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# Soil organic matter quality and weed diversity in coffee plantation area submitted to weed control and cover crops management

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ABSTRACT

Soil organic matter (SOM) plays an important role for soil quality and productivity maintenance, acting as energy source, promoting biological diversity, enhancing terrestrial ecosystems composition. This study assessed the effects of long-term weed control and cover crops between coffee rows on SOM quality in a very clayey (80 dag $kg^{-1}$ of clay) Typic Haplorthox (Dystroferric Red Latosol) from State of Paraná, Southern Brazil. Seven weed control and cover crops were assessed between coffee rows: (i) hand weeding—HAWE; (ii) portable mechanical mower—PMOW; (iii) pré + post-emergence herbicides—HERB; (iv) peanut horse (*Arachis hypogeae*) cover crop—GMAY; (v) dwarf mucuna (*Mucuna deeringiana*) cover crop—GMMA; (vi) no-weed control between coffee row—SCAP; (vii) weed check—CONT. Soil samples were collected in the center of the inter-rows between coffee trees at four depths: 0–10 cm, 10–20 cm, 20–30 cm, and 30–40 cm. SOM quality assessment included total soil organic carbon (SOC) content and organic matter humification degree ($H_{FIL}$) by laser-induced fluorescence spectroscopy (LIFS). C content was up to 26% higher for SCAP and CONT samples, compared to the other field conditions, denoting influence of plant material accumulation at top soil (0–10 cm). Higher $H_{FIL}$ results (up to 47%) were observed at deeper layers, inferring incidence of less humified/labile structures at top soil, and condensed/recalcitrant character for organic matter at depth, regardless of cover crops and weed control method considered. In terms of weed density it was observed a higher negative impact on weed growth in areas under GMMA cover crop (decrease of 90.8% in weed density). The behavior may be attributed to the chemical composition of the species, ultimately leading to possible occurrence of allelopathic phenomenon.

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## 1. Introduction

Weed control is one of the most intensive aspects of managing coffee plantations. Most weeds have deleterious effects on coffee plantation yield and production, due to competition for available resources, such as light, water, and nutrients (Silva and Tomaz, 2008).

Developing agricultural management strategies that control weeds, increase soil organic carbon (SOC) stocks to mitigate climate change and sustain ecosystem processes for food production and environmental quality is a global priority (Beniston et al., 2014).

Cover crops and crop residues used in some agricultural systems serve to (1) protect the soil surface against rain drop impacts that can break soil aggregates and increase water erosion, (2) maintain soil moisture, and (3) provide shelter and food for the soil biota, thus enhancing soil organic matter (SOM) quality (Blanchart et al., 2006). Crop residues and cover crops can also exert an effect on weed germination and establishment through several mechanisms, such as allelopathy and competition among crop/weed species for the nutrients released (Kruidhof et al., 2009).

Any drop in SOM content can adversely affect soil fertility through an alteration of the physical, chemical, and biological

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properties of soils (Oorts et al., 2007; González-Ubierna et al., 2012).

Total soil organic carbon (SOC) and degree of humification are considered crucial to evaluate soil quality, and qualitative and quantitative changes related to different soil management systems. One classical method of SOC determination is the Walkley–Black chromic acid wet oxidation method (Walkley and Black, 1934), where soil organic carbon is oxidized by potassium dichromate ($K_2Cr_2O_7$) solution.

Laser-induced fluorescence spectroscopy (LIFS) is a rapid, non-destructive, sensitive and selective technique with good applicability for SOM characterization by assessing humification degree in bulk soil samples (Milori et al., 2006). The LIFS emission spectra measure C in complex or rigid structures, such as aromatic and quinone groups in whole soil samples. The ratio between the area under the fluorescence emission spectrum and the soil carbon content is proportional to the SOM humification degree, and it is expressed as humification index ($H_{FIL}$). Higher fluorescence intensities are related to greater humification degrees, and thus higher humification index values (Martins et al., 2011).

Studies evaluating the impacts of various cover crops and weed control methods on SOM quality and weed diversity in coffee plantations in tropical regions are scarce. The purpose of this study was to evaluate SOM quality by assessing carbon content and humification degree in coffee plantations under various weed control methods and using various cover crop species. Our hypothesis is that different cover crops and weed control methods will improve SOM quality, by altering soil chemical and physical properties.

