 Doi: 10.33158/ASB.2016v2i2p68

Weed control methods and coffee shrub residue effects on carbon stocks in a Latosol under conservation management practices

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ABSTRACT

Weed control methods in coffee crops can significantly influence carbon (C) stocks of soil humic substances. The aim of this study was to evaluate C stocks in an experimental coffee crop submitted to conservation agriculture for weed control between coffee rows. The study was carried out in a very clayey Dystroferric Red Latosol, Londrina, Paraná state (23°21'30" S; 51°10'17" W), cultivated with cultivar Mundo Novo IAC 379-19. In 2008, the experiment was established as randomized block design with four replicates within split-split plot scheme. Seven weed control methods between coffee rows were considered (hand weeding; portable mechanical mower; herbicides application; two cover crops; weed check and spontaneous). In September 2013, coffee shrub pruning was conducted and residues were distributed along inter rows. The weed control methods were considered as the main-plot factor and sampling period (March 2014 and February 2015) as the split-plot. Soil samples were collected at the center of the inter rows at four depth increments. C stocks evaluation included total organic carbon determination by chromic acid wet oxidation. Humic substances were characterized by UV-Vis spectroscopy. Most of the considered weed control methods did not affect organic carbon storage in 0 – 40 cm layer, nevertheless led to increase at topsoil. In 2015, the humin fraction C stock was 54 % higher at superficial layer than subsequent depth, presenting 39 % average increase at the 2014/2015 interval. Although C stocks from humic and fulvic acids did not vary, more conjugated/condensed characteristic for the fulvic fraction was observed.

Key words: Soil organic carbon, humic substances, cover crops, conservation agriculture, inter rows area.

INTRODUCTION

Conservation agriculture practices (use of cover crops, reduced tillage activities, crop rotations, intercropping, and integrated weed control) contribute to soil organic carbon (SOC) levels, distribution and quality, by means of (i) fresh C inputs such as plant residues/cover crops; (ii) reduced decomposition rates; and (iii) changes in the quality of some SOC fractions (Zhang et al., 2011).

Studies conducted in different coffee crop regions in Brazil have shown that weed control methods, spacing between plants, and soil sampling location influenced SOC content and fertility attributes (Pavan et al., 1999; Motta et al., 2006; Rangel et al., 2008; Araujo-Junior et al., 2013; Cogo et al., 2013; Coelho et al., 2013; Siqueira et al., 2015). Likewise, recent studies have shown that the use of cover crops as cultural methods and green manure for weed control between coffee rows affected weed root and shoot dry mass content on the inter rows area of the coffee plantation, as well as soil organic matter (SOM) dynamics and humification degree (Martins et al., 2015).

Soil management and practices must assure maintenance or enhancement of soil biological, chemical, and physical features, consequently providing sustainable production and crop yield (Lopes et al., 2015). Certain fractions of SOM play key role on maintaining soil quality, being more sensitive to management practice effects (Ebeling et al., 2011). The humic substances (HS), SOM major component and C pool, are widely used as indicators of soil quality, for during mineralization process, this passive C pool undergoes the largest structural changes (Zech et al., 1997).

Ultraviolet and visible (UV-Vis) spectroscopy has been frequently used in HS investigations, providing information regarding structural features and humification process evolution (Fuentes et al., 2006). The E_4/E_6 ratio (quotient between absorbance intensity at 465 and 665 nm) is a classical UV-Vis spectroscopy index that allows HS condensation/assessment of humification degree, presenting inverse relation to average C residence time in soils (Chen et al., 1977).

Studies evaluating conservation agriculture effects in soil C stocks from coffee crops in tropical regions are scarce. The hypothesis considered is that different weed control methods, and distribution and biological incorporation of coffee tree pruning residues between coffee rows, will affect soil C dynamics, by improving C stocks in whole soil and humic substances. The purpose of this study was to assess C storage potential and distribution in coffee plantations on a Dystroferric Red Latosol under various weed control methods.

MATERIALS AND METHODS

Experimental field

The experiment was conducted in an experimental coffee crop area under conservation agriculture system in Londrina, Paraná state, Brazil (23°21'30" S; 51°10'17" W). The soil at the site was a very clayey (80 dag kg^{-1} of clay) Dystroferric Red Latosol (Typic Haplorthox), presenting the following chemical attributes at superficial layers (0–20 cm): pH in $CaCl_2$ (4.8), available P (28.45 mg dm^{-3}), exchangeable Ca (4.92 cmolc dm^{-3}), exchangeable K (0.46 $cmol_c$ dm^{-3}) and exchangeable Mg (2.45 $cmol_c$ dm^{-3}) (Martins et al., 2015).

Coffee shrubs (*Coffea arabica* L.), cultivar Mundo Novo IAC 379-19 , were planted in 1978, in 3.50 m between row spacing x 2.00 m within row spacing between coffee pits , with two plants per pit. In 2008, the experiment was set up in a randomized block design with four replicates, comprising a split-plot scheme. Each plot consisted of two rows with eight pits (sixteen coffee shrubs).

Seven different weed control methods between coffee rows were employed: two mechanical (hand weeding – HAWE and a portable mechanical mower – PMOW); one chemical pre- (oxyfluorfen, 240 g L^{-1}) and post-emergence (glyphosate, 360 g L^{-1}) herbicide application – HERB); and four cultural (peanut horse (*Arachis hypogeae*) cover crop – GMAY: dwarf mucuna (*Mucuna deeringiana*) cover crop – GMMA; no-weed control between coffee rows – SCAP, and weed check – CONT (spontaneous, no-weed control between coffee rows and below canopy) (Figure 1).

