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Effect of Sickle Bush (*Dichrostachys cinerea* (L.)) on the Quality of Degraded Sialitic Brown Soil in Camagüey, Cuba

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ABSTRACT

Sickle bush (*Dichrostachys cinerea* (L)) is one of the exotic invasive species found in Cuba, spreading over idle and productive lands. However, this plant may bring benefits to the soil, including protection from erosion. In order to prove the effects of sickle bush on soil quality, an experiment was carried out in the Maximo River basin, in the municipality of Camagüey, Cuba, on mulled sialitic brown soil, in field conditions to determine the influence of sickle bush on the physical, chemical, and biological properties of the soil for over 20 years. A completely randomized design with 4 variants was used (more than 20-year sickle bush infestation, extensive farming, intensive farming, and diversified farming). Three soil samples were collected per variant at the same time and under the same conditions. The data gathered were used to estimate the soil quality index, by the SENCA software. Improvements in cationic exchange capacity, real density, apparent density, hygroscopic humidity, organic matter content, and biological activity of the soil was demonstrated in sickle bush-covered soils and diversified farming, in contrast to the conventional farming systems used, which deteriorate soil quality. The sickle bush-covered soils showed the closest value to 1 in the scale, which demonstrated soil quality improvements.

Key words: /soil quality, alien species, sustainable land management, Dichrostachys cinerea

INTRODUCTION

Soil is a fundamental component of land ecosystems in terms of plant nutrition and support (Vandermeer, 2011). Besides, it holds most living organisms, since it is the main source of mineral nutrients. Proper soil management practices guarantee that minerals do not become deficient in or toxic to plants, so they can be part of the food chain (FAO, 2017).

Soil degradation is defined as the long-term loss of function and productivity of ecosystems, which is caused by distortions that damage the soil irreversibly without the possibility to recover by itself (Oldeman and Ahakkeling, 1991). Some of the consequences of this phenomenon include a decline in farm production, migration, food insecurity, damage to basic resources and ecosystems, and the loss of biodiversity due to changes in the habitats both genetically and in the species (Oldeman and Hakkeling, 1991).

In addition to the problems of soil degradation caused by inadequate use of lands, mismanagement of plant and animal species has caused negative effects. The introduction of exotic species in fragile environments has produced an ecological unbalance of ecosystems,

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globally. The province of Camagüey, Cuba, has been severely affected, with 236 479.85 ha of idle lands (Instituto de Suelos (UCTB), 2014), that withstand the emergence of invasive species, like sickle bush (*Dichrostachys cinerea* (L)), needle bush (*Acacia farnesiana* (L)), Weyler (*Mimosa pigra* (L)), paspalum (*Paspalum virgatum* (L)), and wild pineapple (*Bromelia pinguin* (L)). However, sickle bush is by far the one offering the strongest resistance to control actions. This problem also effects on climatic change and soil degradation, so new alternatives to cope with food safety and sovereignty must be implemented to increase the number of available farmland, and achieve sustainability.

Dichrostachys cinerea (L.) is an invasive species that has struck farm production; its spreading over Camagüey has reduced the amount of usable farmlands and grazing lands, in addition to the migration of native species. The above-mentioned, along with mismanagement of soil recovery, has caused damages that bring about far more issues than the expansion of the species per se.

Sickle bush (*D. cinerea*) might be more appealing if its components were applied usefully; however, there is little knowledge about its potential and effects on soil quality and fertility. Sickle bush-covered soils are significantly more fertile than other soils. Hence, the aim of this paper is to evaluate the effect of sickle bush spread out on soil quality of highly degraded and vulnerable areas due to human activity.

MATERIALS AND METHODS

Location and description of the area studied

This research took place on three reference farms in suburban agricultural areas, in Camagüey, (farm No. 1: La Lucha, farm No. 2: Nueva Esperanza, and farm No. 3: Villa Luisa). The areas studied are located within the hydrographic basin of the province made by the Máximo River and its affluents.

Site description

The Victoria II UBPC (farming cooperative), from the Camagüey Varied Crops Company in the Maximo River basin (municipality of Camagüey), provided some areas for the study. It is located in Altagracia, (cartographic page 4680 III-b, between the N-311.900 and E: 404.600 coordinates; 21º27´46´´ north latitude, and 77º45´10´´ east longitude). The mean annual precipitation value is 930 mm, with a mean temperature of 27.1 ºC, and relative humidity of 82%. The area sits on a mulled sialitic brown soil (Hernández *et al*., 2015), varying between mid-deep (25-50 cm) to deep (51-100 cm). Clay is abundant in the soils, OM 2-4%, considered moderately humid, which is on intermediate igneous rocks and sand, without carbonates. Gravels and small rocks can be observed, particularly in the areas with the lowest effective depth. The soils are saturated, with predominance of Ca^2 and Mg^2 for cationic exchange capacity.

