WATER RETENTION AND S INDEX OF AN OXISOL SUBJECTED TO WEED CONTROL METHODS IN A COFFEE CROP

Retenção de água e índice S de um Latossolo Vermelho-Amarelo submetido a métodos de controle de plantas invasoras na cultura do café

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ABSTRACT

Weed control in different crops affects the chemical, physical, and biological properties of the soil and consequently its structural quality. The objective of this study was to evaluate, using water retention characteristics and the S index, the physical quality of an Oxisol (Red-Yellow Latosol), subjected to weed control during the cultivation of coffee. The following weed control methods were evaluated: harrowing, brushcutting, residue crushing, manual weeding, post-emergence herbicide application, pre-emergence herbicide application, and maintenance of soil cover with peanut forage, Brachiaria grass, and spontaneous vegetation (no weed treatment). The following properties were determined for physical characterization of the soil: bulk density, total porosity, macroporosity, microporosity, water retention, and the S index. The weed control method significantly affected the physical properties and water retention in the subsurface layer of the Oxisol. Soil bulk density, total porosity, macroporosity, and microporosity were significantly correlated with the S index. According to the S index, the physical quality of the soil was classified as very good for the various weed control methods investigated.

Index terms: Weed management, physical quality of the soil, soil water retention.

RESUMO

O controle das plantas daninhas nos diferentes cultivos influenciam atributos químicos, físicos e biológicos do solo e consequentemente sua qualidade estrutural. O objetivo deste trabalho foi avaliar, por meio da retenção de água e do índice S, a qualidade física de um Latossolo Vermelho-Amarelo (LVAd) submetido a métodos de controle de plantas invasoras na cultura do café. Foram avaliados os seguintes métodos de controle de plantas invasoras: grade, roçadora, trincha, capina manual, herbicida de pós-emergência, herbicida de pré-emergência, emanutenção da cobertura do solo com amendoim-forrageiro, capim-braquiária e vegetação espontânea (tratamento sem capina). Para a caracterização física do solo foram determinados os seguintes atributos do solo: densidade do solo, porosidade total, macroporosidade, microporosidade, retenção de água e o índice S. Os métodos de controle das plantas invasoras afetaram significativamente os atributos físicos e a retenção de água das camadas superficial e subsuperficial do Latossolo Vermelho-Amarelo. Densidade do solo, porosidade total, macroporosidade e microporosidade correlacionaram-se significativamente com o índice S. De acordo com o índice S, a qualidade física do solo foi classificada como muito boa para os diversos métodos de controle empregados.

Termos para indexação: Manejo de plantas daninhas, qualidade física do solo, retenção de água.

INTRODUCTION

Previous studies have shown that the use of different management and weed control systems for coffee cultivation influences the physical, chemical, and biological properties of the soil (Alcântara et al., 2007; Pais et al., 2011; Araujo-Junior et al., 2011; Melloni et al., 2013). In general, such systems should contribute to the improvement or maintenance of the physical quality of the soil and the environment as a whole, and should also ensure satisfactory long-term crop yields (Costa et al., 2003). Alcântara and Ferreira (2000) showed that different weed control methods in coffee plantations influenced the physical quality of the soil, most significantly in the 0-15 cm layer.

According to Dexter (2004), the physical quality of the soil manifests in various ways and the degradation of the soil structure is a common cause of poor physical quality. Soil structure refers to the arrangement of the particles that make up the soil, forming a porous system. According to Ferreira (2010), soil structure has a dynamic nature, and any alteration in the pore space will lead to an alteration in the behavior of the processes occurring within the soil.

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The impacts of land use and management have been quantified according to the physical attributes that determine the structural stability of the soil. The attributes most commonly used for soil physical characterization are aggregate stability, porosity, and soil bulk density (Bd) (Aratani et al., 2009).

The use of the S index as a parameter for evaluating the physical quality of the soil was proposed by Dexter (2004). The value of the S index is dependent on the characteristic water retention curve (WRC) and represents the slope at its inflection point. In the study by Dexter (2004), an S index of 0.035 was reported as the borderline between soils with good and poor structural quality.

Andrade and Stone (2009) evaluated the S index as an indicator of the physical quality of soils of the Brazilian Cerrado, allowing meaningful comparison with the present study. According to these authors, the S index was an appropriate indicator of the physical quality of the soil in the Cerrado, and an S index of 0.045 reflected the distinction between good soil structure and soil structure at risk of degradation. The usefulness of the S index for assessing the physical quality of the soil has also been demonstrated in a number of other studies (Tormena et al., 2008; Streck et al., 2008; Beutler et al., 2008; Pereira et al., 2010; Cavalieri et al., 2011; Calonego; Rosolem, 2011; Mota et al., 2012; Silva et al., 2012).