The cover crop pits were dug using a hoe, and seeds were manually distributed for sowing every year since 2008 between September and October. The seeding was accomplished on each inter row of the coffee crop, at a 0.5 m row spacing, with each row being 0.25 m. Cover crop shoots were cut off by hand hoe at the flowering stages about 130 days after seedling.

In September 2013, coffee shrub pruning was conducted by cutting off all plagiotropic branches at 20–30 cm from the orthotropic branch (also known as "skeleton cut") and by cutting off the orthotropic branch at 1.60 m above ground (also known as "cleavage cut"). Pruning residues were mowed and left on the soil surface to allow biological incorporation. Further details regarding trial and site conditions are given by Araujo-Junior et al. (2013) and Martins et al. (2015).

Soil sampling

Soil samples were collected in March 2014 and February 2015 in the center of inter rows (Figure 2), using a traditional mattock at four depth layers (0–10, 10–20, 20–30, and 30–40 cm). In each plot and soil layer, four simple samples were collected comprising 112 samples per year (7 weed management x 4 soil depths x 4 replicates). Samples were stored in plastic bags with air dried at room temperature, sieved through a 2.0 mm opening mesh and mechanically ground using a knife mill. Ground samples were stored dry until further analyses were conducted.

Humic substances extraction

Humic substances (HS) were separated (Figure 3) according to the methodology proposed by Benites et al. (2001). Briefly, the method consisted of the extraction with NaOH 0.1 mol L^{-1}, at a sample to solvent ratio of 1:10. After centrifugation processes, humic (HA) and fulvic acids (FA) (supernatant) and humin (HU) (precipitate) were separated. Given the difference on solubility according to pH levels, the supernatant was separated by adding H_2SO_4 20 % until pH 1.0. The precipitated HA was vacuum filtered on 0.45 µm membrane and washed with NaOH 0.1 mol L^{-1} to a 50 mL volumetric flask. The filtered FA was also collected in a 50 mL volumetric flask. The fractions obtained were reserved for further analysis.

Whole soil and humic substances 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. Volumes of 10 mL of 0.167 mol L^{-1} K2Cr2O7 and 10 mL of concentrated H_2SO_4 were added to this flask. Vials were gently swirled to mix the reagents and the soil sample and were set aside in a chamber with appropriate exhaust while cooling to room temperature. About 30 mL of H_3PO_4 3.0% was added to facilitate titration endpoint identification. Ten drops of diphenylamine indicator were added prior to titration. Two blanks were also titrated. Carbon content determination for humic fractions was carried out according to modified Walkley-Black method (Benites et al., 2001).

Figure 1 – Experimental field showing the weed managements between coffee rows. A: hand weeding plot before soil sampling March, 11, 2014; B: portable mechanical mower at the moment of the treatment; C: soil bare in plot managed with herbicides; D: green manure peanut horse used as cover crop; E: green manure dwarf mucuna; F: details of weed diversity in no-weed control; G: weed check for reference of soil analysis; and H: coffee shrubs residues mowed between coffee rows.
Source: Cezar Francisco Araujo-Junior, Instituto Agronômico do Paraná – IAPAR.

Figure 2. Detail of experimental field at the moment of the soil sampling in February 2015. The equipments were put in center of the inter rows.
Source: Cezar Francisco Araujo-Junior, Instituto Agronômico do Paraná – IAPAR.

Figure 3. Humic fractions separated from soil samples in volumetric flasks in laboratory. Humic acids (brownish) at the left of the bench and fulvic acids (yellow) at the right.
Source: Cezar Francisco Araujo-Junior, Instituto Agronômico do Paraná – IAPAR.

Carbon stocks determination

Carbon stocks for each whole soil sample and extracted humic substances were calculated according to Ellert and Bettany (1995) as follows:

C Stock = C content x soil bulk density x layer thickness Units:

C Stock = Mg ha^{-1}

C Content = g kg^{-1}

Soil bulk density = Mg m^{-3}

Layer thickness = cm

Undisturbed soil samples were collected using volumetric inox rings (5 cm height by 5 cm diameter) in the center of the inter rows, about 1.75 m from coffee shrubs (Araujo-Junior et al., 2013), to determine soil bulk density for each sampling depth using the core method, as proposed by Blake and Hartge (1986).

UV-Vis spectroscopy

The UV-Vis spectroscopy measurements were carried out in a Genesys 10UV spectrometer (Thermo Fisher Scientific Inc., Waltham, MA), scanning at a 200 to 800 nm range, with 1.0 nm spectral resolution. HA and FA solutions at a 200-400 ppm concentration were diluted to 10 mL adding 0.05 mol L^{-1} $NaHCO_3$, and pH was adjusted to 8.0. The E4/E6 ratios were obtained by quotient between absorbance intensities at 465 and 665 nm (Chen et al., 1977).

Data analysis

The weed control methods between coffee rows were considered as the main factor and sampling period (March 2014 and February 2015) as the split-plot. All data were statistically analyzed using Origin Pro 8.0 software (OriginLab, Northampton, MA), by Analysis of Variance (ANOVA) by depth increments, with $p < 0.05$ significance level. For the statistical analysis, in each depth, the sampling period (2014 and 2015) was considered as a split-split-plot as well. Averages were compared by Tukey test.

