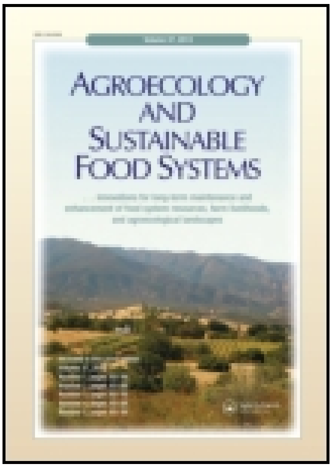

Agroecology and Sustainable Food Systems

Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/wjsa21

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Accepted author version posted online: 20 Mar 2015.

To cite this article: Ana Leônia de Araújo Girão, Renato Teixeira de Oliveira, Tiago Osório Ferreira, Maria Eugenia Ortiz-Escobar, Fábio Rodrigues Miranda & TeóGenes Senna de Oliveira (2015) Assessment of Soil Moisture by Family Farmers Under Multi-Cropping Systems in a Semiarid Region, Agroecology and Sustainable Food Systems, 39:7, 747-761, DOI: 10.1080/21683565.2015.1029602

To link to this article: http://dx.doi.org/10.1080/21683565.2015.1029602

Agroecology and Sustainable Food Systems, 39:747–761, 2015

ISSN: 2168-3565 print/2168-3573 online
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Assessment of Soil Moisture by Family Farmers Under Multi-Cropping Systems in a Semiarid Region

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Sustainable practices are key factors in the advancement of environmental protection in agroecosystems, especially if these systems are situated in degraded and vulnerable areas, such as semiarid regions. One sustainable practice developed primarily in tropical farms is the use of a multi-cropping system. This system was applied using participatory approaches by family farmers from a semiarid region of Brazil and evaluated based on the perception and monitoring of the farmers, particularly the soil moisture enhancement in their productive areas. Thus, this study aimed to evaluate the impact of management practices on soil moisture in multi-cropping areas using an alternative method, based on the standard method, developed and applied by farmers in the field. In addition, the soil moisture alterations in multi-cropping systems were evaluated considering the water retention curve and the soil moisture monitoring in situ. We concluded that conservative practices in multi-cropping systems do contribute to water conservation. Furthermore, the establishment of a methodology to evaluate multi-cropping systems directly in the field by farmers is an important strategy to show

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to the farmers' results that confirm the importance of the practices developed by them to maintain good production and general benefits to the environment.

KEYWORDS conservation practices, developing methodologies, participatory approaches

1. INTRODUCTION

Ceará is a northeastern Brazilian state, which is located in one of the most densely populated semiarid regions in the world (Instituto Brasileiro de Geografia e Estatística 2010). The high-intensity use of natural resources, the lack of conservation practices in agriculture, climatic limitations and scarce governmental incentives have promoted soil degradation, thus restricting agricultural production. Currently, more than half the area in the northeastern region is considered degraded to various degrees (Ministério da Integração Nacional 2005).

In this scenario, adopting more sustainable actions, such as multi-cropping systems, may provide relevant benefits to farm development and food production, allowing social equality, economic stability and environmental well-being (Gliessman et al. 2007). The multi-cropping system promotes diversity of diet, reduces the risk of crop losses, intensifies the efficient use of labor (Altieri 1999), and needs limited external inputs (Hyvönen et al. 2003) as well as reduces erosion risks (Daellenbach et al. 2005). Such agroecosystems provide ecological services such as nutrient recycling and soil carbon sequestration (Liu et al. 2007).

Multi-cropping systems fit well with farmers' daily lives in the studied area, as most of them were already using them but without adopting conservation practices. Other positive aspects promoted by multi-cropping system experience is the establishment and development of organizational entities of farmers that can help to better represent their needs.