The hypothesis of present study is that weed control methods that improve the physical quality of the soil will result in higher values of the S index. Given the considerations above, this work seeks to evaluate the water retention characteristics and the S index in an Oxisol cultivated with coffee and subjected to different weed control methods.

MATERIAL AND METHODS

The present study was conducted on the Dr. Silvio Menicucci experimental farm belonging to the Empresa de Pesquisa Agropecuaria de Minas Gerais (EPAMIG) (45°06′43.8″ W, 21°21′12″ S), located in Lavras, Minas Gerais (MG), Brazil. The average annual rainfall at the study site is 1511 mm and the average relative humidity is 76.2% (Brasil, 1992). According to the Köppen climate classification, the region has a Cwa climate, characterized as subtropical with a dry winter and prevailing summer rainfall. The soil at the site is an Oxisol, classified as a dystrophic Red-Yellow Latosol (LVAd) with a clayey texture. The chemical and physical characterization of the soil at the study site is shown in table 1.

The installation of the coffee crop took place in January 2005. The cultivar planted was IAC Catuaí 99, with a spacing of 0.8 m between plants and 3.5 m between rows. The various methods of weed control (Table 2) were applied in strips to facilitate field operations. The data for this study were collected in January 2012, seven years after the beginning of the experiment.

The details of the weed control methods are as follows: Peanut forage (PF) planted on installation at a density of 150 kg ha^{-1}; Brushcutting (BC) with a Kamaq KDD ECO 230 Cruiser brushcutter with an approximate mass of 560 kg (average of five operations); Harrowing (HR) with 16 disks arranged in a V and an approximate mass of 262 kg (average of three operations); Residue crushing (RC) with an RB Tritton 1300 with six rows of hammers and an approximate mass of 570 kg (average of five operations); Post-emergence herbicide (PstH), glyphosate at 3 L ha^{-1} in 300 L of water (an average of three applications); Pre-emergence herbicide (PreH), oxyfluorfen at a dose of 3 L ha^{-1} in 300 L of water (an average of two applications); Manual weeding (MW) (average of five operations); No weeding (NW); and Brachiaria grass (BR) planted on installation at a density of 150 kg ha^{-1}.

In each strip of about 144 m in length, three 48 m parcels were randomized, each containing 60 holes for coffee plants. Each control method was applied to two adjacent strips, so that one served as a border for the surrounding treatments. The experimental had a 9 × 2 factorial, randomized block, split-plot design. The factors were the nine weed control methods and two soil depths, with three replications.

Table 1 – Physical and chemical characterization of the 0–15 and 15–30 cm layers of the Oxisol at the study site.

Layer (cm)	Sand	Silt	Clay	pH	K	P	Ca	Mg	Al	SB	T	V
	-------g kg^{-1}-------				--mg dm^{-3}--		------------cmol$_c$ dm^{-3}-----------					(%)
0–15	130	330	540	5.9	176.45	0.65	1.31	0.88	0.15	2.64	2.79	43.53
15–30	110	360	530	5.8	120.99	0.56	0.64	0.47	0.28	1.42	1.70	25.08

At the time of the installation of the coffee crop, the equivalent of 3 t ha^{-1} of agricultural gypsum and 500 kg ha^{-1} of 20-5-20 NPK were applied in the planting furrows, plus 300 g per hole of simple superphosphate. The weed control operations were initiated when 90% of the soil between rows was covered by weeds (Table 3) and/or the plants were approximately 0.45 m tall.

Undisturbed samples were used for the determination of the physical properties of the soil and WRCs of the nine treatments. Samples were collected with Uhland samplers, with average ring dimensions of 4.90 cm in diameter and 2.65 cm in height. The volumetric ring method (Blake; Hartge, 1986) was used to determine the soil Bd and the pycnometer method (Flint, Flint, 2002) was used to determine particle density (Pd). The total porosity (TP) was calculated using the formula $TP = (1-Bd/Pd) \times 100$. The microporosity (Micro) was determined as equivalent to the water content of the sample at a tension of 6 kPa (Oliveira, 1968) in a suction unit composed of Buchner funnels, which promoted the drainage of the sample at different suction heights, emptying the soil pores of a target diameter. The macroporosity (Macro) was calculated as the difference between TP and Micro. For the water retention evaluation, undisturbed soil samples were saturated and then subjected to tensions corresponding to −2, −4, −6, and −10 kPa, using the suction unit and

Table 2 – Weed control methods in Oxisol cultivated with coffee in Lavras, MG.