RESULTS AND DISCUSSION

Whole soil carbon stocks

In 2015, weed control managements between coffee rows presented varied effects on carbon stocks at the 0–40 cm layer (Table 1). The considered weed control methods on the inter rows of the coffee crop, except for the chemical weed control method, led to higher C stocks at 0–10 cm depth, compared to the subsequent collected layers.

Table 1. Whole soil C stock for soil samples collected in February, 2015, from a Dystroferric Red Latosol of a coffee crop submitted to weed control methods at the inter rows.

	Weed control methods between coffee rows						
Depth	HAWE1	PMOW	HERB	GMAY	GMMA	SCAP	CONT
(cm)	Whole soil Carbon stock, Mg ha-1						
0-10	18.92Aab (1.54)	20.10Aa (0.96)	14.65Ab (1.67)	18.01Aab (1.42)	21.39Aa (2.47)	21.01Aa (0.40)	20.11Aa (2.13)
10-20	13.56Ba (0.42)	14.12Ba (0.19)	12.67Aa (1.08)	12.34Ba (0.77)	14.32Ba (0.23)	14.43Ba (0.68)	14.26Ba (1.11)
20-30	12.90Ba (0.27)	13.95Ba (0.39)	12.89Aa (1.03)	12.04Ba (0.55)	12.77Ba (0.57)	13.25Ba (0.57)	12.68Ba (1.04)
30-40	12.28Ba (0.68)	12.20Ba (0.49)	11.40Aa (0.70)	11.40Ba (0.44)	11.84Ba (0.39)	11.77Ba (0.84)	11.72Ba (1.00)
TOTAL	57.66a (4.33)	60.37a (2.85)	51.61a (7.51)	53.79a (2.39)	60.32a (3.13)	60.46a (4.77)	58.77a (9.11)

[1]HAWE: hand weeding; PMOW: portable mechanical mower; HERB: herbicide application; GMMA: dwarf mucuna covering; GMAY: peanut horse covering; SCAP: no-weed control between coffee rows; CONT: weed check. Upper case letters means statistical analysis along depth increments within a given weed control method. Lower case letters means statistical analysis between weed control method at given depth (Tukey test, alpha=0.05).

Chemical weed management with pre and post-emergence herbicides (HERB) did not affect carbon stocks along depth increments. Also, samples from these areas presented the lowest carbon stock (14.65 Mg ha^{-1}) at superficial layer (0 – 10 cm) between the analyzed weed control methods. The behavior observed for such samples may be attributed to the impact caused by herbicide application. Herbicide action may have disturbed microbial community activities by decreasing available substrate (weeds and plants), which after decomposition, would be integrated as C stock.

At 0-10 cm depth, PMOW, GMMA, SCAP and CONT presented the highest C stock. The HAWE and GMAY weed control methods presented an intermediary behavior between HERB, and PMOW, GMMA, SCAP and CONT. Also, the mowed and distributed residues from pruned coffee shrubs may have influenced C stocks dynamics along all soil depth profile, regardless of weed control method.

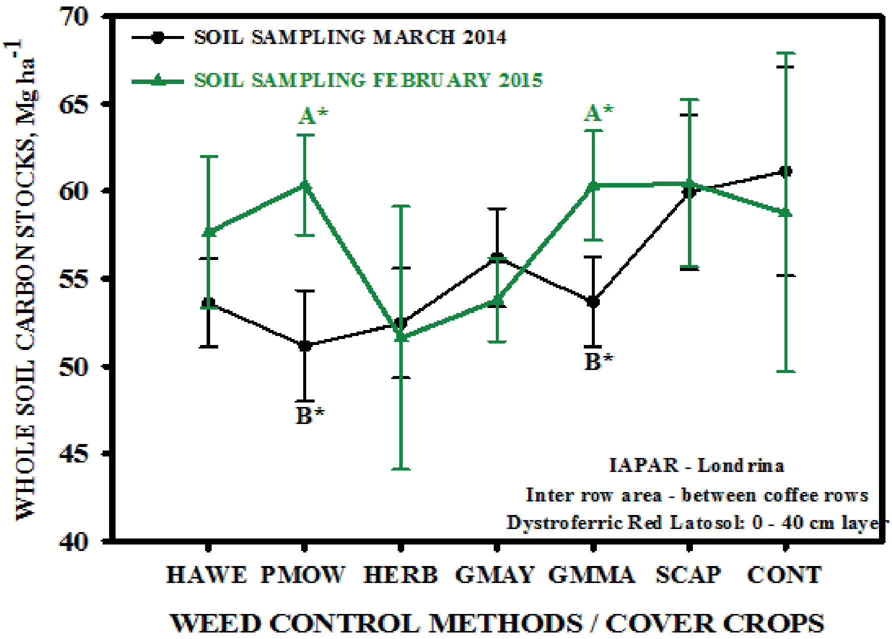
The C accumulation on SOM labile and stable fractions presents dynamic equilibrium and is directly affected by plant and vegetal residues chemical composition (C/N ratio) (Luo et al., 2010). Among leguminous species used as green manure and cover crops, the mucuna species are considered to be one of the most successful in terms of increasing biomass, nutrient concentration, and consequently SOM content and C storage (Matos et al., 2008).

In coffee crops, the main organic C carbon, and consequently organic matter sources are: weed residues; leaves and branches naturally fallen or loosen during harvest; organic compounds released by roots, such as exudates and dead cells; and decomposition of dead roots and microorganisms as well (Pavan et al., 1999). Also, generally increase on carbon storage in areas with wide plant diversity may be attributable to longer persistence of plant-derived organic materials with slower decomposition (Jastrow et al., 2007), as observed for the GMMA, SCAP and CONT samples.