Experimental design

Soil samples were chosen to determine the effects of sickle bush on the chemical, physical, and biological properties. Four experimental variants and three replicas were evaluated (Table 1).

Table 1: Variants used in the research

Variants	Soil type	Farming system	Location
1	Mulled Sialitic Brown	Farm No. 2: Infested with sickle bush for more than 20 years	UBPC Victoria II Camagüey Varied Crops Company
2		Farm No. 3: Extensive farming system. plantain, (*Musa paradisiaca* (*L*))	
3		Farm No. 1: Intensive farming system tomato (*Solanum lycopersicum* (*L*))	
4		Farm No 2: Diversified farming system. Sugar cane, Bermuda grass, plantain, papaya, beans	

Sample collection and determinations

Soil sample collection was made with the sampling grid, at random, with longitudinal spots (Hellkamp *et al*., 1995). Three compound soil samples were collected per variant at the same time and under the same conditions.

The samples were air dried, and the samples for microbiological determinations were sieved, using a 2 mm sieve. Then they were stored indoors at room temperature for 60 days (Calero *et al*., 1999), in order to stabilize most of the autochtonous flora, and provide a latency status, until the optimum temperature and humidity conditions were met to evaluate metabolic expression.

Analyses of the physical, chemical, and biological properties were made at the Science and Technology Unit of the provincial Soil Laboratory (Ministry of Agriculture) for determination of soil fertility and quality. The indicators are described in Table 2.

Table 2. Description of analytical methods used for the physical, chemical, and biological indicators

Indicators	Description	REFERENCE
Physical		
Hygroscopic humidity (Hy)	Gravimetric method	MINAG, 1980
Real density (RD)	Pycnometric method in xylol	MINAG, 1987
Ad - Apparent density (AD)	Ring method (determined at a soil moisture very close to the field capacity or upper limit of available water).	MINAG, 1984
Chemical		
pH in Potassium Chloride pH (KCl)	Potentiometric method	NC ISO 10390, 1999
Electric conductivity (CE)	Soil/water ratio (1:5)	NC 112, 2001
Cationic exchange capacity in the soil (CEC)	Modified Melich method (Schactschabel)	NC 65, 2000
Biological		
Organic matter in the soil (OM)	Walkley black method	MINAG, 1999
Basal respiration (BR)	Moisturizing 25g of the soil at 60% of the maximum capacity of retention, and CO_2 determination after 24 h of incubation, at 30ºC.	Calero *et al*., 1999
Carbon-induced breathing (CIB)	Application of glucose to find the minimum concentration and reach the maximum breathing, according to soil grouping.	Font, 1999 Calero *et al*., 1999 Chaveli *et al*., 2002
Real nitrifying capacity (RN)	Phenoldisulfonic acid method (colorimetric)	Bolotina and Abramova, 1968

The data collected from the physical, chemical, and biological analyses were used to estimate the soil quality index for each variant, by SENCA software (Font, 2008), to obtain a quality range between zero and one, being one the ideal state of the soil.

Analysis and data processing

All the data were statistically processed in a completely randomized design by simple variance analysis (ANOVA) of means, to determine the significant differences between treatments. The Duncan's multiple range test was used for mean comparison, with 95% confidence. SPSS for Windows, 11.5.1 (2002) was used for data processing.

RESULTS AND DISCUSSION

Soil characteristics

The chemical characterization of the mulled sialitic brown soil is shown in Table 3. In the different variants, the soil pH (KCl) was between slightly alkaline and slightly acidic, except for the intensive system (acidic). This may have been linked to intensive tomato (*Solanum lycopersicum* (*L*.)) farming, which coincided with the results of García (2011), who stated that one of the problems that might originate soil acidification is mismanagement of intensive farming.

The best pH results were achieved for the variables corresponding to extensive plantain farming, and the ones infested by sickle bush for more than 20 years. The soils covered with sickle bush kept optimum pH conditions, proper nutrient availability, and an excellent behavior of crops (Andres *et al*, 2014). Similar results were achieved by García (2006) in sialitic brown soils covered with woods in agroecosystems in the province of Santiago de Cuba, which demonstrated that sickle bush forests were able to maintain an optimum pH for these kinds of soils.

The highest value reported for CEC was observed in soil infested with sickle bush; the other variables did not show any significant differences among them. The values observed in the sickle bush-infested soil may be attributed to the permanence of the species in the soil, thus increasing the soil fertility indicator, and demonstrating the enhanced potential of the plant for these soils. This indicator may be stimulated by the large contribution of plant material, as in the results reported by Bautista *et al*. (2005) in forests. He claimed that the high cationic exchange capacity (CEC) is mainly related to high contents of organic matter on the surface. However, the percentage of base saturation showed no significant differences among the variables.