## 2. Material and methods

### 2.1. Experimental field

The experimental field was located in the Experimental Station of the Agronomic Institute of Parana (IAPAR) at Londrina, State of Paraná, Southern Brazil (23° 21′30″ S; 51° 10′17″ W). The soil at the site is a very clayey (80 dag $kg^{-1}$ of clay) Typic Haplorthox (Dystroferric Red Latosol) according to the Brazilian Soil Classification System (Santos et al., 2013). Additional soil properties are listed in Table 1.

Coffee trees (*Coffea arabica* L.), cultivar Mundo Novo IAC 379-19, were planted in 1978, with 3.50 m between row spacing ×2.00 m within row spacing between coffee pits with two plants per pit. In 2008, the experiment was installed in a randomized block design with four replicates, comprising a split-plot scheme. The weed control and cover crops between coffee rows are the main plot factor and sampling depth (0–10 cm; 10–20 cm; 20–30 cm; 30–40 cm) is the split plot. Seven different weed control/cover crop treatments were established: (i) hand weeding—HAWE; (ii) portable mechanical mower—PMOW; (iii) pre (oxyfluorfen, 240 g $L^{-1}$) and post (glyphosate, 360 g $L^{-1}$) emergence herbicides—HERB; (iv) peanut horse (*Arachis hypogeae*) cover crop—GMAY; (v) dwarf mucuna (*Mucuna deeringiana*) cover crop—GMMA; (vi) no-weed control between coffee rows—SCAP; (vii) weed check—CONT (no-weed control between coffee rows and below canopy). In each inter row of the coffee crop, two rows of the cover crops were sown at a 0.5 m row spacing and each row being 0.25 m from coffee pits.

In September 2013, coffee tree pruning was conducted by cutting off all plagiotropic branches at 20–30 cm from the orthotropic branch ("esqueletamento") and by cutting off the orthotropic branch at 1.60 m above ground ("decote"). The pruning residues were mowed and left on the soil surface to allow biological incorporation. Cover crops were cut off in March, 2014. Further details regarding trial and site conditions are given by Araujo-Junior et al. (2013).

### 2.2. Weed diversity and density

Weed material was collected in March, 2014. In each coffee inter-row, weed densities were determined by sampling the above and below ground fresh weed matter in randomly chosen 0.5 m × 0.5 m quadrats (Hoogmoed and Derpsch, 1985), comprising four replicates for each plot. Weed diversity was measured inside the quadrats by collecting and the identifying weed species according to Lorenzi (1994).

### 2.3. Soil sampling

Soil samples were collected in October, 2013, and March, 2014, at the center of the inter-rows using a traditional mattock at four depth increments (0–10 cm; 10–20 cm; 20–30 cm and 30–40 cm) within the four replications for each experimental cover crop and weed control method, comprising a total of 112 samples. Samples were stored in plastic bags, air dried at room temperature, sieved thru a 2.0 mm opening mesh and mechanically ground using a knife-mill. Ground samples were stored dry until analyses were conducted.

### 2.4. Soil carbon content

Total soil organic carbon content was determined by wet oxidation (Walkley and Black, 1934). About 1.0 g of each dried soil sample was weighed and transferred to an Erlenmeyer flask. Ten mL of 0.167 mol $L^{-1}$ $K_2Cr_2O_7$ and 10 mL of concentrated $H_2SO_4$ were added to the flask. The vials were gently swirled to mix the reagents and the soil sample. Vials were set aside in a chamber with appropriate exhaust while cooling to room temperature.