One of the fundamental factors for the success of multi-cropping systems is the engagement between the participants, farmers, technicians and researchers, creating an environment of shared knowledge. The benefits of the interrelationship between the participants have already been presented by several authors (see, e.g., Barrera-Bassols and Zinck 2003; Payton et al. 2003; Grossman 2003; Barrios et al. 2006; Mairura et al 2007). Moreover, the joint monitoring and constant review of the developed actions enhance the chance to notice changes and motivate the continuation of the activities.

Considering the joint work and based on the findings reported by farmers, that soil conservation practices enable the retention of higher moisture over a longer period compared to the areas without multi-cropping systems, we thought of defining a method to quantify the moisture variation using a methodology accessible to farmers. This could represent a more tangible way for farmers to sense the efficacy of multi-cropping practices and help assimilate the importance of continuing development actions and even stimulate interest in evaluating other properties in the future.

Assuming that the changes in soil moisture could be quantified through an alternative methodology, a method was developed based on scientific principles and applied directly by the farmers to evaluate soil moisture. The soil moisture alterations by multi-cropping systems were also studied considering the water retention curve and the soil moisture monitoring in situ to confirm the field observations and provide complementary results.

2. MATERIALS AND METHODS

2.1. Soil Management: History and Sampling Areas

Local experience in this region with multi-cropping systems started in the late 1990s after serious damage occurred in monoculture cotton production, the main crop produced in the region, that was caused, in addition to other factors, by soil erosion and an insect (*Anthonomus grandis*) attack.

The scope of this project has grown through time, and today it integrates 255 farmers in a participatory project based on soil and water conservation practices. The group of farmers received certification in organic production and fair trade from the Instituto Biodinâmico (IBD), which are important elements in the process of economic development.

Farmers reported that improvement occurred in soil moisture levels, and due to its strategic importance in the agricultural development of a semiarid environment, we selected three farmers from the group that had taken part since 2003 in the multi-cropping project for the present study.

The multi-cropping system developed by farmers included cotton (G*ossypium hirsutum*), maize (*Zea mays*), cowpea (*Vigna unguiculata*), and sesame (*Sesamum indicum*) under different arrangements that were cultivated simultaneously and have been replanted every year since they began participating in the projects of a nongovernmental organization. They applied conservation practices such as contour planting, soil cover with weeds, constant inputs of organic matter, retention bands with residues or stones, no use of fire, minimum tillage using mainly manual tools, collecting cotton flower buds contaminated by *Anthonomus grandis*, using natural products for fertilization, and ecological control of insects. These farmers have organic certification, training and technical assistance.

Three natural vegetation areas near the multi-cropping ones were used to represent a natural situation that could serve as a standard of soil quality.

The study areas were located in Choró County, in the central part of the Ceará State, Brazil. These areas have a tropical warm semi-arid climate (BSw'h') based on Köppen. The annual mean rainfall and temperature are

922 mm and 27°C, respectively. The annual rainfall is concentrated in a few months, which indicates a long period of water scarcity. The natural vegetation is characterized as Caatinga, that is, predominantly shrubs and trees with adaptive mechanisms to resist the dry seasons (Ministério do Meio Ambiente. Secretaria de Biodiversidade e Florestas 2002). The characterization methods of the soil profiles in a study area were described in the work of Schoeneberger et al (2002), and the results were classified based on the Soil Survey Staff (2010) (Table 1).

2.2. Alternative Assessment of Soil Moisture

Soil moisture determination was performed using the established thermogravimetric method described by Empresa Brasileira de Pesquisa Agropecuária (1997) and by an alternative method, based on this standard, that used an iron plate (25 × 21 cm) to dry the soil and a balance with two trays to weigh the soil sample.

The balance consisted of a horizontal stick fastened to a vertical stick and two containers at the horizontal extremities, one for soil and the other for a standard weight (100 g). A moistened soil sample (100 g) weighed on this balance was heated and then transferred to the container. When this sample was returned to the balance, an imbalance due to the loss of water occurred. Next, using a syringe, water was added to the container with the soil sample until balance was once again achieved. The quantity of water added represented the amount of water that was initially in the sample. A water density of 1 g cm^{-3} was used to convert from the volume to the mass of the water.