Table 3. Chemical indicators for the two types of soil

Variants	pH (KCl)	(CEC) cmol$^{(+)}$ kg^{-1}	V (%)	EC dS.m-1	Ca^{2+}/Mg^{2+}
	Mulled Sialitic Brown				
Sickle bush for more than 20 years	6.5 b	55.46 a	95.01	0.28	5.71 a
Extensive farming system	6.45b	45.68 b	97.80	0.15	3.51 b
Intensive farming system	4.85 c	47.82 b	98.67	0.62	1.73 c
Diversified farming system.	7.66 a	46.31 b	95.35	0.16	5.82 a
Esx	0.170*	1.660*	1.471ns	0.260ns	0.233*

Note: a, b, c Means with equal letters do not differ from $p \leq 0.05$, according to the Duncan multiple range test.

For EC, the acceptable range (1999) for growth of most crops established by the USDA is 0-0.8 dS m^{-1}. The values of this indicator for the different variants are within this range, and no significant differences were observed.

Intercationic ratios are important for nutrient assimilation. The Ca^{2+}/Mg^{2+} ratio reported an ideal 6:1 for most species; when the ratio is below 2, excess magnesium may cause problems; whereas above 10:1, the differences for the element are remarkable (Stevens *et al.*, 2005). The results from the analysis of this indicator demonstrated that the values were generally within the optimum range. Besides, significant differences were observed in a tighter ratio in sickle bush-infested soils with diversified farming. It was possibly associated to the contribution of organic matter of a deciduous forest, which showed the benefits of this indicator in soils under that type of management.

Moreover, intensive farming evidenced a poor ratio, with a potential unbalance of nutrients for these soils, which may have been caused by inappropriate management of intensive farming (García, 2011).

Physical characteristics

Table 4 shows the characterization of the physical indicators. Since RD varied according to the type of farming on the soil and the contents of organic matter, this soil showed low values, generally (mulled sialitic brown), due to moderate contents of organic matter (OM). According to Hernández *et al.* (2015), RD increases when soil OM is lost.

The lowest RD values were observed in sickle bush-infested soils, which may have been linked to root activity and the incorporation of organic matter (Mudzengi, 2014).

The behavior of AD was similar. According to MINAG (1987), it is essential to determine the physical state of the soil, since it shows the dynamic behavior of structure and porosity, whose variations are produced by the action of outer and inner agents, such as soil compaction and particle dispersion, respectively. Consequently, the sickle bush areas showed the best results with the optimum values suggested by Mesa and Naranjo (1982) for this type of forest.

These results may be related to AD variations due to the action of the plant after long periods of permanence. Accordingly, Carmenate *et al.* (2008) demonstrated that the roots of this species could reach a considerable depth, which is possibly the reason why some physical properties of the soil have improved, such as AD and Hy. George (2006) noted that the plant material accumulated (like dead leaves and others) might form a kind of mattress of OM, which means low AD values in the superficial layers of the soil. Sickle bush is a semi-residual plant that makes a large contribution of dead leaves to the soil Mudzengi (2014).

MINAG (1984) said that the appropriate Hy values for most species are between 6 and 8%, the optimum range, provided there are no other obstacles. The values achieved in all the variants were higher than the range established, which may have been linked to the type of soil (mulled sialitic brown), with elevated montmorillonitic contents that produce high concentrations of water which is usually firmly trapped in the soil. The best result for this indicator was achieved in the sickle bush-covered soil with diversified farming, perhaps caused by the contribution of organic matter and the physical improvements these variants introduce in the soil (Carménate *et al.*, 2008).

Table 4: Chemical indicators of the two types of soil

Variants	Rd	Ad	Hy
	$g.cm^{3-}$	$g.cm^{3}$	%
	Mulled sialitic brown soil		
Sickle bush for more than 20 years	2.12 c	0.96 b	11.67 ab
Extensive farming system	2.37 b	1.21 a	11.37 b
Intensive farming system	2.51 a	1.27 a	10.50 c
Diversified farming system.	2.34 b	1.19 a	12.27 a
Esx	0.037*	0.053*	0.242*

Note: a, b, c Means with equal letters do not differ from p≤0.05, according to the Duncan's multiple range test.

Biological characteristics

The highest OM values (Table 5) were achieved in the soils with diversified farming, which may be explained by the constant incorporation of organic fertilizers in the systems (Tremont and Cuevas, 2006).

This indicator had a positive influence on almost all the soil properties (Magdoff, 1997), which was confirmed by the behavior of the rest of the indicators studied, like CEC; and by other authors (Resk. 1998), on soil structure, water and nutrient availability. Ad and Rd were also influenced, with a high negative correlation between them (Apezteguía *et al*., 2001).