**Table 1**
Trial soil chemical and physical properties.

| Soil chemical and physical properties | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Depth (cm) | pH | P (mg $dm^{-3}$) | Ca ($cmol_c$ $dm^{-3}$) | K | Mg | SOC[a] (g $dm^{-3}$) | Clay (dag $kg^{-1}$) | Silt | Sand | FC[b] ($cm^3$ $cm^{-3}$) | PWP[c] | Bd[d] (kg $dm^{-3}$) | Pd[e] | TP[f] ($cm^3$ $cm^{-3}$) |
| 0–10 | 4.9 | 48.34 | 4.99 | 0.32 | 2.84 | 29.98 | 78 | 16 | 6 | 0.35 | 0.29 | 0.91 | 2.78 | 0.67 |
| 10–20 | 4.4 | 11.79 | 2.85 | 0.20 | 1.46 | 19.44 | 80 | 14 | 6 | 0.42 | 0.36 | 1.00 | 2.79 | 0.64 |
| 20–30 | 4.3 | 28.59 | 2.51 | 0.31 | 1.15 | 18.41 | 81 | 14 | 5 | 0.42 | 0.36 | 1.08 | 2.81 | 0.61 |
| 30–40 | 4.2 | 7.87 | 2.22 | 0.23 | 0.91 | 15.36 | 81 | 14 | 5 | 0.43 | 0.37 | 1.13 | 2.82 | 0.60 |

Means of $n = 4$.
[a] Soil organic carbon.
[b] Field capacity.
[c] Permanent wilting point.
[d] Bulk density.
[e] Particle density.
[f] Total porosity.

About 30 mL of $H_3PO_4$ 3.0% was added to facilitate the titration endpoint identification. 10 drops of diphenylamine indicator were added prior the titration. Two blanks were also titrated.

### 2.5. Laser induced fluorescence spectroscopy (LIFS)

The LIFS measurements were carried out on air dried soil sample pellets using portable fluorescence spectroscopy equipment, belonging to Embrapa Instrumentation. Each pellet was made by compressing 0.5 g of a soil sample to 8.0 t pressure. The pellets were 1 cm in diameter and 2 mm thick. The equipment consisted of a diode laser (Coherent—CUBE) emitting at 405 nm (50 mW), an optical shutter, a bifurcated optical fiber bundle with seven optical fibers in a stainless steel ferrule: six illumination fibers around one read fiber (Ocean Optics), a high sensitivity mini-spectrometer (USB4000 – Ocean Optics), an adjustable optical filter, and a notebook.

All the measurement parameters and data acquisition were controlled using suitable software. The spectral resolution was adjusted to 4 nm. Four replicates were recorded for each sample. The humification degree index ($H_{FIL}$) was calculated as the ratio between the fluorescence emission spectra area and the carbon content from the analyzed sample (Milori et al., 2002 2006).

### 2.6. Data analysis

All the data were statistically analyzed using Origin Pro 8.0 software (OriginLab, Northampton, MA), by split plot Analysis of Variance (ANOVA) by depth increments, with $p < 0.05$ significance level.

## 3. Results and discussion

### 3.1. Weed diversity and density

The weed diversity distribution between coffee rows of the seven weed control systems are given in Table 2. There were clear differences in weed diversity and density among the weed control methods. The weed density and diversity data revealed a highest weed suppression/control effect in areas under dwarf mucuna (GMMA) cover crop/weed control (90.8% decrease, compared to the CONT area). In their research, Castillo-Caamal et al. (2014) also showed that mucuna species can provide strong weeds suppression. The authors attribute this suppression effect to the potential impact from chemical compounds, also known as allelochemicals, present in the mucuna foliage, leading to a phenomenon known as allelopathy. Rosa et al. (2013) also reported a positive allelopathic effect of several cover crops species (including *M. deeringiana*) on weed control/suppression compared to a control area. Nevertheless, it is important to monitor this phenomenon, since allelopathic effects can inhibit both weed and crop species (Rice, 1984).

The root and shoot dry masses for the weed control treatments are given in Table 3. There were no differences between the root dry mass results among the weed control methods. The relationship between root dynamics and SOM stabilization has become a major environmental issue and has received increasing attention recently (Redin et al., 2014). The HAWE and HERB treatments had lower shoot dry mass than other treatments, while CONT and SCAP treatments (both presenting similar field characteristics) had higher shoot dry mass, since the amount of above-ground residue tended to be higher than in the other treatments. This pattern is consistent with the weed density results; although there were no statistically significant differences among the entire set of cover crop/weed control treatments, there was a trend that mirrored that for weed shoot dry biomass.