Hence, structures not readily decomposed containing recalcitrant C (such as lignin and cellulose) present in cover crops, coffee shrub pruning residues, and even weed residues, may have been incorporated to SOC and favored C stock increase in the observed areas. Decreased or increased SOC content results from the equilibrium of several ecosystem levels. Stored C can be related to plant root system cycle, and to transference of carbon-enriched compounds from shoot to soil microbiota as well.

According to Melloni et al. (2013), herbicide application as weed control method on coffee crops may generate a stressful environment on plant rhizosphere, altering soil microbiota, negatively affecting soil biomass and C cycle, which may ultimately influence soil C storage.

Figure 4 shows the C stock dynamics data within one-year interval. PMOW and GMMA samples presented increase within the whole depth profile considered (0-40 cm) (around 53 and 27 %, respectively), while the other treatments considered did not present variation. The great fresh material input from the coffee shrub pruning distributed along the inter rows associated to conservational practices may have contributed to the expressive C stock increase samples submitted to PMOW and GMMA weed control method.



HAWE: hand weeding; PMOW: portable mechanical mower; HERB: herbicide application; GMMA: dwarf mucuna covering; GMAY: peanut horse covering; SCAP: no-weed control between coffee rows; CONT: weed check. Upper case letters means statistical analysis between years at a given weed control method (Tukey test, alpha=0.05).

Figure 4. C stock dynamics for soil samples collected in March, 2014 and February, 2015 from a Dystroferric Red Latosol of a coffee crop submitted to weed control methods at the inter rows.

The portable mechanical mower device cuts weed plants into smaller fragments and distributes them over soil surface, generating a mulch layer, providing available substrate for soil microbial community, enabling high incorporation newly formed and stabilized C compounds on topsoil. In addition, the use of such device on the inter rows of coffee crops causes intermediary effects on soil microbiota and its processes, altering soil biomass equilibrium (Melloni et al., 2013), and ultimately affecting soil C storage.

The results were consistent to the study conducted by Cogo et al. (2013), analyzing C storage potential in coffee crop areas under weed control management. The authors observed that SOC storage on areas under mechanical mower pulled on tractor management were no different than native forest.

Humic substances carbon stocks

Table 2 lists the C stock results for HS. HA and FA did not present variations along depth increments and between weed control methods analyzed. However, HU was 54 %, in average, higher at topsoil than subsequent depth for mechanical (PMOW and HAWE) and cultural (SCAP, CONT, GMMA and GMAY) weed control methods.

Table 2. C stock for humic substances extracted from a Dystroferric Red Latosol of a coffee crop submitted to weed control methods at the inter rows.

Humic Substances C Stock, Mg ha^{-1}, and Distribution, %

	Depth (cm)	C-HA	C-FA	C-HU	Total	% HA	% FA	% HU
HAWE[1]	0-10	1.27 (0.11)Aa	1.02 (0.12)Aa	5.27 (0.71)Aa	7.56	16.80	13.49	69.71
	10-20	1.46 (0.15)Aa	1.16 (0.30)Aa	3.49 (0.27)Ab	6.11	23.90	18.99	57.11
	20-30	1.42 (0.34)Aa	1.30 (0.33)Aa	3.41 (0.08)Ab	6.13	23.16	21.21	55.63
	30-40	1.38 (0.21)Aa	1.30 (0.29)Aa	3.33 (0.23)Ab	6.01	22.96	21.63	55.41
PMOW	0-10	1.46 (0.26)Aa	1.32 (0.18)Aa	5.55 (0.21)Aa	8.33	17.53	15.85	66.62
	10-20	1.57 (0.14)Aa	0.97 (0.40)Aa	3.76 (0.05)Ab	6.30	24.92	15.40	59.68
	20-30	1.75 (0.19)Aa	1.29 (0.43)Aa	3.59 (0.15)Ab	6.63	26.40	19.46	54.14
	30-40	1.63 (0.20)Aa	1.47 (0.24)Aa	3.22 (0.31)Ab	6.32	25.79	23.26	50.95
HERB	0-10	1.30 (0.34)Aa	0.99 (0.33)Aa	3.77 (0.65)Ba	6.06	21.45	16.34	62.21
	10-20	1.29 (0.43)Aa	1.01 (0.26)Aa	3.35 (0.29)Aa	5.65	22.83	17.88	59.29
	20-30	1.33 (0.45)Aa	1.09 (0.26)Aa	3.07 (0.12)Aa	5.49	24.23	19.85	55.92
	30-40	1.28 (0.48)Aa	1.46 (0.23)Aa	2.98 (0.14)Aa	5.72	22.38	25.52	52.10
GMMA	0-10	1.41 (0.06)Aa	1.32 (0.13)Aa	5.95 (0.58)Aa	8.68	16.24	15.21	68.55
	10-20	1.62 (0.17)Aa	1.49 (0.17)Aa	3.48 (0.19)Ab	6.59	24.58	22.61	52.81
	20-30	1.37 (0.26)Aa	1.45 (0.09)Aa	3.33 (0.22)Ab	6.15	22.28	23.58	54.14
	30-40	1.34 (0.35)Aa	1.37 (0.28)Aa	3.04 (0.13)Ab	5.75	23.30	23.83	52.87
GMAY	0-10	1.36 (0.19)Aa	1.10 (0.21)Aa	4.70 (0.61)ABa	7.16	19.00	15.36	65.64
	10-20	1.52 (0.24)Aa	1.07 (0.26)Aa	3.30 (0.14)Ab	5.89	25.81	18.17	56.02
	20-30	1.71 (0.28)Aa	1.40 (0.14)Aa	3.12 (0.10)Ab	6.23	27.45	22.47	50.08
	30-40	1.30 (0.14)Aa	1.15 (0.36)Aa	3.03 (0.15)Ab	5.48	23.72	20.99	55.29
SCAP	0-10	1.42 (0.24)Aa	1.31 (0.29)Aa	5.61 (0.24)Aa	8.34	17.03	15.71	67.26
	10-20	1.53 (0.27)Aa	1.41 (0.26)Aa	3.39 (1.00)Ab	6.33	24.17	22.27	53.55
	20-30	1.20 (0.16)Aa	1.35 (0.17)Aa	3.16 (0.13)Ab	5.71	21.02	23.64	55.34
	30-40	1.80 (0.24)Aa	1.51 (0.26)Aa	2.78 (0.15)Ab	6.09	29.56	24.79	45.65
CONT	0-10	1.64 (0.11)Aa	1.45 (0.17)Aa	5.25 (0.75)Aa	8.34	19.66	17.39	62.95
	10-20	1.54 (0.13)Aab	1.12 (0.20)Aa	3.66 (0.19)Ab	6.32	24.37	17.72	57.91
	20-30	1.31 (0.18)Aab	1.26 (0.19)Aa	3.40 (0.17)Ab	5.97	21.94	21.11	56.95
	30-40	0.98 (0.12)Ab	0.93 (0.23)Aa	3.15 (0.28)Ab	5.06	19.37	18.38	62.25