Control Method	Identification
Peanut forage (*Arachis pintoi* L.)	PF
Harrowing	HR
Brushcutting	BC
Residue Crushing	RC
Post-emergence Herbicide	PstH
Pre-emergence Herbicide	PreH
Manual Weeding	MW
No Weeding	NW
Brachiaria grass (*Brachiaria decumbens)*	BR

Table 3 – Principal weed species present in the experimental area, classified according to Lorenzi (2006).

Scientific Name	Popular Name
Brachiaria decumbens Stapff.	Surinam grass
Bidens pilosa L.	Spanish needle
Portulaca oleracea L.	Pigweed
Vernonia spp.	Ironweed
Baccharis dracunculifolia DC.	Broom
Conyza canadensis (L.) Cronquist.	Horseweed
Sida rhombifolia L.	Arrowleaf sida
Pennisetum purpureum Schum.	Napier grass
Digitaria horizontalis Willd.	Crabgrass
Amaranthus hibridus L.	Smooth amaranth
Spermacoce latifólia Aubl.	Oval-leaf false buttonweed
Sida cordifolia L.	Flannel weed
Digitaria insularis (L.) Fedde.	Sourgrass

to tensions of −33, −100, −500, and −1500 kPa, using the Richards extractor (Klute, 1986). The WRCs were obtained by nonlinear fitting of the gravimetric water content values (U) as a function of soil water tension (kPa) to the model proposed by Van Genuchten (1980) with the Mualem constraint [m = 1 − (1/n)] using RTEC software (Van Genuchten et al., 2009).

The S index values were calculated on a weight basis according to Dexter (2004) using the following equation:

$$S = -n\left(U_{sat} - U_{res}\right).\left[1 + \frac{1}{m}\right]^{-(1+m)}$$

Where:
S = the slope of the WRC at its inflection point;
U_{sat} = saturated water content (kg kg^{-1});
U_{res} = residual water content (kg kg^{-1});
and m and n = equation empirical parameters.

The results of physical characterization and water retention were subjected to analysis of variance and averages were compared by the Scott–Knott test at 5% probability. SISVAR statistical software (Ferreira, 2011) was used for both procedures. Correlation analysis between variables was carried out using SigmaPlot software (SigmaPlot, 2011).

RESULTS AND DISCUSSION

In the present study, significant differences among the different weed control methods were only found among the physical properties of the soil in the 15-30 cm layer (Table 4). However, in the study by Alcântara and Ferreira (2000), weed control methods did not affect the physical quality of the soil in this deeper layer.

Table 4 – Soil bulk density (Bd), total porosity (TP), macroporosity (Macro), and microporosity (Micro) of an Oxisol subjected to weed control methods in the cultivation of coffee.

Control Methods	Bd	TP	Macro	Micro
	mg m^{-3}	----------cm^3 cm^{-3}----------		
		Layer 0-15 cm		
PF	1.11a	0.58a	0.21a	0.37a
HR	1.13a	0.58a	0.20a	0.38a
BC	1.14a	0.57a	0.20a	0.37a
RC	1.12a	0.58a	0.21a	0.37a
PstH	1.08a	0.60a	0.24a	0.36a
PreH	1.11a	0.58a	0.19a	0.39a
MW	1.12a	0.57a	0.19a	0.38a
NW	1.16a	0.56a	0.16a	0.40a
BR	1.15a	0.56a	0.18a	0.38a
		Layer 15- 30 cm		
PF	1.14b	0.57b	0.20b	0.37b
HR	1.13b	0.58b	0.20b	0.38b
BC	1.07c	0.60b	0.23b	0.37b
RC	1.01d	0.63a	0.27a	0.36b
PstH	0.94d	0.64a	0.30a	0.34b
PreH	1.05c	0.60b	0.24b	0.36b
MW	1.05c	0.60b	0.25b	0.35b
NW	1.05c	0.60b	0.25b	0.35b
BR	1.30a	0.51c	0.09c	0.42a

Averages followed by the same letter in columns within each layer do not differ by the Scott–Knott test at 5% probability.

In the specific case of the BR plot, there was a higher Bd, lower TP and Macro, and a higher number of micropores in the 15-30 cm layer compared with the 0-15 cm layer. Conversely, lower Bd and higher TP and Macro were observed where weed control was performed with PstH or RC. A study by Pragana et al. (2012), to assess differences in the soil physical attributes of no tillage and conventional tillage systems in a typical dystrophic Yellow Latosol, found higher absolute Bd values in soils with less soil turnover (no tillage) compared with soils subjected to conventional tillage.