BR is a potential basic activity index, considered as a direct indicator of microbial activity, and an indirect indicator of OM contents in the soil (Alef and Nannipieri, 1995; Leita *et al*., 1995).

The variant including sickle bush and diversified farming showed the highest BR and RN values, which is explained by the more than 20 years of sickle bush establishment as a forest, where the microbiological properties of the soil are restored and enhanced, coinciding with Chavarría *et al*. (2012).

Table 5: Biological indicators of the two types of soil

Variants	OM %	BR mg $CO_2 \cdot 100\ g^{-1}$	RN mg $NO_3^- \cdot kg^{-1}$
	Mulled Sialitic Brown Soil		
Sickle bush for more than 20 years	4.59 b	65.12 a	20.48 b
Extensive farming system	4.27 b	26.32 b	17.32 c
Intensive farming system	4.55 b	14.59 c	13.75 d
Diversified farming system.	5.31 a	32.56 b	22.80 a
Esx	0.173*	2.378*	0.49*

Note: a, b, c. Means with equal letters do not differ from p≤0.05, according to the Duncan's Multiple Range test.

The reports of Prochette and Desjardius (1991) in relation to the direct correspondence between that indicator and a quick break down of organic residues in nutrients available for crops were corroborated. Additionally, the percentage of soil OM should be stable; otherwise, it would have a negative effect on other physical and chemical processes, like soil aggregation, cationic exchange, and the capacity to retain water.

Intensive and extensive farming had the lowest values in terms of microbiological indicators (Table 5), which may have been caused by the aggressive exploitation conditions undergone by the soil.

Therefore, the microbial activity of the soil is one fundamental ecological measure, since, on one hand, it represents the level of biological activity (labile component of OM); and on the other, it integrates the environmental factors and their influence (Zagal *et al*., 2002). It is also important in terms of soil quality (Stevenson y Cole, 1999), since soil fertility changes are shown with higher sensitivity than the chemical determinations of carbon and nitrogen (Beyer, 1995; Franzluebbers *et al*., 1995).

Soil quality

The quality indexes were between zero and one; the closer to one the better the quality of the soil for each variant (Font, 2008). The results of ICS evaluation indicated that the sickle bush variants showed higher quality indexes (Table 6), which demonstrated that the permanence of *Dichrostachys cinérea* (*L*.) improved soil quality significantly, in comparison to the other variants. Moreover, despite its aggressive nature, it can improve soil in degraded lands, due to significant inputs of carbon and nutrients. Less soil deterioration was observed in diversified farming, which was induced by the contribution of organic fertilizers, coinciding with Tremont and Cuevas (2006).

Furthermore, the intensive and extensive farming systems led to lower soil quality. These variants might cause greater degradation of the soil due to aggressive farming conditions, coinciding with García (2011) on the effects of intensive practice on soil quality.

Table 6: Evaluation of quality indexes of the soil under different farming systems compared to sickle bush-infested soils

Variants	ICS
Sickle bush for more than 20 years	0.6933 a
Extensive farming system	0.6133 c
Intensive farming system	0.5233 d
Diversified farming system.	0.6567 b
Esx	0.003*

Note: a, b, c. Means with equal letters do not differ from p≤0.05, according to the Duncan's Multiple Range test.

The ICS achieved proved the existence of sensitive indicators capable of showing the changes caused by management practices in this type of soil, coinciding with Bautista *et al.* (2004).

Overall, the results achieved indicated that the ICS values were higher in the systems where the physical, chemical, and biological properties were balanced, which coincided with the sickle bush-covered soils for over 20 years variant, and where human activity had a positive impact, with soil-preserving management practices, like diversified farming.

The above-mentioned suggests the inclusion of the criterion of sickle bush-covered soils as a reference to evaluate soil quality by farming system, in order to reverse anthropogenic effects. It will help determine which farming system causes less soil degradation in the ecosystems affected (Lal *et al*., 2003).

ICS varied in accordance with the crop established and farming management. Monocropping in perennial or semi-perennial farming systems caused the highest soil deterioration. It may be associated to the utilization of conventional farming practices that hinder soil viability over time, due to unbalanced ecological processes that maintain sustainability (Funes, 2006).

The response observed in the diversified system with positive management favored an increase in ICS produced by some physical, chemical, and biological properties of the soil, in comparison to conventional systems. This fact may have been attributed to greater possibilities offered by diversified farming in maintaining a balance, as a result of the multiple relationships between biotic and abiotic components (Guazzelli *et al*., 2007).

CONCLUSIONS

The physical, chemical, and biological indicators underwent changes in their behavior due to the farming system used. Moreover, the soil quality index varied thanks to the relationship among the farming systems used; it was greater in the sickle bush-infested soils, which enhanced soil quality in degraded areas, in contrast to conventional systems.

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