The amount of residue returned to the soil influences SOM content, but quality differences among residues become important

**Table 3**
Root and shoot dry mass for the analyzed cover crops / weed control systems collected in March, 2014. SCAP: no-weed control between coffee row; GMAY: peanut horse covering; PMOW: portable mechanical mower; HAWE: hand weeding; CONT: weed check; GMMA: dwarf mucuna covering; HERB: herbicide application.

| | Weed control/cover crop | | | | | | |
|---|---|---|---|---|---|---|---|
| | HAWE | PMOW | HERB | GMAY | GMMA | SCAP | CONT |
| Root dry mass (g) | 30.6 (1.3)$^{a}$ | 74.6 (4.8)$^{a}$ | 27.7 (0.3)$^{a}$ | 45.3 (5.0)$^{a}$ | 32.6 (0.1)$^{a}$ | 65.2 (5.9)$^{a}$ | 70.7 (9.3)$^{a}$ |
| Shoot dry mass (g) | 69.1 (11.9)$^{b}$ | 153.7 (8.3)$^{ab}$ | 32.1 (0.4)$^{b}$ | 163.5 (1.2)$^{ab}$ | 139.4 (22.2)$^{ab}$ | 218.7 (47.4)$^{a}$ | 230.6 (14.7)$^{a}$ |

Means of $n = 4$.
() Standard error.
(Lower case letters refers to statistical analysis between cover crop/weed control (Tukey test, alpha = 0.05).

**Table 2**
Weeds found between coffee rows in a trial submitted to different weed control and cover crops. SCAP: no-weed control between coffee row; GMAY: peanut horse covering; PMOW: portable mechanical mower; HAWE: hand weeding; CONT: weed check; GMMA: dwarf mucuna covering; HERB: herbicide application.

| Weeds distribution (%) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Weed scientific name | Common names | Weed control/cover crop | | | | | | |
| | | HAWE | PMOW | HERB | GMAY | GMMA | SCAP | CONT |
| *Urochloa plantaginea* (Link) Hitch. | Plantain signalgrass | 4 | 26 | N/D | 4 | N/D | 18 | 16 |
| *Digitaria horizontalis* Wild | Jamaican crabgrass | 2 | 5 | N/D | 2 | N/D | 2 | 5 |
| *Commelina bengalensis* L. | Benghal dayflower | 18 | 13 | N/D | 8 | 1 | 21 | 36 |
| *Bidens pilosa* L. | Black jack | 26 | 5 | 11 | 4 | 2 | 1 | 1 |
| *Amaranthus* spp. | Pigweed | 1 | N/D | N/D | N/D | 1 | N/D | N/D |
| Other species* | 13 | 36 | 7 | 13 | 5 | 40 | 40 | |
| Total | 64 | 85 | 18 | 31 | 9 | 82 | 98 | |

Means of $n = 4$.
N/D = not detected.
* Other species: *Alternanthera ficoidea* (L.) R.Br. (Joy Weed); *Euphorbia heterophylla* L. (Lechosa); *Richardia brasiliensis* Gomez (tropical Mexican clover); *Momordica charantia* L. (Bitter Melon); *Phyllanthus corcovadensis M. Arg.* (local Indian herb); *Portulaca oleracea* L. (Purslane); *Sida* spp. (Arrowleaf Sida); *Ipomoea* spp (Morning glories); *Digitaria insularis* (L.) *Mea ex Ekman* (Sourgrass); *Talinum patens* (Jewels-of-Opar).

when other field and environmental factors are held constant (Redin et al., 2014).

