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Evaluation of soil structure using participatory methods in the semiarid region of Brazil[1]

Avaliação da estrutura do solo utilizando métodos participatórios na região semiárida brasileira

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ABSTRACT - Conservation practices are important in improving the environmental protection of agroecosystems in semiarid regions, as these are considered to be fragile environments. Soil-quality indicators are useful elements in evaluating the impact of some agricultural management practices, and the use of recognized indicators which are able to be measured by farmers is an innovative approach that seeks to integrate both scientific and local knowledge. This study aimed to evaluate the impact of various management practices through indicators of soil quality related to soil structure, in areas of family farming where agroecological consortiums are employed. These indicators were identified as important by the farmers themselves, and methodologies were suggested for field application by the farmers, which were later compared to applications made in the laboratory. The indicators used were penetration resistance of the soil and stability and dispersion of aggregates for areas of agroecological consortium and natural vegetation. It can be concluded that agroecological consortia contribute to the conservation of soil structure and that the involvement of farmers plays an important role in developing research.

Key words: Soil structure. Soils - management. Family farm.

RESUMO - Práticas conservacionistas são importantes na melhoria da proteção ambiental de agroecossistemas em regiões semiáridas por estes serem considerados ambientes frágeis. Indicadores de qualidade do solo são elementos úteis na avaliação do impacto de algumas práticas de manejo agrícola e a utilização de indicadores reconhecidos e possíveis de serem mensurados por agricultores é uma abordagem inovadora que busca integrar conhecimento científico e local. Este estudo objetivou avaliar o impacto de algumas práticas de manejo em áreas de agricultores familiares que utilizam consórcios agroecológicos através de indicadores de qualidade do solo relacionados à estrutura do solo. Estes indicadores foram apontados como importantes pelos próprios agricultores, sendo propostas metodologias para aplicação em campo por eles mesmos, que foram posteriormente comparadas com aplicações em laboratório. Os indicadores utilizados foram resistência do solo à penetração, estabilidade e dispersão de agregados para áreas sob consórcio agroecológico e vegetação natural. Pode-se concluir que os consórcios agroecológicos contribuem para a conservação da estrutura do solo e o envolvimento dos agricultores é uma importante parte do desenvolvimento da pesquisa.

Palavras-chave: Estrutura do solo. Solos-manejo. Agricultura familiar.

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INTRODUCTION

The Brazilian northeastern is one of the most densely populated semiarid regions in the world (INSTITUTO BRASILEIRO DE GEOGRAFIA E ESTATÍSTICA, 2010). The intensive use of natural resources, lack of adoption of conservative management practices and climatic limitation (frequent droughts) can lead to soil quality degradation, restricting agricultural production. Nowadays, more than half of the area in the northeastern region is considered degraded in different levels (BRASIL, 2005).

Thereby, sustainable agriculture represents an important alternative for food production (GLIESSMAN *et al*., 2007). Multi cropping system (MCS) is a model of sustainable agriculture, promoting diversity of diet, reducing risk of losses, efficient use of labor, and low external inputs (HYVÖNEN *et al*., 2003) as well as smaller erosion risks (DAELLENBACH *et al*., 2005).

Under these agroecosystems, soil quality is a substantial element as it is related to the capacity of a soil to be functional, within the limits imposed by the ecosystem and land use, to preserve the biological productivity and environmental quality, and promote plant, animal and human health (DORAN; PARKIN, 1994). Using an approach to gather farmers and their knowledge, technicians and researchers to evaluate soil quality is an innovative way to create a shared knowledge, and many researchers have identified that this synergism is important (BARRERA-BASSOLS; ZINCK, 2003; BARRIOS *et al*., 2006; GROSSMAN, 2003; MAIRURA *et al*., 2007; PAYTON *et al*., 2003).

Scientific methods are based in standard procedures and can be used to evaluate the practices developed in MCS, however, in a complementary way, using methods developed or adapted to the farmer's perception enables to get a more realistic assessment (GUIMARÃES; BALL; TORMENTA, 2011; MUELLER *et al*., 2009). Farmer's perception related to soil quality indicators were identified by Sousa (2006) and a group of technicians and researchers from Universidade Federal do Ceará (UFC) and Viçosa (UFV). Some family farmers led by ESPLAR, a non-governmental organization (NGO), were stimulated to discuss about conservative farming practices and its effects in their productive areas. From the reported indicators, "s*oil softness*" from MCS areas were considered by farmers as an indicator of the sustainable practices effects and it was chosen for an in depth evaluation, with the farmer's effective participation.