The heating of the iron plate was performed by igniting 200 mL of ethyl alcohol, and the time of heating, defined in a previous evaluation of the temperature, was 20 min. Initially, a comparison was performed in the laboratory between multi-cropping and natural vegetation situations using the alternative method only, measuring the soil moisture in 4-h intervals. Subsequently, a brief workshop was prepared to present the methodology to the farmers and to hand out the necessary materials to apply the method in the field. The measurements were performed twice, at 10-h intervals, with six repetitions implemented both in the field (by the farmers) and in the laboratory (by the authors) to compare the results. Soil aggregates with a size of 8 mm were used and were moistened with a syringe.

2.3. Soil Water Retention and Water Field Dynamic

To evaluate water retention, 80 undisturbed soil samples were collected in cylinders from soil at a depth ranging from 0 to 10 cm from multi-cropping systems and natural vegetation. Tension values of 0.5, 1.0, and 2.0 kPa were

TABLE 1 Description of farms, soil classification, and main physical and chemical soil attributes of multi-cropping system (MCS) and natural vegetation (NV) areas of three family farmers from Choró–CE, Brazil

		Physical and chemical attributes									
			Texture (g. kg^{-1})								
Farms/geographic position	Soil classification	Hor.[a]/ Depth (cm)	Sand	Silt	Clay	Structure[b]	pH H_2O (1:2.5)	SOC[c] g. kg^{-1}	SB[d] cmolc. kg^{-1}	CEC[e] cmolc. kg^{-1}	Historical use of MCS and NV areas
Area 1 S4°43'11.7" W39°10'46.8"	Inceptic Haplustalfs	A 0–6 B 19–41	770 480	170 170	60 340	sbk, 2, f c, 3, co	7.4 6.4	18.4 5.0	6.9 12.2	7.0 12.3	**MCS**: Slash and burn in 1985 and cultivated with maize, cowpea and cotton until 1987. Fallow for 14 years. Slash and burn in 2003 to cultivate maize and cowpea. Initiated MCS in 2004. **NV**: Fallow with natural vegetation restoration since 1987.
Area 2 S4°43'9.8" W39°11'48.8"	Aquic Haplustult	A 0–8 B 34–89	830 630	110 80	60 290	sbk, 1, me c, 3, co	6.2 6.0	8.4 3.1	2.2 2.2	2.3 2.4	**MCS**: Slash and burn in 1992 and cultivated with maize and cowpea until 1995. Fallow period from 1996 until 2002. Cultivating in MCS since 2003. **NV**: Untouched natural vegetation.
Area 3 S4°40'20.2" W39°15'30.8"	Typic Ustipsamments	A 0–22 C 22–48	750 740	160 160	90 100	sbk, 2, me m, 3, no	6.5 6.2	5.5 5.3	2.9 3.3	3.0 3.3	**MCS**: Slash and burn in 1980 and cultivated with Carnaúba (a native palm tree) until 1987. In 1988, they changed the works to cultivate maize and cowpea. Prepared the soil with ploughing and planted until 1994. Fallow for two years and cultivated again with maize, cotton and cowpea until 2002. Cultivating in MCS since 2003. **NV**: Fallow and natural vegetation restoration since 1988.

[a]Horizons.

[b]Type: sbk = subangular blocky, c = columnar, m = massive; grade: 1 = weak, 2 = moderate, 3 = strong; size: vf = very fine, f = fine, m = medium, co = coarse, vc = very coarse, ec = extra coarse, no = not defined.

[c]Soil organic carbon.

[d]Sum of bases.