[1]HAWE: hand weeding; PMOW: portable mechanical mower; HERB: herbicide application; GMMA: dwarf mucuna covering; GMAY: peanut horse covering; SCAP: no-weed control between coffee rows; CONT: weed check. Lower case letters means statistical analysis along depth increments within a given weed control method. Upper case letters means statistical analysis between weed control method at given depth increment layer for each humic fraction (Tukey test, alpha=0.05).

The two considered soil cover crops presented HU C stocks increase. Nevertheless, when comparing each cover crop separately, the highest increase percentage (82 %) was observed for GMMA samples, while the lowest was noted at GMAY areas (49 %).

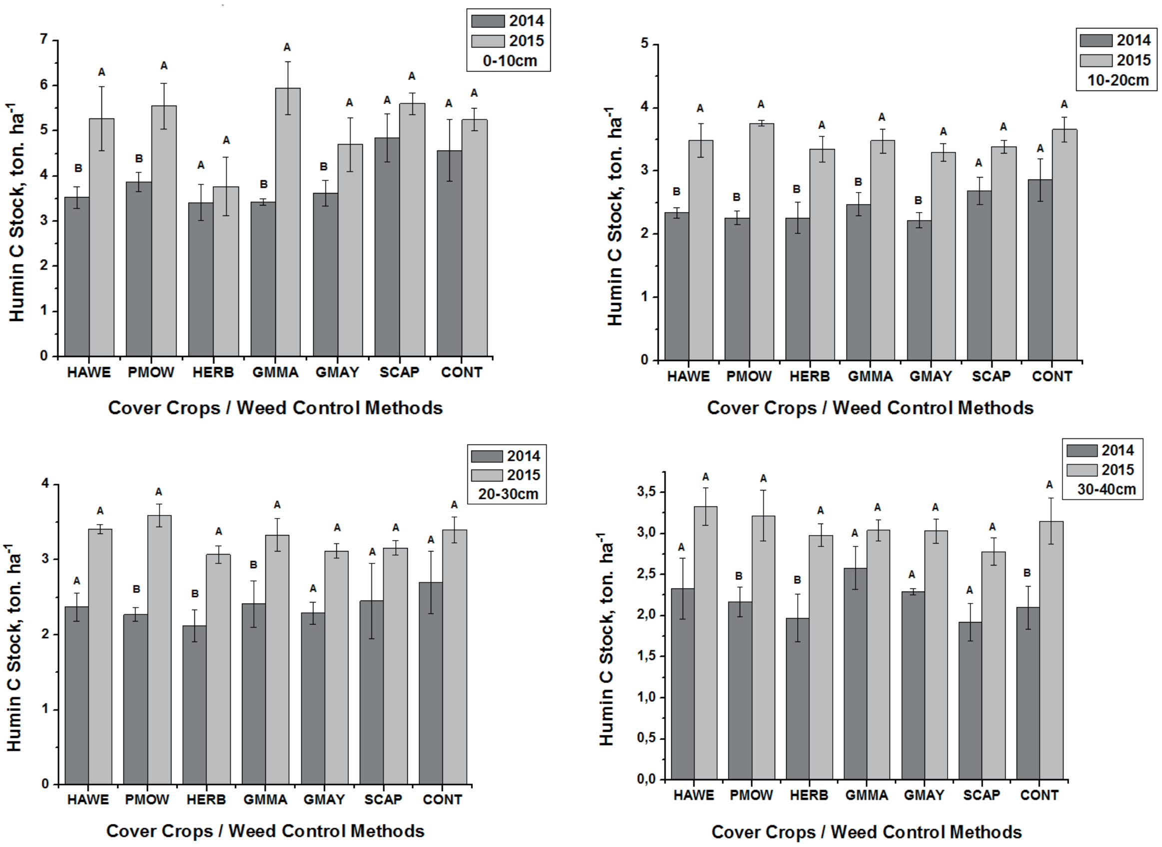
Humin fraction tends to accumulate at superficial layers, once humification process tends to occur with higher intensity on topsoil, considering its physical and chemical features (high stabilization with the mineral matrix, high apparent molecular weight, and lack of solubility) (Stevenson 1994).