Based on the assumption that farmer's can perceive changes in soil properties due to management practices and is possible to evaluate it in the field, alternative methods were developed from standard ones which farmers and authors used to apply in field and in laboratory conditions, respectively. The objectives were i) evaluate the behavior of the indicator under the MCS areas and ii) compare the results obtained in the field and in the laboratory to certify that the methods applied were accurate.

MATERIAL AND METHODS

The experience with MCS started in the late 90's by ESPLAR with only four farmers adopting the practices, and in 2007 that number had grown to 245 (LIMA, 2008). It was a participatory project based in soil conservation practices and organic production. The group of farmers got organic certifications and fair trade, which are important elements in the process of economic development.

For the present study, three farmers were selected among the ones who worked with ESPLAR and in the research conducted by Sousa (2006). The MCS were composed by cotton (*Gossypium hirsutum*), maize (*Zea mays*), cowpea (*Vigna unguiculata*), and sesame (*Sesamum indicum*) under different arrangements. The natural vegetation (NV) areas are near the MCS, were not used for cropping and reflected a natural situation.

The study area is located in Choró county in the central part of Ceará state, Brazil, around the coordinates 4º40'20" S; 39º10'46" W with mean altitude of 250 m and topography predominantly gently slope with tropical warm semi-arid climate (BSw'h') based in Köppen. Annual mean rainfall and temperature are 922 mm and 27 ºC, respectively. Rainfall is concentrated in a few months characterizing a long period with water scarcity. The natural vegetation is characterized as Caatinga, predominantly shrubs trees, with adapted mechanisms to resist dry seasons (MOREIRA *et al*., 2006). A characterization of the areas and soil classification is described in Table 1.

Aggregate stability

Stability of aggregates was determined by the standard method (SM) proposed by Yoder (1936). The alternative method used aggregates of 15 mm of diameter weighing 50 g that were put in a plastic bottle of 1 L capacity with 800 mL of water and shaked at breast height for 20 s. After shaking, the material was transferred to a sieve of 2 mm and the material which remained in the sieve was put in an iron plate to dry and its moisture was calculated. To weigh the soil a simple balance was used with a horizontal stick fastened in a vertical structure and two containers in the horizontal extremities, one for soil and other for a standard weight (100 g). A moisted soil sample weighed in this balance was heated and then

Table 1 - Soil classification, main physical and chemical soil attributes and historical use of multi cropping system (MCS) and natural vegetation (NV) areas from studied family farmers

Areas	Soil classification	Physical and chemical attributes						Historical use of MCS and NV areas
		Hor.1/ Depth (cm)	Texture (g kg^{-1})			SOC[2] (g kg^{-1})	CEC[3] ($cmol_c$ kg^{-1})	
			Sand	Silt	Clay			
1	Inceptic Haplustalfs	A 0-6	770	170	60	18,4	7,0	MCS - Slash and burn in 1985 and cultivated until 1987. Fallow by 14 years. Initiated MCS in 2004. NV- Natural vegetation resto ring since 1987
		B 19-41	480	170	340	5,0	12,3	
2	Aquic Haplustult	A 0-8	830	110	60	8,4	2,3	MCS-Slash and burn in 1992 and cultivated until 1995. In fallow until 2002. Culti vating in MCS since 2003. NV- Natural Vegetation untouched
		B 34-89	630	80	290	3,1	2,4	
3	Typic Ustipsamments	A 0-22	750	160	90	5,5	3,0	MCS- Slash and burn in 1980 and cultivated with Carnaúba (a na tive palm tree) until 1987. In 1988, turned to cultivate maize and cowpea. Culti vating in MCS since 2003. NV- Natural vegetation restoring since 1988
		C 22-48	740	160	100	5,3	3,3	

1: Horizons; 2: Soil Organic Carbon; 3: Capacity of Exchangeable Cations; Determinations according to Schoeneberger, *et al*. (2002)

transferred to the container. Putting the sample again in the balance, it showed an imbalance due to the loss of water and soil, therefore, using a syringe, some water was put in the container with the soil sample until a balance was reached. The iron plate heating was done with 200 mL of etilic alcohol and time of heating of 20 minutes. To define shaking time of 20 s, different time intervals were tested (20; 40; 60 and 80 s) and compared to the SM. With times stablished, the proceedings were done in the field by farmers and then repeated in laboratory by authors to compare the performance of the methodology.