[e]Capacity of exchangeable cations; determinations according to Schoeneberger et al. (2002).

used employing a tension table (Lima et al. 2007), and 5, 8, 10, 20, 40, 60, 80, 100, 1000, and 1500 kPa were used in the pressure chamber. The curves were adjusted using the model proposed by Van Genuchten (1980). Microporosity was estimated using the same model (at 6 kPa), and macroporosity was obtained by determining the difference. The total porosity was calculated using a particle density of 2.65 g cm^{-3}.

For the soil moisture variation in situ, ECH_2O model EC-10 capacitive sensors (Decagon Devices, Inc., Pullman, WA, USA) were used in the multi-cropping and natural vegetation only for area 2. Two observation points were sampled, and at each point, four sensors at depths of 5, 15, 25, and 35 cm were used and evaluated over a period of 3 months during the main part of the rainy season, coinciding with the cultivation time. The sensors were calibrated based on Miranda et al. (2007), using soil samples from the depths of 0-10, 10-20 and 20-40 cm in multi-cropping and natural vegetation, applying an equation in which the values of the electric potential (mV) were correlated with the soil moisture (cm^3cm^{-3}): $U_v = 0.086\ EP - 30.85$, where U_v is the volumetric moisture (cm^3cm^{-3}), and EP is the electric potential (mV). A rain gauge was also installed in the area.

2.4. Farmers' Evaluation of Soil Moisture

The perception and acceptance of the alternative methodology were evaluated primarily based on the answers to the following questions: What was your impression of the methodology? What do you think could be improved in the methodology? What was the most difficult step to accomplish? Do you think that the methodology demonstrated the differences between the multi-cropping system and natural vegetation? What have you learned from this experience?

2.5. Statistical Analysis

The results were statistically analyzed using variation analysis (ANOVA), linear regression, and the Tukey and Dunnett tests with $P < 0.10$. Statistical analyses were performed using the software SAEG 6.0 (Fundação Artur Bernardes 1993).

3. RESULTS AND DISCUSSION

3.1. Development and Application of Soil Moisture Assessed by Farmers

During the methodology development, the first results obtained in the laboratory with the alternative methodology showed that the decrease in soil

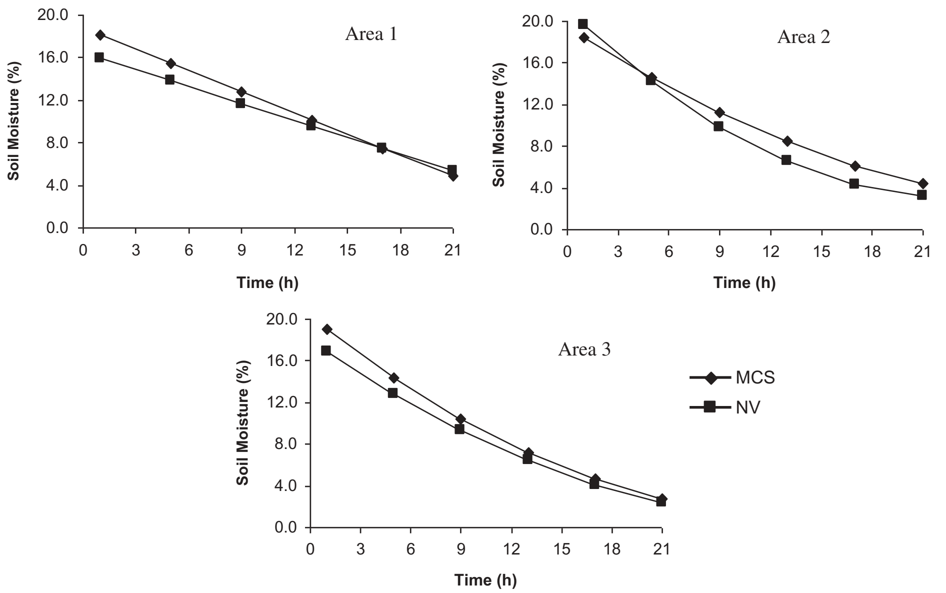

FIGURE 1 Soil moisture for different drying times using the alternative methodology in the multi-cropping systems (MCS) and natural vegetation (NV) samples from the three studied areas of family farmers from Choró–CE, Brazil.

moisture from the multi-cropping system from the three evaluated areas was higher in the first hours after moistening, increasing the similarity to natural vegetation over an increased time of exposure (Figure 1).