Carmo et al. (2011) evaluated the effect of different coffee cultivation systems on soil physical properties and observed lower soil Bd in native forest and coffee plantations without mechanization, while slightly higher Bd was observed in high stand density farming and mechanized farming, although the differences were not significant. Higher Micro was also observed by Pereira et al. (2010), also using a grass, Pearl millet (*Pennisetum americanum* (L.) Leeke), in an experiment to evaluate the physical quality of a soil cultivated with maize subjected to cover crops, pre-harvest.

Similar to the physical attributes, almost all the differences in water retention among the different weed control methods were observed in the 15-30 cm layer (Table 5).

As shown in figures 1 and 2, the differences in WRCs among different weed control methods were larger in the 15–30 cm layer (Figure 2) than in the 0-15 cm layer (Figure 1).

Table 5 – Water retention at various applied tensions in an Oxisol subjected to weed control methods in the cultivation of coffee.

Control Methods	Tension (−kPa)								
	0	2	4	6	10	33	100	500	1500
	---------kg kg^{-1}---------								
	Layer 0-15cm								
PF	0.54a	0.39a	0.35a	0.34a	0.32b	0.22b	0.21a	0.19a	0.18a
HR	0.53a	0.38a	0.35a	0.33a	0.32b	0.22b	0.21a	0.19a	0.18a
BC	0.52a	0.39a	0.35a	0.33a	0.32b	0.22b	0.21a	0.19a	0,18a
RC	0.54a	0.40a	0.36a	0.34a	0.33a	0.22b	0.21a	0.19a	0.18a
PstH	0.56a	0.40a	0.36a	0.34a	0.32b	0.22b	0.21a	0.19a	0.17a
PreH	0.49a	0.42a	0.37a	0.35a	0.34a	0.24a	0.22a	0.20a	0.19a
MW	0.51a	0.40a	0.36a	0.34a	0.33a	0.23a	0.22a	0.20a	0.19a
NW	0.47a	0.39a	0.36a	0.35a	0.33a	0.24a	0.22a	0.20a	0.19a
BR	0.49a	0.40a	0.36a	0.34a	0.33a	0.23a	0.22a	0.20a	0.18a
	Layer 15-30cm								
PF	0.52c	0.38b	0.34c	0.33c	0.31b	0.22a	0.21a	0.19a	0.18a
HR	0.51c	0.38b	0.35c	0.33c	0.32b	0.23a	0.21a	0.19a	0.18a
BC	0.56b	0.42a	0.37b	0.35b	0.33a	0.22a	0.20a	0.18a	0.17a
RC	0.62b	0.44a	0.38b	0.35b	0.34a	0.22a	0.21a	0.19a	0.17a
PstH	0.70a	0.46a	0.39a	0.37a	0.35a	0.23a	0.20a	0.18a	0.17a
PreH	0.61b	0.40b	0.36b	0.35b	0.33a	0.22a	0.21a	0.19a	0.18a
MW	0.58b	0.41a	0.37b	0.34b	0.33a	0.23a	0.21a	0.20a	0.19a
NW	0.55b	0.40b	0.36b	0.35b	0.33a	0.23a	0.22a	0.20a	0.19a
BR	0.39d	0.35b	0.33c	0.32c	0.32b	0.23a	0.22a	0.20a	0.19a

Averages followed by the same letter in columns within each layer do not differ by the Scott–Knott test at 5% probability.

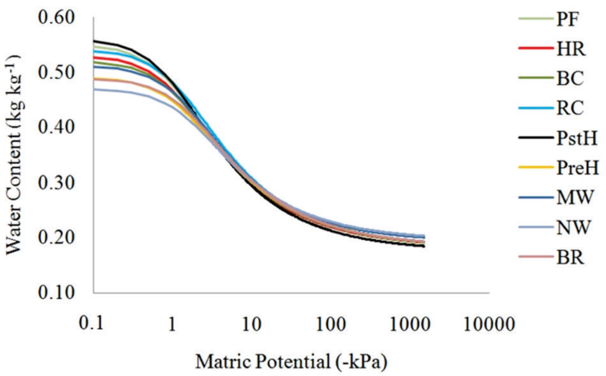

Figure 1 – Water retention curves in the 0–15 cm layer of an Oxisol subjected to weed control methods in the cultivation of coffee.

As shown in figure 2, among the weed control methods, the strip controlled with BR stands out, having a WRC similar to that for the compacted soil.