Aggregate dispersion

The methodology proposed by Emerson (1967) and Cerda (1998) was applied with no adaptations. Ten aggregates of 10 mm were put in 200 mL of water to evaluate its dispersion after 12; 24 and 36 hours, considering the scale: 0: no dispersion and aggregates completely stable; 1: dispersion of some particles, milkiness close to the aggregates; 2: Aggregates partly dispersed or divided into different smaller aggregates; 3: Considerable dispersion with most of the aggregates have been dispersed and milkiness very intense; 4: Total dispersion. This analysis was done in the laboratory by authors and in the field by farmers using samples from MCS and NV.

Soil penetration resistance (SPR)

The penetrometer method was chosen as the standard method (STOLF; FERNANDES; FURLANI, 1983) and the alternative method used an iron bar, common in civil engineering that consists of a bar with 5,12 kg and a cone basal area of 6,15 cm^2.

To obtain an equation of SPR from the iron bar, it was assumed that all the energy was transformed in soil penetration, so: $E = t$ and $E = m.g.h$, where: m = weight of the iron bar (kg), g = gravity's acceleration ($m\ s^{-2}$) and h = height of release (m). Considering that SPR is energy per area, and the tool's basal area is $6.15x10^{-4}$ m^2, it follows that $SPR = E/Basal\ area$ or $SPR = 81.586{,}9\ h$. Considering also the tool penetration by impact influencing the SPR value we will obtain the final equation as $SPR = 81{,}5\ N.h$ ($kN\ m^{-2}$). Where $N = 1/Penetration's\ depth$ (m) and h = height of tool's release (m).

In the alternative method, the iron bar was released from 4 heights (0,2; 0,4; 0,6 and 0,8 m), and the penetration into the soil surface was quantified. The two methods were applied simultaneously in MCS and NV areas.

Statistical analysis

The results were analyzed, except for soil penetration resistance, using analysis of variance (ANOVA) with a completely randomized design with split plot, comparing means using Tukey test ($\alpha = 0{,}10$) as was used field and farmer's measurements. Statistical analyses were performed using SAEG 6.0 (FUNDAÇÃO DE APOIO À UNIVERSIDADE FEDERAL DE VIÇOSA, 1993).

RESULTS AND DISCUSSION

Although just the area 2 showed differences between MCS and NV (Table 2) this result outpoints a similarity between MCS and the reference situation (NV) in soil structure, which may be related to the management practices as the addition of organic matter and decreasing soil handling (BERTOL *et al*., 2004; PEIGNÉ *et al*., 2007). Besides, a high earthworms activity was noted in these areas during the cropping season, which can be related to favourable effects on structural condition (MAHBOUBI; LAL, 1998). Allied to it, root action in promoting aggregation and surface protection led by the spontaneous plants also contributed to these results (SILVA *et al*., 2008).

An evaluation of mean weight diameter (MWD) revealed larger values for NV, what could indicate a better soil structural condition. In the alternative method, the time of shaking of 20 s, was chosen considering NV as a reference condition. No significant differences were found when the alternative method was applied in the field or in the laboratory, except for area 1 (Table 2).

Comparing the application in the field and in the laboratory did not reveal differences (Table 3), what could predict that it is an accurate way to evaluate aggregate stability and is accessible for farmers. It was not possible to obtain results from field measurements due to lack of data from field measurements.

Aggregate dispersion values from area 1 showed differences between times and applications, with dispersion increasing with time (Figure 1). Furthermore, significant differences were found between MCS and NV in area 2 with a smaller dispersion class for MCS, with two times of evaluation with zero dispersion (Figure 2).