We can suppose that the increased water retention capacity in aggregates from multi-cropping areas is related to an improved structure (Hillel 1998). In addition, the management practices involving the farmers constantly adding organic matter leads to an increase in structural conditions influencing water retention and movement (Bronick and Lal 2005).

Defining the times of exposure of 1 and 10 h, which best demonstrated the moisture variation, the comparison of the measurements performed by the farmers and those performed in the laboratory showed higher values for the field measurements (Table 2), and the higher water content in the multi-cropping system than the natural vegetation was reaffirmed. The differences between the field and the laboratory measurements in the three areas evaluated do not invalidate this approach, as they are related to differences in the environmental conditions of the methodology performance. Despite these differences, both measurements assure increased values for soil moisture under the multi-cropping system compared to natural vegetation, as obtained in the preliminary evaluation (Figure 1).

The water retention curves from the multi-cropping systems and natural vegetation exhibited similar performance (Figure 2). The adjustable parameters are shown in Table 3.

TABLE 2 Soil moisture averages after 1 and 10 h of drying, evaluated in the laboratory and in the field in multi-cropping system (MCS) and natural vegetation (NV) for the three studied areas of family farmers from Choró–CE, Brazil

		Laboratory		Field	
		1 h	10 h	1 h	10 h
Areas	Situation	(%)			
1	MCS	14.3Ab	8.8Ab	18.7Aa	11.5Aa
	NV	12.6Bb	6.7Bb	17.2Ba	8.8Ba
2	MCS	11.1Ab	3.1Ab	20.8Aa	13.3Aa
	NV	12.8Ab	6.9Ab	21.3Aa	11.5Aa
3	MCS	19.9Ab	12.9Aa	30.5Aa	8.3Ab
	NV	15.3Bb	10.0Ba	23.3Ba	5.8Bb

Notes. The mean values followed by the same upper case letters in the same column compare the situation for each type of measurement (laboratory and field) and for each time of evaluation, and the mean values followed by the same lower case letter in the same line compare the laboratory and field conditions for each time of evaluation that do not differ at the 10% level of probability under the Tukey test.

