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Fertigation with nitrogen and humic substances on soil chemical attributes cultivated with west Indian cherry

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Abstract

The use of humic substances (HS) in the soil can increase the efficiency of nitrogen fertilizers and contribute to the increment in soil organic matter and plant nutrient availability. Hence, this study aimed to evaluate, in two production cycles, the effect of applying HS and different nitrogen (N) doses on the chemical attributes and organic matter fractions of a soil cultivated with West Indian cherry in the Brazilian semiarid region. The experiment was set up in split plots, arranged in strips with four replicates. The absence or presence of HS using KS100 as the source was tested in the plots, and N fertilization (50; 75; 100; 125 and 150% of the recommended dose), using urea, was tested in the subplots. Soil pH, H+Al, Al^{3+}, and Na^+, K^+, P, Ca^{2+}, Mg^{2+}, Fe^{2+}, Mn^{2+} and Zn^{2+} contents were determined, and cation exchange capacity and bases saturation (V %) in the 0-0.2 and 0.2-0.4 m layers were calculated. Analyses of stocks of total organic carbon and carbon (C) of the humic acid, fulvic acid and humin fractions, and humic substances were performed. It was possible to observe that, in the second production cycle of West Indian cherry, the soils showed higher contents of nutrients available to plants. Increase in N availability did not enable a clear trend in the behavior of chemical attributes and organic C stocks in the soil. Under the studied conditions, KS100 application allowed a reduction in the C stocks of the HS of the soil.

Keywords: fertilization, humic acid, macronutrients, *Malpighia emarginata*, *total organic carbon*

Introduction

The commercial interest for the cultivation of West Indian cherry is due to the high content of vitamin C found in its fruits, which makes it a high quality product, standing out in the medicinal and food fields. Brazilian West Indian cherry production is mostly concentrated in the Northeast region, mainly in the São Francisco Valley region, which accounts for 25% of national production (IBGE, 2019).

West Indian cherry yield may vary according to the variety, environmental conditions and the management used (Franzão & Melo, 2017). Thus, in order to achieve an economically viable exploitation, it is necessary to develop technologies that contribute to increasing yield, especially in terms of mineral nutrition of the crop.

There are still few studies on the mineral nutrition and fertilization of West Indian cherry. However, it is known that in the initial stage of plant development, this crop requires a large amount of nitrogen (N) and potassium (K) (Rozane et al., 2007).

High temperatures, low rainfall, low biomass production (Santos et al., 2019) and the predominance of poorly weathered soils, with sandy texture, low availability of nutrients and high drainage rates, characterized as fragile soils (Albuquerque et al., 2017), are factors that contribute to limiting the stocks of soil organic matter (SOM) in the semiarid region of Brazil.

Therefore, with the objective of increasing SOM and improving the efficiency of absorption of N and other nutrients, the use of soil conditioners has been widely studied, including humic substances (HS) (Cunha et al., 2015). HS are commonly applied by fruit producers to the soil in the Brazilian semiarid region, mainly due to the edaphoclimatic conditions of this region, but this application has been carried out without scientific

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foundation.

HS exert a number of beneficial effects on the soil, including increased water storage capacity, formation and maintenance of soil aggregates, cation exchange capacity, nutrient availability, increasing N absorption by plants (Selim & Mosa, 2012). In *Neossolo* (Entisol) and *Argissolo* (Ultisol) cultivated with sugarcane in the Cerrado of Goiás, Bezerra et al. (2015) observed higher P availability after HS application. In addition, under controlled conditions, Arjumend et al. (2015) observed positive effects of HS on N, P, K and SOM content.

On the other hand, the addition of organic acids to the soil can cause priming effect, a phenomenon through which the decomposition of SOM is intensified (Liu et al., 2019). Huo et al. (2017) observed that the addition of organic acids to the soil can stimulate the decomposition of SOM by up to 59%.

Thus, the present study aimed to evaluate, in two production cycles, the chemical attributes and SOM fractions under cultivation of West Indian cherry fertigated with N and HS in the semiarid region.

Materials and Methods

Experimental area and crop management

The experiment was conducted in two production cycles in an experimental field in Petrolina, Pernambuco state, located at the geographic coordinates – latitude: 09°19'28'' S, longitude: 40°33'34'' W, altitude: 393 m.