### 3.2. Soil carbon content

In surface layers (0–10 cm), total soil carbon content decreased in most of the cover crops and weed control methods analyzed (PMOW, HAWE, GMMA, GMAY, and HERB) in the 2013/2014 sampling period (Table 4). In 2013, SOC content between coffee rows was not affected by any of the treatments. Nevertheless, in 2014, cover crops and weed control methods led to SOC decrease in the topsoil (0–10 cm). Soil samples were collected before cover crops were sow and after coffee crops were pruned, in 2013, and after cover crops were cut off, in 2014. The sampling period and the cover crop management may have contributed to SOC content decreases in surface layers. The changes in total soil organic carbon only at the surface are typical in coffee plantations submitted to different weed control methods (Alcântara and Ferreira, 2000; Araujo-Junior et al., 2011, 2013). Guimarães et al. (2013) reported higher organic carbon content in surface layers in soils under conservation practices; however, no changes were found in deeper layers (below 10 cm). According to the authors, the lack of disturbance, presence of natural cover crop/living mulch, and the relatively short time of land use implementation may have led to higher SOM accumulation in superficial layers. Hence, the experimental results observed at the trial field may reflect the influence of soil management within a time interval, in addition to cover crops/weed control effects. Analyzing each set of cover crops and weed control methods at a given depth, it was possible to observe an increase in C content up to 26% for the CONT and SCAP samples at 0–10 cm, when compared to the other cover crop and weed control methods (Fig. 1). Given that there were practically no tillage activities in our treatments in these treatments, C accumulation was due to greater plant material input, as verified by the shoot dry mass results. There were statistically significant differences ($p < 0.05$) with higher C content at superficial layers (0–10 cm) for all the cover crops and weed control methods analyzed. At deeper layers, C content tends to be more stabilized and biologically transformed, regardless of the cover crop or weed control methods used, given is expected higher incidence of recalcitrant structures, lower incidence of aliphatic chain structures availability, and thus, lower C content. The protected (stabilized, complexed) fraction is more stable, has a longer turnover time, and is older than the unprotected (free, uncomplexed) fraction. This pool comprises the high densimetric fraction, the complexed OM of the silt and clay fractions, the intra-aggregate, chemically altered OM (humic substances), and initially stable organic materials and compounds. The unprotected pool includes components of high energy and nutritional status rapidly entering into stabilization processes, comprising plant and animal residues, mono- and polysaccharides, water- and salt-extractable organic substances, the low-weight fraction, the non-aggregated OM, and the interaggregate OM (Semenov et al., 2010). When analyzing each set of cover crop and weed control methods at each following depth increment, it was not observed any statistically significant difference between results ($p > 0.05$).

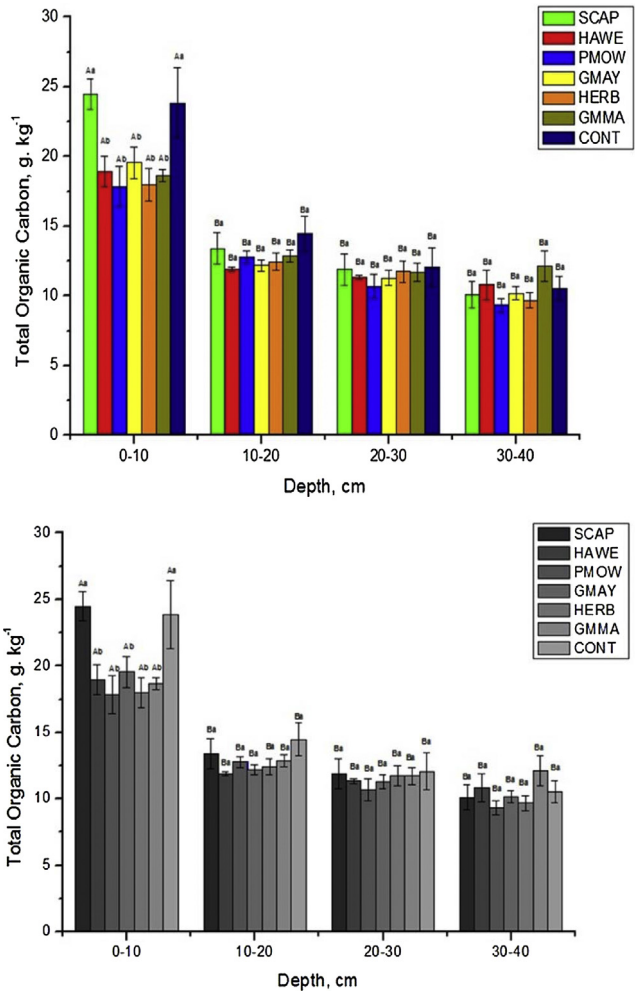


**Fig. 1.** Soil total organic carbon data for analyzed treatments. SCAP: no-weed control between coffee row; GMAY: peanut horse covering; PMOW: portable mechanical mower; HAWE: hand weeding; CONT: weed check; GMMA: dwarf mucuna covering; HERB: herbicide application. Upper case letters means statistical analysis along depth increments within a given weed control/cover crop system. Lower case letters means statistical analysis between weed control/cover crop at given depth increment layer (Tukey test, alpha = 0.05).