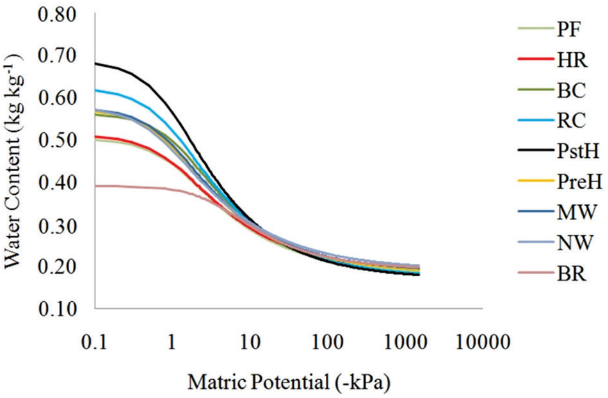

Figure 2 – Water retention curves the 15–30 cm layer of an Oxisol subjected to weed control methods in the cultivation of coffee.

With a higher Bd and lower TP (Table 4), and thus lower water content at saturation (0 kPa) (Table 5), the WRC for the BR strip is positioned below the others, until the tension reaches about −6 kPa. In soils with higher Bd there is a reduction in porosity, and in particular, larger diameter pores are suppressed. These larger pores are responsible for water retention at low tensions. Therefore, the higher Bd explains the lower water retention in the strip managed using BR in this experiment. Conversely, the WRCs for strips controlled with PstH or RC showed higher water retention. The results of Araujo-Junior et al. (2011), evaluating the effects of weed control methods on soil porosity and water retention, differed from the results of the present study. Those authors did not observe large differences in water content in the deeper soil layers, but observed large differences in the surface layer. It is important to note that Araujo-Junior et al. (2011) studied the soil with a higher degree of weathering, BR and PF treatments were not included, and the duration of the study was longer.

In the 0–15 cm layer, the S index did not differ significantly among weed control methods. Significant differences in the S index were only observed in the 15–30 cm layer. These results support the results for the physical attributes and water retention discussed above (Table 5).

For Cerrado soils, Andrade and Stone (2009) defined an S index of 0.045 as the value for separating soils with favorable physical conditions from those with unfavorable conditions. Therefore, the values of the S index obtained in the present study suggest that the weed control methods have maintained the soil with good structural quality (Table 6).

Silva et al. (2008) also observed higher S index values in the soil maintained without tillage, as is the case in weed control with PstH, which indicates a better soil pore configuration and less physical restriction for the plant roots by aeration, mechanical restriction, or water retention.

Beutler et al. (2008) found that S index values of 0.056–0.062 limited the development of soybean and corn. Freddi et al. (2009) found positive correlations between maize hybrid productivity and S index values of ≤0.035, which was established as a limit for the unstructured soil. Higher values were associated with marked declines in corn yield.

Soil Bd, TP, Macro, and Micro are indices traditionally used to assess the physical quality of the soil and to qualify the structural conditions underlying different soil quality. Bd and Micro were negatively correlated with the S index, while TP and Macro were positively correlated with the S index (Table 7). This shows that the S index is sensitive to structural changes in the soil, and varies with the porous soil rearrangement triggered by different management methods.

The correlations shown in table 7 support the use the S index to assess the physical quality of the soil, as reported by Dexter (2004), Andrade and Stone (2009), Silva et al. (2012), and Emami, Neyshabouri and Shorafa (2012).

Table 6 – S Index in Oxisol subjected to different weed control methods in the cultivation of coffee.

Weed Control Methods	S Index	
	0-15cm	15-30cm
Peanut forage (*Arachis pintoi* L.)	0.083aA	0.077aB
Harrowing	0.080aA	0.077aB
Brushcutting	0.077aA	0.097aA
Residue Crushing	0.083aA	0.110aA
Post-emergence Herbicide	0.093bA	0.130aA
Pre-emergence Herbicide	0.077aA	0.100aA
Manual Weeding	0.080aA	0.097aA
No Weeding	0.070aA	0.080aB
Brachiaria grass (*Brachiaria decumbens*)	0.073aA	0.053aB

Averages followed by the same letters, lowercase letters in the rows and uppercase letters in the columns, do not differ by the Scott–Knott test at 5% probability.

Table 7 – Correlations between the S index and physical attributes of two layers of an Oxisol subjected to weed control methods in the cultivation of coffee.

	0-15 cm	15-30 cm
Bd	−0.90**	−0.89**
TP	0.91**	0.86**
Macro	0.91**	0.88**
Micro	−0.81**	−0.85**

** P value significant at 1% by the correlation test.

CONCLUSIONS

The weed control methods used in a coffee crop significantly affected the physical properties and water retention of the subsurface layer (15-30 cm) of the Oxisol.

Soil Bd, TP, Macro, and Micro were significantly correlated with the S index.

According to the S index, the physical quality of the soil was classified as good for the various control methods employed in the present study, with all the values >0.045.

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