Despite the conflicting results (Figure 1 and 2) in the situations observed, the values found were low,

Table 2 - Aggregate stability of MWD, C1 (4-2 mm) and C5 (< 0,25 mm) obtained using the standard method (SM) and the alternative method with shaking times of 20; 40 and 60 s for multi cropping system (MCS) and natural vegetation (NV) areas

Areas	Classes	SM		20s		40s		60s	
		MCS	NV	MCS	NV	MCS	NV	MCS	NV
1	MWD	4.33 Aa	3.57 Aa	2.43 Ab	3.06 Aa	3.36 Aa	3.20 Aa	3.89 Aa	3.12 Aa
2		3.61 Aa	6.13 Aa	4.69 Aa	5.36 Aa	4.98 Aa	5.38 Aa	4.92 Aa	5.27 Aa
3		2.03 Aa	4.15 Aa	2.22 Aa	3.53 Aa	2.26 Aa	3.76 Aa	1.79 Aa	3.76 Aa
1	C1	49.59 Aa	39.95 Aa	26.57 Ab	34.05 Aa	37.64 Aa	35.44 Aa	43.89 Aa	34.49 Aa
2		40.89 Aa	71.14 Aa	53.86 Aa	61.64 Aa	57.31 Aa	61.98 Aa	56.65 Aa	60.68 Aa
3		21.61 Aa	47.6 Aa	24.04 Aa	40.13 Aa	24.45 Aa	43.03 Aa	18.63 Aa	42.85 Aa
1	C5	38.80 Aa	38.90 Aa	59.07 Ab	49.71 Aa	46.41 Aa	42.76 Aa	38.62 Aa	45.42 Aa
2		47.30 Aa	20.98 Ba	36.06 Aa	26.76 Ba	31.75 Aa	27.08 Aa	34.59 Aa	27.81 Ba
3		59.92 Aa	44.1 Aa	61.94 Aa	49.61 Aa	56.61 Aa	47.79 Aa	58.95 Aa	45.60 Aa

Means with same upper case letters in column compare each class (MWD, C1 and C5) for the situations MCS and NV and means with same low case letters in row compare methods with the situations MCS and NV do not differ by Tukey test ($\alpha = 0{,}10$)

Table 3 - Mean stable aggregates > 2.0 mm in water by shaking for 20 s in alternative methodology to multi cropping system (MCS) and natural vegetation (NV) areas, under laboratory and field conditions for areas 1 and 2

Areas	Situation	Laboratory	Field
1	MCS	59.47 Aa	67.33 Aa
	NV	66.37 Aa	68.33 Aa
2	MCS	67.17 Aa	66.50 Aa
	NV	72.40 Aa	65.67 Aa

Means with same upper case letters in column compare the situations MCS and NV for each area and means with same low case letters in row compare applications in laboratory and in field do not differ by Tukey test (α = 0,10)

Figure 1 - Mean aggregate dispersion classes in water in 12; 24 and 36 hours in laboratory and field aplication of area 1. Means with same upper case letters compare application in each time of dispersion and means with same low case letters compare application with times of dispersion do not differ by Tukey test (α = 0,10)

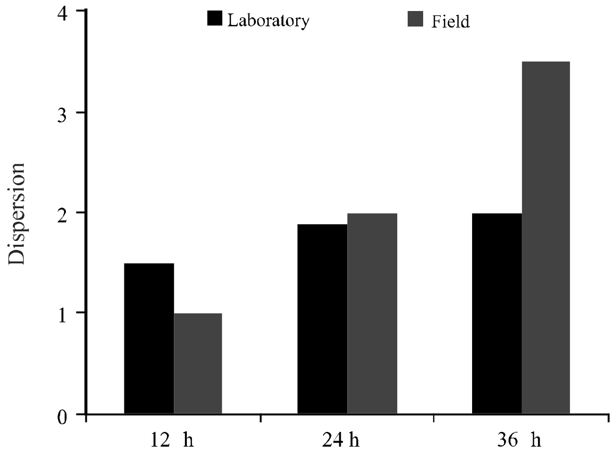
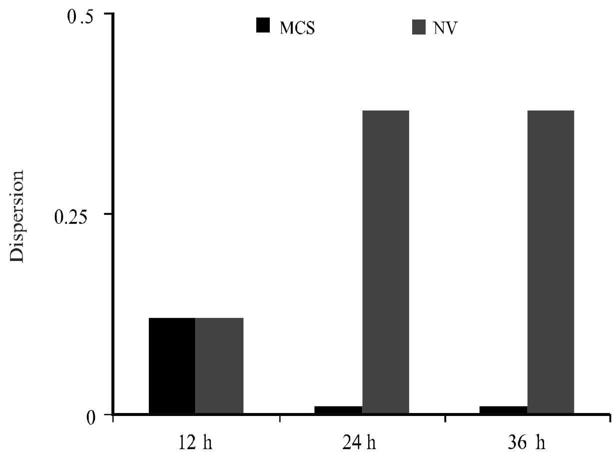