According to Ebeling et al. (2011), when analyzing a set of soils with diverse textures, higher incidence of HU C content is verified on superficial layers, particularly in Latosols. The authors observed the effect of texture on the humification process, and consequently SOM maintenance, by verifying higher interaction with the soil mineral fraction, and thus resistance to microbial decomposition, when compared to Ultisols and Inceptsols.

The HU C stock followed the same pattern observed for whole soil samples. The fresh vegetal input – whether by the wide variety of weed species, cover crops, or mowing residues – enhanced root and shoot dry mass (Martins et al., 2015), accelerating soil microbial activity, ultimately leading to high incorporation of biologically transformed and more stable C compounds.

In a study conducted by Lange et al. (2015), high C storage in areas under plant diversity due to enhanced microbial activity was observed. The authors stated that C storage is primarily governed by soil microbial community interaction with root inputs and other mechanisms.

Figures 5 and 6 list the 2014/2015 C stock dynamics for HU and HA fractions extracted in March 2014 and February 2015. The behavior presented by the HU (Figure 5) fraction may be related to humification process in advanced stage, once HU is widely assumed be the oldest and most recalcitrant soil humic fraction, presenting the highest turnover and residence time in the soil environment (Ebeling et al., 2011).



HAWE: hand weeding; PMOW: portable mechanical mower; HERB: herbicide application; GMMA: dwarf mucuna covering; GMAY: peanut horse covering; SCAP: no-weed control between coffee rows; CONT: weed check. Upper case letters means statistical analysis between years at a given weed control method (Tukey test, alpha=0.05).

Figure 5. Carbon stock dynamics for humin extracted in March, 2014 and February, 2015 from a Dystroferric Red Latosol of a coffee crop submitted to weed control methods at the inter rows.

The presumed advanced stage of humification may also be attributable to high incidence of recalcitrant structures, precursors of humified material (celluloses, hemicelluloses, lignin fragments) (Flaig 1988), from fresh vegetal material input originated from incorporated plant material of coffee crop pruning, and cover crop management and incident weed species. Such structures are selectively preserved after microbial degradation and may be incorporated into the humic fractions, particularly to humin (Serramiá et al., 2013).

It is important to highlight that the field control conditions (SCAP and CONT) did not show HU C stock variation, despite showing HA decrease. These results may be an indication of likely equilibrium on humification for these conditions at the analyzed period.

Soils have a limited capacity for SOC storage. After a change in soil management, a certain amount of time is needed until a new SOC equilibrium level is reached. Likewise, the new equilibrium level achieved will remain until a new management change is adopted (West and Six 2007).

In terms of HA C stocks (Figure 6), once this HS represents the intermediary parcel between organic and soluble acids incidence and the mineral matrix, the behavior observed may be related to high polymerization and mineralization potential this fraction presents, leading to a concentration decrease tendency on soil when subjected to different tillage practices (Fontana et al., 2006).