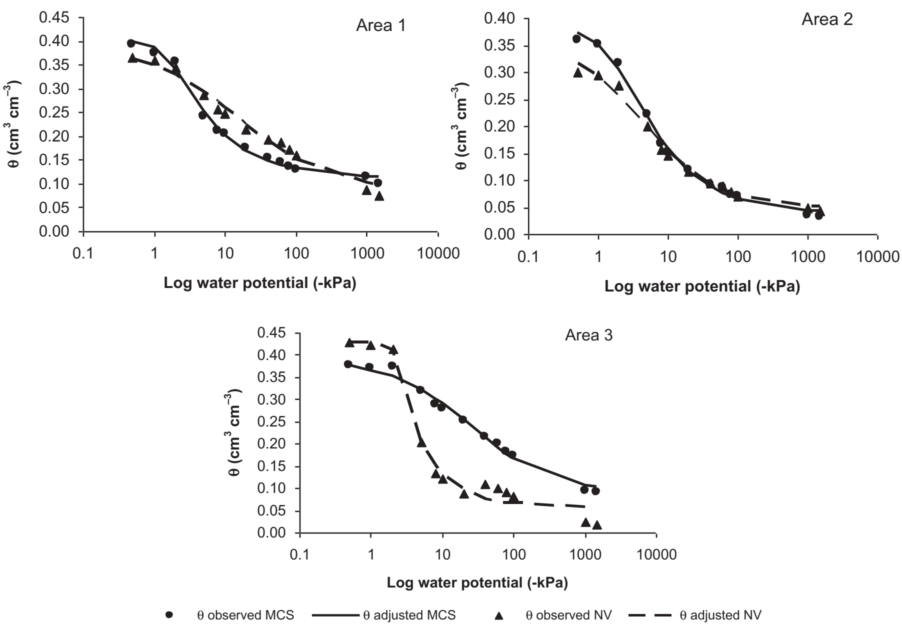

FIGURE 2 Water retention curves under multi-cropping systems (MCS) and natural vegetation (NV) of the three studied areas of family farmers from Choró–CE, Brazil.

For areas 1 and 2 in the multi-cropping system, the water content was higher for low tension, while it tended to be similar to natural vegetation for higher tensions. Higher water content for low tension indicates an improved soil structural condition (Hillel 1998), which was evident in these areas due to the longer periods of farmer involvement with sustainable practices (Table 1).

TABLE 3 Adjustable parameters from the water retention curves under multi-cropping systems (MCS) and natural vegetation (NV) of the three studied areas of family farmers from Choró–CE, Brazil

		Adjustable parameters					
Area	Situation	θ_s	θ_r	A	m	N	R^2
Area 1	MCS	0.3998	0.1092	0.0610	0.2238	2.7760	0.99
	NV	0.3923	0.0844	0.0059	1.0456	0.6604	0.99
Area 2	MCS	0.3863	0.0374	0.0494	0.3832	1.6741	0.99
	NV	0.3606	0.0483	0.0216	1.0162	0.8239	0.99
Area 3	MCS	0.3942	0.0979	0.0012	1.8780	0.6645	0.99
	NV	0.4277	0.0571	0.0521	0.0337	28.3612	0.99

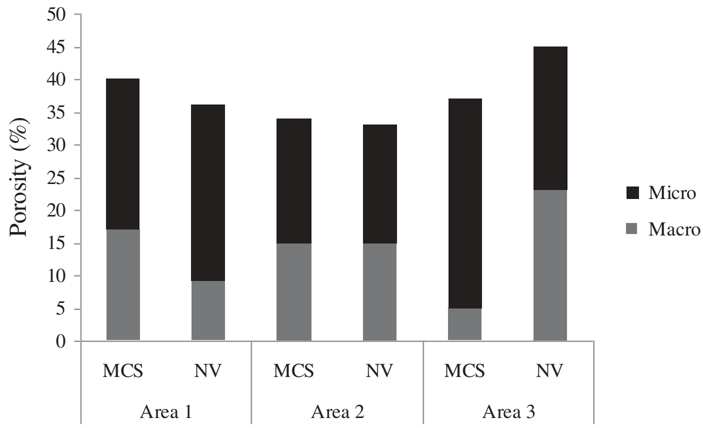

FIGURE 3 Mean microporosity (MICRO) and macroporosity (MACRO) under multi-cropping systems (MCS) and natural vegetation (NV) of the three studied areas of family farmers from Choró – CE, Brazil.

In area 3, the water retention curves exhibited an outstanding differentiation between the situations, which can be due to the wide granulometric variation that is typical of soil profiles developed from alluvial deposits. Note that natural vegetation is close to a stream and exhibited high quantities of sand, which led to a prominent decrease in water retention from the 5 kPa tension. Nevertheless, in multi-cropping systems, for the same tension, there was a slight decrease, possibly due to the higher microporosity. This is the only area that showed significant differences in macro- and micropore values (Figure 3), accounting for the larger water retention (Carvalho et al. 2004). Porosity is a variable influenced by management practices, granulometry being the main component in the definition of micro or macropore predominance, and high micropore values may indicate the capillarity present (Bertol et al. 2004).

The moisture values obtained from both methods in the first hour after moistening fell into a range that, when compared with the soil moisture retention curve (Figure 2), did not show significant differences, as the retention tension corresponding to the moisture values (transformed to volumetric moisture) in the multi-cropping system and natural vegetation varied from 3 to 5 kPa.