Figure 2 - Mean aggregate dispersion classes in water in 12; 24 and 36 hours in multi cropping system (MCS) and natural vegetation (NV) of area 2. Means with same upper case letters compare time of dispersion for each situation and means with same low case letters compare situation for each time do not differ by Tukey test (α = 0,10)



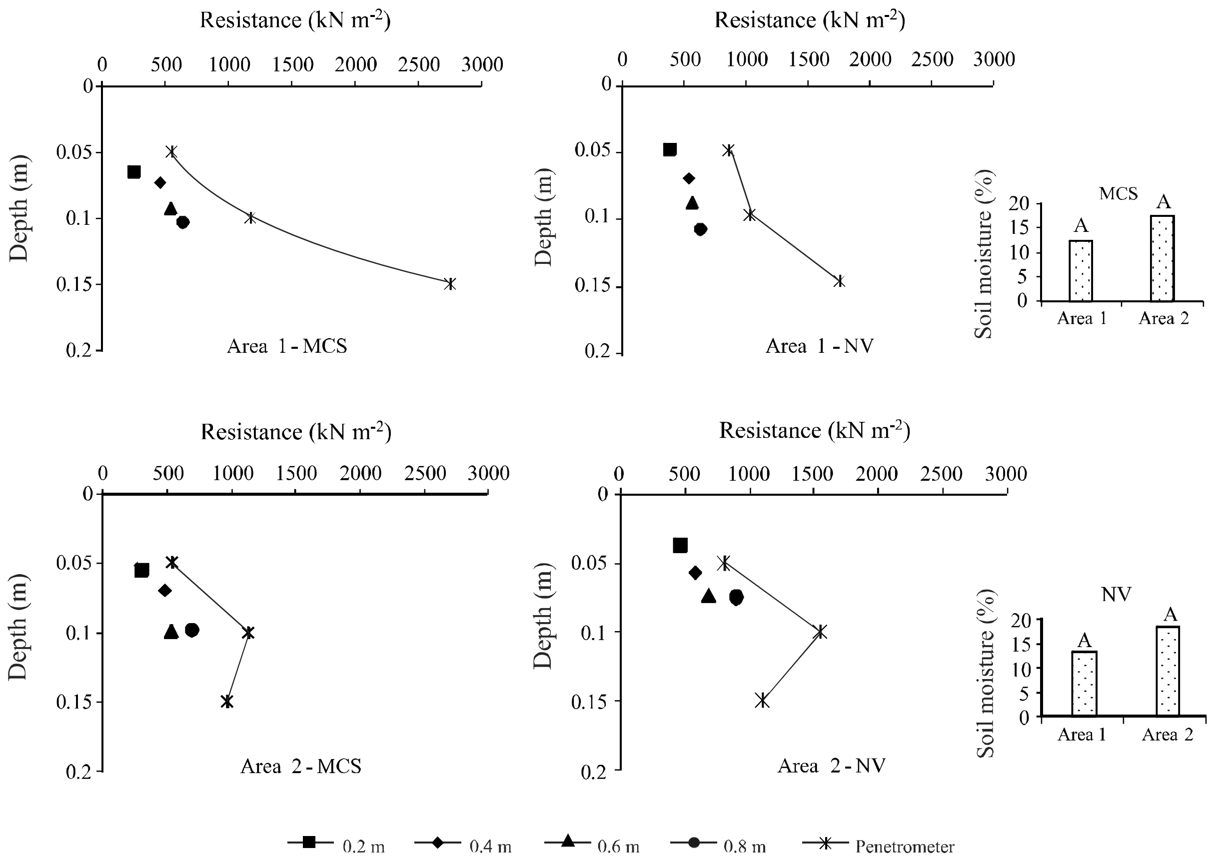
placing them in the class of few particles dispersion or partially dispersed aggregates. Cerda (1998) suggests that the vegetation coverage and the maintenance of aggregates are important to maintain the stability of aggregates.

