O_3	11.57
K (%)	0.91	F_2O_3	0.81
Ca (%)	1.00	MgO	0.92
Mg (%)	0.50	CaO	-
OM (%)	43.00	TiO_2	0.45
C (%)	24.94	Fe_2O_3	1.87
C:N	8.75	Na_2O	2.39
		P_2O_5	0.09
		Humidity	3.44

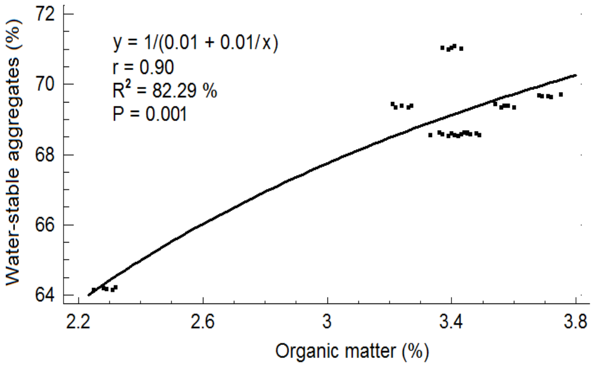

Fig 3. Relation between organic matter and water-stable aggregates (simple regression equation, inverse double model, p≤0.05).

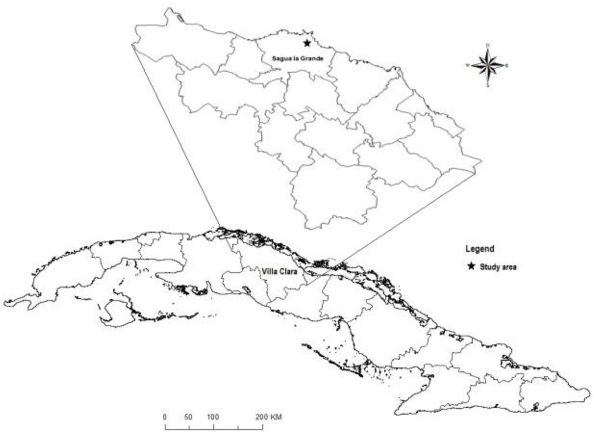

Fig 4. Map of Cuba with the study area in Villa Clara province.

latitude and 80º 03′74″ W longitudes. The soil under study was Vertisols (Soil Survey Staff, 1999). Vertisols are very clayey, but plastic under intense water regime. The local climate is clasisified as Aw according to Köppen. Annual rainfall in the study area is 1150 mm and average temperature is 25°C.

Experimental design and treatments

The Experiment was set up as a randomized complete block design with 9 treatments and 4 replications. The individual plot sizes were 10 × 9.6 m. Sugarcane variety Ja 60-5 was used and was planted in furrows at 1.60 m row spacing. Organic fertilizer (sugarcane filter cake-SFC), and natural mineral (zeolite-Z) and chemical fertilization (nitrogen-phosphorus-potassium-NPK) were applied.

The treatments were: T1- control (without application of fertilizer), T2- Z 7.5 t ha^{-1}, T3- Z 15 t ha^{-1}, T4- Z 7.5 t ha^{-1} + N 100 kg ha^{-1}, T5- Z 15 t ha^{-1} + N 100 kg ha^{-1}, T6- Z 7.5 t ha^{-1} + SFC 22.5 t $ha^{-1,}$ T7- Z 3 t ha^{-1} + SFC 18 t ha^{-1}, T8- Z 7.5 t ha^{-1} + NPK (100-60-200 kg ha^{-1}), T9- Z 7.5 t ha^{-1} + NPK (100-60-200 kg ha^{-1}).

Analysis of soil properties

Soil sampling was performed 20 months after crop planting in each plot. Samples were taken from soil depth of 0 to 20 cm. The chemical and physical properties were determined by the following methods: assimilable P_2O and K_2O by Oniani, (1964) with extractive solution of sulfuric acid (0.1N). The P_2O_5 was colorimetrically determined and K_2O by flame photometry. Organic matter was determined by the colorimetric method of Walkley and Black, (1934) and pH (in water and KCl) by pH-meter relation soil-water 1:2.5. Permeability (log 10k) was analysed according to Henin et al. (1958) and the degree of soil aggregationas described in Vageler and Alten, (1931). Water-stable aggregates were determined using the methodology by Henin et al. (1958) and the lower plastic limit by the Atterberg rolls method, Atterberg, (1911). Control treatments without fertilizer and Z 7.5 t ha^{-1} + SFC 22.5 t ha^{-1} sampling soil moisture was carried out to a depth of 1m after a rainfall of 25 mm.

Soil quality assessment

The selection of soil quality indicators has its theoretical basis in the investigations carried out by different authors such as Doran and Parkin, (1994); Karlen et al. (1997); Torstensson et al. (1998); Lal, (2015). Cairo et al. (2010) suggested a procedure that includes behavior of soil properties, sensitivity of properties to external changes, significance of properties in statistical processing, changes in property evaluation categories, and the quality indicators and their relationships to yield.

Sugarcane yield and statistical analysis

We also evaluated the total number of stems per plot and their weight in order to determine cane yield (t ha^{-1}) and sucrose yield (t ha^{-1}). For statistical processing, we used the package SPSS ver 13.0 and STATGRAPHICS 5.1 on Windows XP. Soil properties and yield were submitted to analysis of variance applying the F-test for significance and means compared by Tukey test ($p \leq 0.05$). Principal components analysis (PCA) and correlation matrix between the variables were applied in order to distinguish variables with a high percentage of correlation. Simple regression analysis was used to determine the degree of dependence between physical and chemical soil properties and properties related to crop yield.

Conclusion

It was found that the zeolite alone or combined with compost and mineral fertilizers produce significant effects on organic matter and soil structure and yields of sugarcane. The best results on yields of sugarcane were obtained with treatment Z 7.5 t ha^{-1} + SFC 22.5 t ha^{-1}, which represents an increase of almost 200%, compared to controls. The use of zeolite combined with organic fertilizer showed a better use of rainwater in the study conditions. Relations between soil properties and principal component analysis confirmed the responses to zeolite application on soil quality and yield of sugarcane.

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