3.2. Field Water Dynamic

The evaluation of the water dynamics in the field through the sensors showed that the areas under multi-cropping systems maintain moisture longer when compared to the areas under natural vegetation (Figure 4). The soil moisture was consistent with the rainfall variation, that is, the sensors responded to the soil moisture variation. Until the one hundredth observation day, the soil moisture in the multi-cropping and natural vegetation areas were similar at depths of 5, 15, and 25 cm, while at a depth of 35 cm, multi-cropping areas exhibited increased values of soil moisture. From the one hundredth date to the end of the observations, all the depths exhibited increased moisture values in the multi-cropping systems (Figure 4).

The higher values of soil moisture in multi cropping areas at a depth of 35 cm can be related to the selection of agricultural species, that is, specifically in arid and semiarid environments, root development is a limiting factor for plants because the maintenance of larger and more

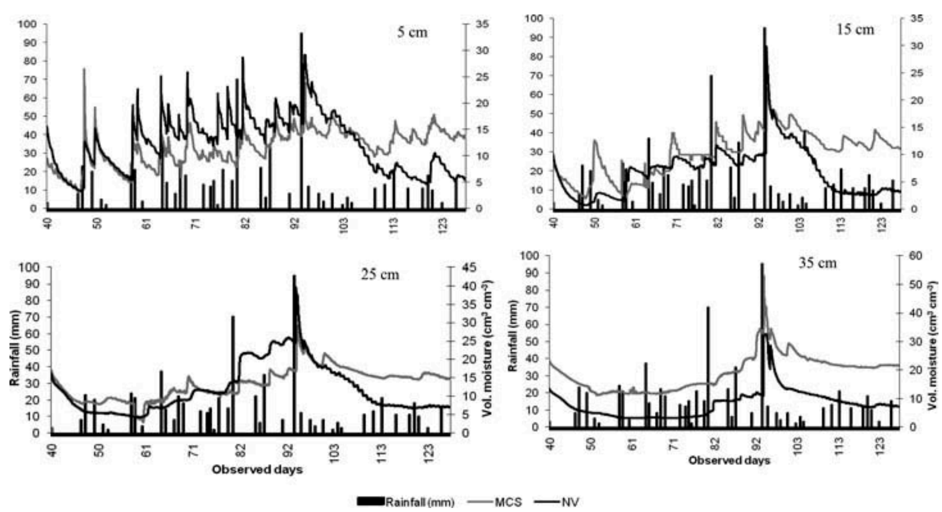

FIGURE 4 Mean volumetric soil moisture content at 5, 15, 25, and 35 cm depths from Day 39 to 128 (Julian date) and rainfall values from the multi-cropping system (MCS) and natural vegetation (NV) of Area 1 of family farmer from Choró–CE, Brazil.

numerous roots requires energy expenditures (Ma et al. 2008). Root development in natural vegetation is not restricted, as the native plants are adapted to their environmental conditions, which can explain the smaller soil moisture values in natural vegetation areas. Besides, the roots of native trees are able to explore a larger portion of soil than agricultural crops.

Soil moisture tended to be lower in natural vegetation areas in the last observed period from all the depths evaluated (Figure 4). Perennial vegetation reduces the rainfall contribution due to drop interception and evapotranspiration (Renault et al. 2001). In multi-cropping system areas, the activities of soil preparation contributed to create a loose layer superficially in the soil, and the water transfer from the moistened part decreased substantially. Thus, the water transfer from deeper layers to the surface occurs mainly in vapor form, contributing to the maintenance of higher moisture in the multi-cropping systems. A similar situation was found from Querejeta et al. (2000) studying moisture loss variation in terraced areas.