**Table 4**
Soil organic carbon content. SCAP: no-weed control between coffee row; GMAY: peanut horse covering; PMOW: portable mechanical mower; HAWE: hand weeding; CONT: weed check; GMMA: dwarf mucuna covering; HERB: herbicide application.

| | Carbon Content (g kg$^{-1}$) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 0–10 cm | | 10–20 cm | | 20–30 cm | | 30–40 cm | |
| | 2013 | 2014 | 2013 | 2014 | 2013 | 2014 | 2013 | 2014 |
| HAWE | 24.16 (2.82)$^{a}$ | 18.94 (1.13)$^{b}$ | 13.30 (0.82)$^{a}$ | 11.90 (0.14)$^{a}$ | 11.08 (0.92)$^{a}$ | 11.34 (0.16)$^{a}$ | 9.35 (0.31)$^{a}$ | 10.81 (1.06)$^{a}$ |
| PMOW | 22.62 (1.16)$^{a}$ | 17.85 (1.43)$^{b}$ | 12.89 (0.18)$^{a}$ | 12.79 (0.42)$^{a}$ | 11.92 (0.61)$^{a}$ | 10.72 (0.82)$^{a}$ | 10.19 (0.39)$^{a}$ | 9.34 (0.50)$^{a}$ |
| HERB | 20.82 (2.67)$^{a}$ | 17.98 (1.15)$^{b}$ | 13.35 (0.73)$^{a}$ | 12.44 (0.61)$^{a}$ | 10.54 (0.81)$^{a}$ | 11.76 (0.77)$^{a}$ | 9.87 (1.24)$^{a}$ | 9.69 (0.58)$^{a}$ |
| GMAY | 22.35 (1.19)$^{a}$ | 19.55 (1.16)$^{b}$ | 11.99 (0.30)$^{a}$ | 12.20 (0.40)$^{a}$ | 11.11 (0.63)$^{a}$ | 11.29 (0.54)$^{a}$ | 9.49 (0.85)$^{a}$ | 10.18 (0.47)$^{a}$ |
| GMMA | 21.72 (1.10)$^{a}$ | 18.65 (0.45)$^{b}$ | 14.63 (1.37)$^{a}$ | 12.87 (0.44)$^{a}$ | 12.03 (0.85)$^{a}$ | 11.71 (0.65)$^{a}$ | 10.74 (0.88)$^{a}$ | 12.13 (1.11)$^{a}$ |
| SCAP | 23.23 (2.95)$^{a}$ | 24.49 (1.10)$^{a}$ | 13.93 (0.68)$^{a}$ | 13.41 (1.14)$^{a}$ | 12.22 (0.69)$^{a}$ | 11.89 (1.13)$^{a}$ | 10.56 (1.00)$^{a}$ | 10.10 (0.95)$^{a}$ |
| CONT | 28.40 (6.18)$^{a}$ | 23.85 (2.54)$^{a}$ | 16.68 (2.35)$^{a}$ | 14.47 (1.22)$^{a}$ | 11.16 (0.76)$^{a}$ | 12.07 (1.41)$^{a}$ | 9.64 (0.93)$^{a}$ | 10.57 (0.83)$^{a}$ |

Means of $n = 4$.
() Standard error.
(Lowercase letters refers to statistical analysis pairwise between years for a given cover crop/weed control at a given depth (Tukey test, alpha = 0.05).