The climate of the region is hot and dry in winter, with rains in summer, being classified by Köppen as BSh, with average rainfall of 538.7 mm year^{-1}, distributed along the months from November to April, and average annual temperature of 26.2 °C. The soil of the area is classified as *Argissolo Amarelo eutrocoeso típico* (Ultisol) (Silva et al., 2017), showing sand contents of 894.22 g kg^{-1} and 843.22 g kg^{-1}, clay contents of 95 g kg^{-1} and 138 g kg^{-1}, and silt contents of 10.78 g kg^{-1} and 18.78 g kg^{-1} in the 0-0.2 and 0.2-0.4 m layers, respectively.

The values of rainfall, mean temperature and relative humidity ranged from 0.0 mm to 70.3 mm, 24.7 °C to 28.6 °C and 52.7% to 62.9% in the first production cycle, respectively, and from 0.0 mm to 85.2 mm, 26.9 °C to 29.1 °C and 44,5% to 49.9% in the second production cycle, respectively, recorded in an automatic weather station installed on the Agrarian Sciences Campus of the Federal University of the São Francisco Valley (UNIVASF).

Before setting up the experiment, 20 single soil samples were collected in the experimental area in the 0-0.2 and 0.2-0.4 m layers to form a composite sample of each layer to determine the chemical attributes of the soil (**Table 1**).

Table 1. Chemical attributes of the soil in the 0-0.2 and 0.2-0.4 m layers before setting up the experiment (Petrolina, PE)

Attributes	0-0.2 m	0.2-0.4 m
pH$^{1/}$	6.54	5.86
CEC$^{2/}$ ($cmol_c$ dm^{-3})	8.83	7.12
Ca^{2+} ($cmol_c$ dm^{-3})	4.02	1.75
Mg^{2+} ($cmol_c$ dm^{-3})	0.42	0.53
K^+ ($cmol_c$ dm^{-3})	0.35	0.33
Na^+ ($cmol_c$ dm^{-3})	0.04	0.04
Al^{3+} ($cmol_c$ dm^{-3})	0.29	0.12
H+Al$^{3/}$ ($cmol_c$ dm^{-3})	4.24	4.62
P (mg dm^{-3})	198.68	191.71
Fe^{2+} (mg dm^{-3})	71.61	85.83
Mn^{2+} (mg dm^{-3})	221.08	108.24
Zn^{2+} (mg dm^{-3})	1.06	0.65
V$^{4/}$ (%)	52.01	35.03
TOC$^{5/}$ (Mg ha^{-1})	22.78	12.25

$^{1/}$pH determined in H_2O at 1:2.5 ratio; $^{2/}$Estimated cation exchange capacity; $^{3/}$Extraction in 0.5 mol L^{-1} calcium acetate at pH 7.0; $^{4/}$Base saturation; $^{5/}$Total organic carbon; P, K^+, Na^+, Fe^{2+}, Mn^{2+} and Zn^{2+}: Mehlich-1 extractant; Al^{3+}, Ca^{2+} and Mg^{2+}: 1.0 mol L^{-1} KCl extractant

Orchard planting and conduction

The seedlings grafted on the 'Junko' variety of West Indian cherry were planted in June 2015 at spacing of 4 m between rows and 3 m between plants, in holes with dimensions of 0.5 x 0.5 x 0.5 m, being irrigated with localized micro-sprinkler irrigation system (flow rate of 42 L h^{-1}). At the time of planting, basal fertilization was performed with 20 g per plant of P_2O_5 and 30 g per plant of K_2O, using single superphosphate (18% P_2O_5) and *potassium chloride - KCl* (60% K_2O) as sources, respectively. 20 L per plant of aged bovine manure were also applied.

During the development of West Indian cherry seedlings, the plants were staked to assist in guiding their growth and, when the seedlings reached about 0.3-0.4 m in height, formative pruning was carried out to grow the plant in a single stem. Thus, three lateral branches were left and, after the plant reached 0.5 m in height, the tip was cut to break the apical dominance. Unwanted branches were eliminated and, systematically, after each production cycle, renovation and cleaning pruning operations were carried out in order to keep the plants at the height of approximately 2.0 m.

All management practices for pruning and control of weeds, pests and diseases were performed according to Barboza et al. (1996).

Experimental design and treatments

The experimental design adopted was in split plots with treatments distributed in 5 x 2 strips, referring to five doses of N (50, 75, 100, 125 and 150% of the recommended dose) and two applications of humic substances (HS)

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(without and with), with four replicates and three plants per subplot. N doses were defined according to fertilization recommendations for the Pernambuco state (Cavalcanti et al., 2008). The recommendation is 100 g per plant of N at planting (growth), 150 g per plant of N in the first year of production, 200 g per plant of N in the second year and 250 g per plant of N from the third year onwards.