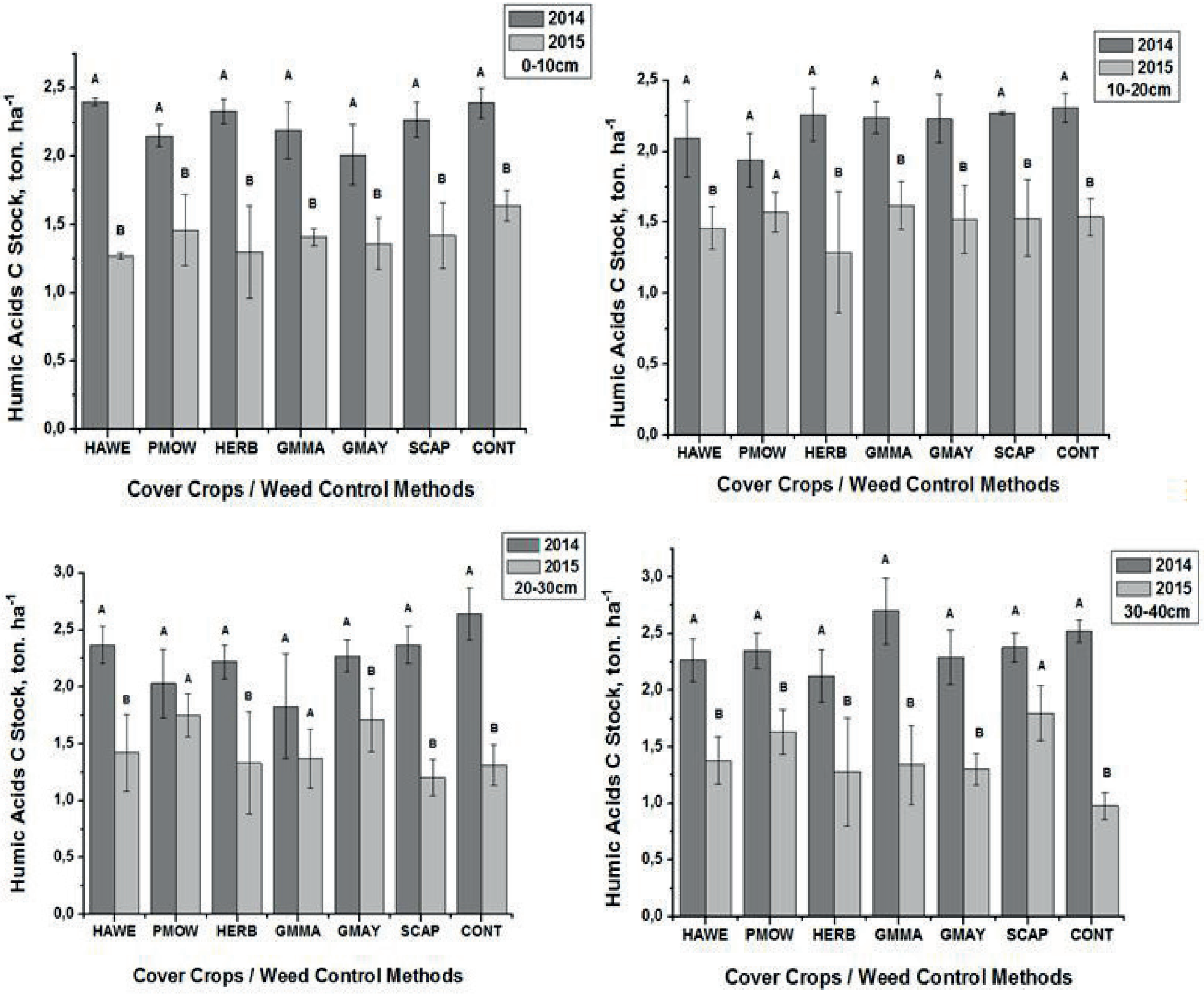


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Figure 6. Carbon stock dynamics for humic acids extracted in March, 2014 and February, 2015 from a Dystroferric Red Latosol of a coffee crop submitted to weed control methods at the inter rows.

Hence, considering the behavior presented by both HS, it could be observed that the distribution of coffee shrub pruning residues may exert higher impact on C stocks dynamics than weed control methods.

Residues distribution over soil surface was accomplished in September 2013, six months before the first sampling, led to high input material and high incidence of structure precursors of humified material, probably affecting humification process, and ultimately C stocks distribution, dynamics and balancing between HA and HU fractions.

FA remained unaltered during the period considered (data not shown). Due to low apparent molecular weight (1,000 to 5,000 Da), this fraction can remain in soil solution for longer periods even under adverse conditions (pH, salt concentrations, tillage), without suffering significant alterations (Calvo et al., 2014). Thus, results may be attributable to the FA long-lasting potential and transient characteristics, leading to unaltered C stocks in the considered period, regardless of weed control methods.

UV – Vis spectroscopy

Tables 3 and 4 list the E4/E6 ratio for humic and fulvic acids. Data presented a variation range of 8.42 in 2014, and 6.35 in 2015 for HA samples, and 9.04 and 7.93 for FA samples, in the same period. Higher values were observed, but with similar behavior as observed by Coelho et al. (2013), when analyzing coffee crops with different cover crops as green manure on the inter rows. The authors obtained an average E_4/E_6 ratio of 8.22 for FA and 4.58 for HA at topsoil (0–20 cm), considering all set of cover crops analyzed.

Table 3. E_4/E_6 ratio for humic acids extracted in March, 2014 and February, 2015 from a Dystroferric Red Latosol of a coffee crop submitted to weed control methods at the inter rows.

	HA E_4/E_6 ratio, a.u.[1]							
	0-10 cm		10-20 cm		20-30 cm		30-40 cm	
	2014	2015	2014	2015	2014	2015	2014	2015
HAWE[2]	9.41Aa (1.07)	8.53Aa (1.00)	7.53Aa (3.43)	9.54Aa (0.43)	8.60Aa (1.59)	9.73Aa (1.84)	9.49Aa (2.15)	5.72ABa (0.59)
PMOW	12.22Aa (2.25)	9.58Aa (1.36)	10.46Aa (2.54)	9.51Aa (1.51)	9.74Aa (2.51)	9.14Aa (0.88)	9.14Aa (2.60)	6.95ABa (0.55)
HERB	9.26Aa (1.90)	8.13Aa (0.85)	11.92Aa (2.03)	6.52Ab (0.38)	10.21Aa (1.60)	10.22Aa (1.29)	9.95Aa (2.04)	5.30ABa (1.35)
GMMA	4.18Ab (1.82)	10.64Aa (0.97)	9.51Aa (1.92)	9.30Aa (1.22)	10.17Aa (2.31)	7.19Aa (0.86)	5.44Aa (1.05)	9.77ABa (1.97)
GMAY	8.83Aa (2.88)	8.41Aa (0.35)	6.34Aa (0.61)	9.27Aa (1.19)	8.09Aa (1.74)	8.06Aa (0.98)	8.15Aa (2.06)	4.33Ba (1.55)
SCAP	9.42Aa (1.70)	10.31Aa (0.99)	6.25Aa (2.52)	10.38Aa (1.10)	10.96Aa (1.45)	7.26Aa (0.72)	8.79Aa (0.90)	10.68Aa (2.41)
CONT	9.27Aa (1.72)	10.21Aa (1.63)	8.02Aa (1.39)	9.16Aa (0.86)	8.05Aa (1.58)	9.95Aa (1.86)	3.80Ab (0.80)	9.50Aa (1.92)

[1]Arbitrary units. [2]HAWE: hand weeding; PMOW: portable mechanical mower; HERB: herbicide application; GMMA: dwarf mucuna covering; GMAY: peanut horse covering; SCAP: no-weed control between coffee rows; CONT: weed check. Lower case letters means statistical analysis between years at a given weed control method. Upper case letters means statistical analysis between weed control method at given depth increment layer for each year (Tukey test, alpha=0.05).