3.3. Farmers' Perception of Alternative Soil Moisture Assessment

The farmers considered the methodology interesting, as it enabled them to obtain results about the management practices they are currently using. The difficulties mentioned by the farmers are related to the need for repetition and the amount of time spent applying the methodology. An alternative methodology was developed to minimize the equipment limitation due to field application while maintaining the accuracy; nevertheless, some farmers reported that the method could have been faster and more practical (Table 4). Scientific requirements that are not part of the typical activities of the farmers influenced the application of the method, as the farmers found the methodology laborious.

The farmers believed that the good results from the multi-cropping system are related to the soil cover and the variations of soil properties throughout the area, calling attention to field irregularities (Table 4). There was no consensus between farmers when comparing multi-cropping systems and natural vegetation differences.

A positive point in this experiment is that the farmers had an opportunity to associate empirical observations to the measured values in their areas. Gray and Morant (2003) stated that the possible contradictions between the perception of farmers and the laboratory analyses are not sufficient to disqualify the participation of farmers in research studies. Payton et al. (2003) affirmed the general agreement that the achievement of research and the extension of joint activities are promoted by further analysis and management of natural resources and by promoting a participatory process.

TABLE 4 Farmers' evaluation of the alternative methodology used to measure soil moisture under multi-cropping system (MCS) and natural vegetation (NV) of three studied areas of family farmer from Choró–CE, Brazil

Evaluated aspect	Area 1	Area 2	Area 3
Methodology impression	New evaluation method	Interesting	Easy to be applied
Points to be improved	None	None	It is better to present the methodology individually
Difficulties	Time to be spent	Time to be spent	Time to be spent
Differences between MCS and NV	It seems that NV areas have more leaves and so have more water than MCS	MCS areas maintain higher moisture than NV	It seems that clods were easier to break up in MCS areas than in NV
Learning	It helped to better know the land and identify small differences such as sandy and stony areas.	The sustainable practices are very important	Learned to quantify differences between the two areas

4. CONCLUSIONS

In general, the results obtained in the laboratory or in the field established that the improved soil conditions observed in the multi-cropping system are related to the conservation management practices adopted. The higher values and the maintenance of soil water are favored by the increase in soil structure, organic matter and residues (Hillel 1998; Bronick and Lal 2005; Ghanbari et al. 2010).

Soil quality is positively affected by conservation management practices, and by utilizing the direct involvement of farmers in this evaluation, one can presume an advance in the integration of formal and local knowledge. Moreover, developing research to set up alternative field methods, may contribute to the integration of knowledge.

An alternative method developed to be applied in the field by farmers, based on standard methods, proved to be compatible to the standard method and accessible, which can favor environmental monitoring and the evaluation of areas under conservation practices over long periods of time. Another important aspect is to reaffirm the benefit of the strategies applied by the farmers, as soil moisture analysis complemented by other techniques showed the same tendency, that is, the water conditions in multi-cropping areas were higher than in natural vegetation areas.

This experience might show that farmers constantly apply qualitative perceptions to evaluate the productivity of a system, as presence or absence of flowers with insects. The quantitative evaluation is not widely used as it needs monitoring and evaluation with more elements to better measure. This aspect may have contributed to hampering the interpretation of the results of the alternative methodology (Van Asten et al. 2009).

In addition to the methodological proposal, it is important to maintain the areas under monitoring (Seely et al. 2010) as this can generate a set of data and assessments that could indicate possible faults in the adoption of multi-cropping systems and help identify the strengths of positive change.

ACKNOWLEDGMENTS

We thank all the farmers who were involved with this study of multi-cropping, especially those directly involved in this research: Mr. José Alberto (area 1), Mr. João Félix (area 2), Mr. Antônio Alberto (area 3), and Mrs. Maria Liduína. We also thank the staff from NGO ESPLAR, who helped with the setup of this project and also with the field work, as well as other people involved from UFC, including Maria Valdenira Oliveira, Vagner Silva, and Pollyanna Silva.

FUNDING

We are thankful for the opportunity provided by the CNPq funding the project and the scholarships of the authors.

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