Soil penetration resistance (SPR) in NV, mainly at the 0.05 m depth, was higher in both areas evaluated when compared to MCS (Figure 3). This tendency was perceived also with the alternative method. Higher resistance in NV can also be related to a higher efficiency of roots in water absortion and also due to the interception, which reduces water that could reach the soil consequently decreasing soil moisture (RENAULT; HEMAKUMANA; MOLDEN, 2001). Incorporating residues in cultivated areas can contribute to smaller SPR as happened in MCS areas. Zeleke *et al*. (2004) found similar results in a study of areas under residues addition comparing to an area without it and associated the structure improvement to management practices. Soil cover management in tropical areas protects it from surface sealing in rainy periods and from crusting during dry periods. Furthermore, these benefits can reduce SPR (THIERFELDER; AMÉZQUITA; STAHN, 2005).

Literature account that SPR values higher than 1960 kN m^{-2} can be considered as limiting to root growth and crop development (AGGARWAL *et al*., 2006). However, superior values were observed in MCS from area 1 (Figure 3), which can be related to a high concentration of stones, conditioning root development among them.

Values for SPR obtained with a penetrometer in MCS and NV from area 1 tended to rise from the 0.1 m depth, due to clay content increase below this depth, since this soil class has an “Abrupt Textural Change” (SOIL SURVEY STAFF, 1999). Increasing in

Figure 3 - Mean soil penetration resistance in kN m^{-2} obtained with standard and alternative methodology (release heights of 0.2; 0.4; 0.6 and 0.8 m) and mean soil moisture (mass based) of multi cropping system (MCS) and natural vegetation (NV) from areas 1 and 2



clay content may promote an increment in soil density and expression of adhesion and cohesion strength (PEDROTTI *et al*., 2001). In area 2, SPR with standard method in both situations (MCS and NV) showed a tendency to increase until 0.1 m, decreasing from then on.

Comparing methodologies is possible to conclude that the height of releasing of 0.6 m from alternative methodology show results resembled to 0.05 m from standard methodology. It is important to mention that soil moisture obtained in the moment of SPR evaluation did not show significant difference between conditions MCS and NV.

In general, results obtained in the laboratory and in the field, showed that the better soil conditions observed in MCS are probably related to the conservative management practices adopted. These results are related to a better soil structural condition favoured by the increase in organic matter and residues (BRONICK; LAL, 2005; GHANBARI *et al*., 2010). Values obtained for aggregate dispersion and penetrometer resistance confirm the statements assumed above as found also by Cerda (1998), Castro Filho *et al*. (2002), Zeleke *et al*. (2004) and Andrade and Stone (2009).

Farmer's impressions on the research were obtained through a questionnaire and they reported that it was an interesting evaluation as it enabled them to obtain results about management practices they are currently using. However, some farmers reported that soil structure evaluation methods could have been faster and more practical.

CONCLUSIONS

1. Alternative methods development to be applied in the field by farmers, based on standard methods were an approved manner to measure changes in the agroecosystems and may favour environment monitoring and evaluation of areas under conservative practices. Moreover, a holistic approach is necessary to understand the impact of sustainable practices and to reach multiple benefits through the development of environmental programs and projects;

2. Soil quality is positively affected by conservative management practices as multi cropping system areas showed similar conditions to natural vegetation ones. Seeing the farmer's direct involvement in indicators identification and mainly in methodologies performance, one can presume an advance in formal and local knowledge integration;
3. A positive point in this experiment is that farmers had an opportunity to associate empiric observations to measured values, what represents an important step in building the bridge between local and formal knowledge.

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