Table 4. E4/E6 ratio for fulvic acids extracted in March, 2014 and February, 2015 from a Dystroferric Red Latosol of a coffee crop submitted to weed control methods at the inter rows.

	FA E_4/E_6 ratio, a.u.[1]							
	0-10 cm		10-20 cm		20-30 cm		30-40 cm	
	2014	2015	2014	2015	2014	2015	2014	2015
HAWE[2]	10.40Aa (2.57)	7.04ABb (1.11)	7.67Aa (1.65)	4.61Aa (0.93)	5.94Aa (1.12)	4.18Aa (1.05)	5.00Aa (1.22)	2.95Aa (0.56)
PMOW	8.69Aa (2.43)	8.04ABa (2.02)	6.44Aa (1.89)	5.44Aa (1.37)	5.06Aa (0.79)	4.68Aa (0.05)	3.98Aa (0.19)	5.39Aa (1.16)
HERB	6.52Ba (0.30)	3.78Bb (1.41)	4.63Aa (0.13)	4.57Aa (0.72)	5.08Aa (0.70)	4.21Aa (0.70)	5.00Aa (1.03)	3.43Aa (0.49)
GMMA	6.72Ba (1.77)	3.26Ba (1.08)	4.46Aa (0.21)	3.84Aa (0.20)	6.03Aa (1.68)	5.71Aa (1.99)	4.81Aa (0.68)	5.15Aa (1.54)
GMAY	12.25Aa (0.63)	7.00ABb (1.29)	5.13Aa (0.66)	3.76Aa (0.61)	5.58Aa (0.82)	3.64Aa (0.24)	4.02Aa (0.78)	3.57Aa (0.42)
SCAP	10.88Aa (2.00)	4.00Bb (0.60)	5.88Aa (0.52)	7.35Aa (1.27)	5.92Aa (1.39)	4.78Aa (0.63)	3.21Aa (0.77)	6.10Aa (1.92)
CONT	9.95Aa (2.00)	9.79Aa (3.16)	6.19Aa (0.98)	8.20Aa (1.85)	5.95Aa (1.39)	1.86Aa (1.08)	4.94Aa (1.36)	2.85Aa (0.90)

[1]Arbitrary units. [2]HAWE: hand weeding; PMOW: portable mechanical mower; HERB: herbicide application; GMMA: dwarf mucuna covering; GMAY: peanut horse covering; SCAP: no-weed control between coffee rows; CONT: weed check. Lower case letters means statistical analysis between years at a given weed control method. Upper case letters means statistical analysis between weed control method at given depth increment layer for each year (Tukey test, alpha=0.05).

Our results showed an E4/E6 ratio of 9.34 for FA and 8.94 for HA on superficial layers in 2014. However, on the following year, the FA fraction showed to be more aromatically condensed/conjugated than HA, presenting 34 % decrease for the first fraction and 5 % increase for the second.

The 460–480 nm spectral range reflects absorbance intensity of the organic material at early humification process, while 600–670 nm spectral range is attributed as an indication of strongly humified material, presenting high degree of aromatic, condensed groups (Chen et al., 1977). Considering the absorbance intensity ratios from these spectral ranges, the degree of maturation (humification) of humic fractions may be assessed (Albretch et al., 2011).

On the 2014/2015 interval, statistically significant difference was observed for fulvic acids at superficial layer (0–10 cm) for most treatments analyzed. The E4/E6 ratio decreased for SCAP, HAWE, GMAY and HERB samples, with the highest variation decrease (63 %) for SCAP and the lowest variation (32 %) for HAWE.

Therefore, since the E_4/E_6 ratio is widely used as parameter to assess the condensation and polymerization degrees of aromatic structures (Albretch et al., 2011), being also correlated to molecular weight increment (Chen et al., 1977), results reflect the impact of different weed control methods on humic substances structural characteristics.

The behavior presented may be related to the presence of aromatic and condensed structures on superficial layers, due to possible accumulation of plant material from coffee crop pruning, cover crop residues and shoot mass (Martins et al., 2015).

CONCLUSIONS

Weed management between coffee rows and coffee shrub pruning distributed on inter rows affect total carbon stocks in a clayey Dystroferric Red Latosol at 0–10 cm depth. At this depth, portable mechanical mower, dwarf mucuna cover crop, no-weed control between coffee rows and weed check control methods increase total carbon stocks.

The mowed residues from coffee shrub pruning left on the soil surface also affect carbon stocks and its distributions in humic substances. Humin C storage potential follows the same pattern observed for whole soil samples. Although humic and fulvic acids C stocks are not affected by weed control management practices, likely incidence of more conjugated/condensed structures for the fulvic fraction within one- year interval is observed.

ACKNOWLEDGEMENTS

The authors would like to thank the Brazilian Agency of Coordination for the Improvement of Higher Education Personnel – CAPES / Post-Doctoral National Program (PNPD20132419-40075010001P1) for a scholarship to the first author; the Araucária Foundation of the Support to Scientific and Technological Development of the State of Paraná – Fundação Araucária, for the research grant to the second author. Finally, we thank the Brazilian Consortium of Coffee Research and Development for the Scientific and Innovation Grant provided to the fifth and sixth authors (Project 0213.02.059.00.05).

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Received: May 13, 2016.
Accepted: August 19, 2016.
Published: October 11, 2016.