### 3.3. Laser induced fluorescence spectroscopy (LIFS)

The LIFS data (Fig. 2) showed an up to 47% increase in the humification degree ($H_{FIL}$) along the depth profile for all treatments considered. Statistically significant differences were observed ($p < 0.05$) for all cover crop and weed control methods considered, with lower $H_{FIL}$ in surface layers (0–10 cm) than at lower depths. According to González-Pérez et al. (2007), when plant residues accumulate in the topsoil in high quantity the incidence of less humified (aromatic/condensed) structures is expected, due to decreased microbial capacity to metabolize this fresh input and to possible incidence of unprocessed plant material. Thus, the data observed may reflect a higher incidence of labile structures in surface layers, compared to deeper layers, regardless of cover crop or weed control method used. At least three major factors of OM stabilization have been proposed, but the relative contribution of each factor to C protection in soils is unknown (Six et al., 2002): (1) physical stabilization due to establishment of physical barriers between microbes and enzymes and their substrates as aggregates form (Six et al., 2004); (2) chemical stabilization, referring to the intermolecular interactions between organic and inorganic substances that decrease the availability of the organic substrate due to complexation of functional groups and changes in conformation (Guggenberger and Kaiser, 2003); and (3) recalcitrance, referring to the preservation of OM caused by structures inherently stable against biochemical decay such as condensed and lignin-derived aromatic carbons, melanoidins, some tannins or aliphatic compounds (Poirier et al., 2003). Hence, our results may also reflect a higher incidence of more physically and chemically protected structures in deeper layers, related to the humification process, also suggesting a more condensed/aromatic character for the organic matter. When analyzing each set of cover crop and weed control methods at each given depth increment, we observed no statistically significant differences among treatments ($p > 0.05$).

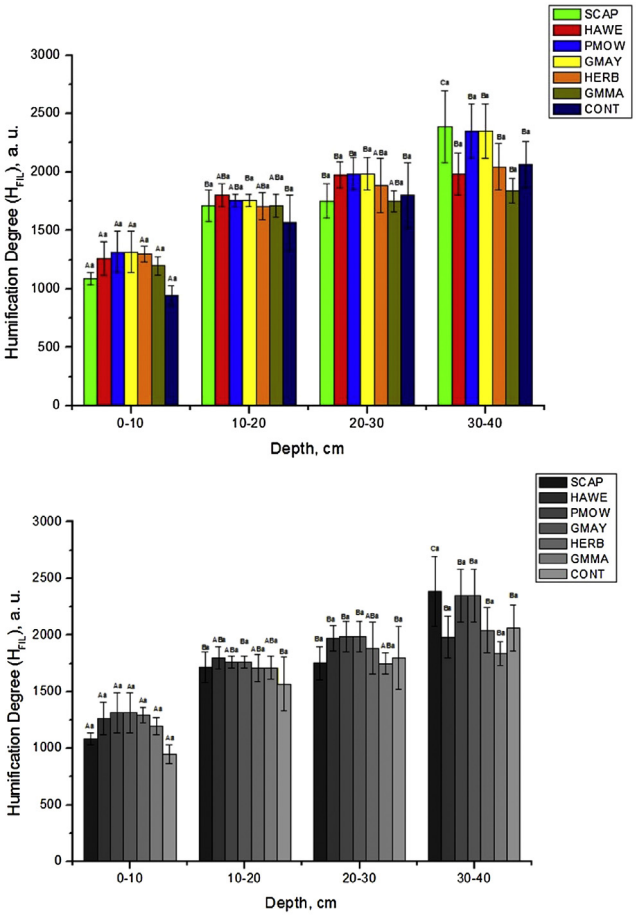


**Fig. 2.** Soil humification degree ($H_{FIL}$) data for analyzed treatments. SCAP: no-weed control between coffee row; GMAY: peanut horse covering; PMOW: portable mechanical mower; HAWE: hand weeding; CONT: weed check; GMMA: dwarf mucuna covering; HERB: herbicide application. Upper case letters means statistical analysis along depth increments within a given weed control/cover crop system. Lower case letters means statistical analysis between weed control/cover crop at given depth increment layer (Tukey test, alpha = 0.05). a.u. = arbitrary units.

## 4. Conclusion

Sampling periods, different cover crops and weed control methods affect weed diversity, weed shoot dry mass, soil carbon content and humification degree, and consequently, impact directly on soil quality. Integrated weed control in coffee plantations in tropical conditions is a promising agricultural system to maintain soil quality.

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