The nitrogen source used was urea (45% N), with weekly fertilization, from 60 days after transplantation (DAT). In the growth and production stages, N doses were split into ten applications, as recommended by Cavalcanti et al. (2008). The source of HS used in the experiment was the commercial product KS100 (Omnia®), from leonardite, whose composition is K_2O (15%), total organic carbon (45%), humic acids (70%) and fulvic acids (8%). The values of electrical conductivity, salt index, pH and solubility were 0.37 mS cm^{-1}, 24, 10 and 140 g L^{-1}, respectively. Fertigation with HS began at 30 DAT, with monthly applications of 6 g per plant of the product KS100 until the end of the experiment.

In addition, fertilization with K was performed using KCl (60% K_2O) as source, applying 130 g per plant of K_2O split into ten weekly applications from 90 DAT. Foliar fertilization with micronutrients (4.5 g per plant of Zn and 1 g per plant of B) were performed in two applications from 90 DAT, using as a source the commercial products Nutrigema, which contains B (67.7 g L^{-1}) and Zn (67.7 g L^{-1}), and Folimax Zinc, which contains Zn (118.89 g L^{-1}) and total organic carbon (TOC) (15.88 g L^{-1}), following the recommendation of Cavalcanti et al. (2008). Fertilization management was carried out through a fertigation system (Viqua® 1" venturi injector at the operating pressure of 10 bar).

Variables analyzed and statistical evaluation

In the early flowering of the plants, in the first production cycle and second production cycle, four soil samples for each experimental unit were collected in the 0-0.2 and 0.2-0.4 m layers in order to form one composite sample per replicate. After obtaining the air-dried fine earth (ADFE), the contents of phosphorus (P), sodium (Na^+) and potassium (K^+) (Mehlich-1), calcium (Ca^{2+}) and magnesium (Mg^{2+}) (1.0 mol L^{-1} KCl), iron (Fe^{2+}), and manganese (Mn^{2+}) and zinc (Zn^{2+}) (Mehlich-1) were determined according to the methodology proposed by Teixeira et al. (2017). In addition, the values of pH in H_2O (1:2.5), potential acidity (H+Al) (0.5 mol L^{-1} calcium acetate at pH 7.0) and exchangeable acidity (Al^{3+}) (1 mol L^{-1} KCl) were determined according to the methodology proposed by Teixeira et al. (2017). Subsequently, cation exchange capacity (CEC) and base saturation (V) were calculated. In order to calculate the C stocks, the bulk density was determined using the volumetric method, according to Teixeira et al. (2017).

The ADFE samples were crushed and passed through a 100-mesh (0.149 mm) sieve to determine TOC, by the wet oxidation method with external heating (Yeomans & Bremner, 1988). HS fractionation was performed according to the method suggested by the International Humic Substances Society (Swift, 1996). From this fractionation, the carbon of the fulvic acid (CFAF), humic acid (CHAF) and humin (CHF) fractions was determined based on solubility in acidic or alkaline solutions, and the C content in each humic fraction was determined by the wet oxidation method with external heating (Yeomans & Bremner, 1988). The C of the humic substances (CHS) was obtained from the sum of CFAF, CHAF and CHF. The C stocks in the different fractions of soil organic matter (SOM), in the different soil layers, were calculated by multiplying the C contents by the mass of soil (Pegoraro et al., 2018).

The data were subjected to analysis of variance to diagnose significant effects between production cycles, N doses and humic substances, by the F test. The treatments without and with humic substances and the production cycle factor were compared by the Scott-Knott test at 1 and 5% probability levels, while the N doses were evaluated by simple regression models.

Results and Discussion

Macronutrients

Although the application of N doses had significant effect on all variables analyzed in the soil, both individually and in interactions, no significant regression models were found for most variables in the two soil layers analyzed. Thus, the treatments were analyzed considering the means of the studied levels and their corresponding standard deviations.

There was an increase in the Ca^{2+} contents of the 0-0.2 m layer from the first to the second production cycle of West Indian cherry, with significant differences between the conditions without and with application of humic substances (HS) only in the second cycle (**Figure 1**A). In addition, HS application in the second production cycle of West Indian cherry resulted in a 9.57% reduction in Ca^{2+} contents (**Figure 1**A). The Ca^{2+} contents in the 0.2-0.4 m layer were considerably higher in the second cycle of West Indian cherry (Figure 1C).

As for the Mg^{2+} content in the 0-0.2 m layer (Figure

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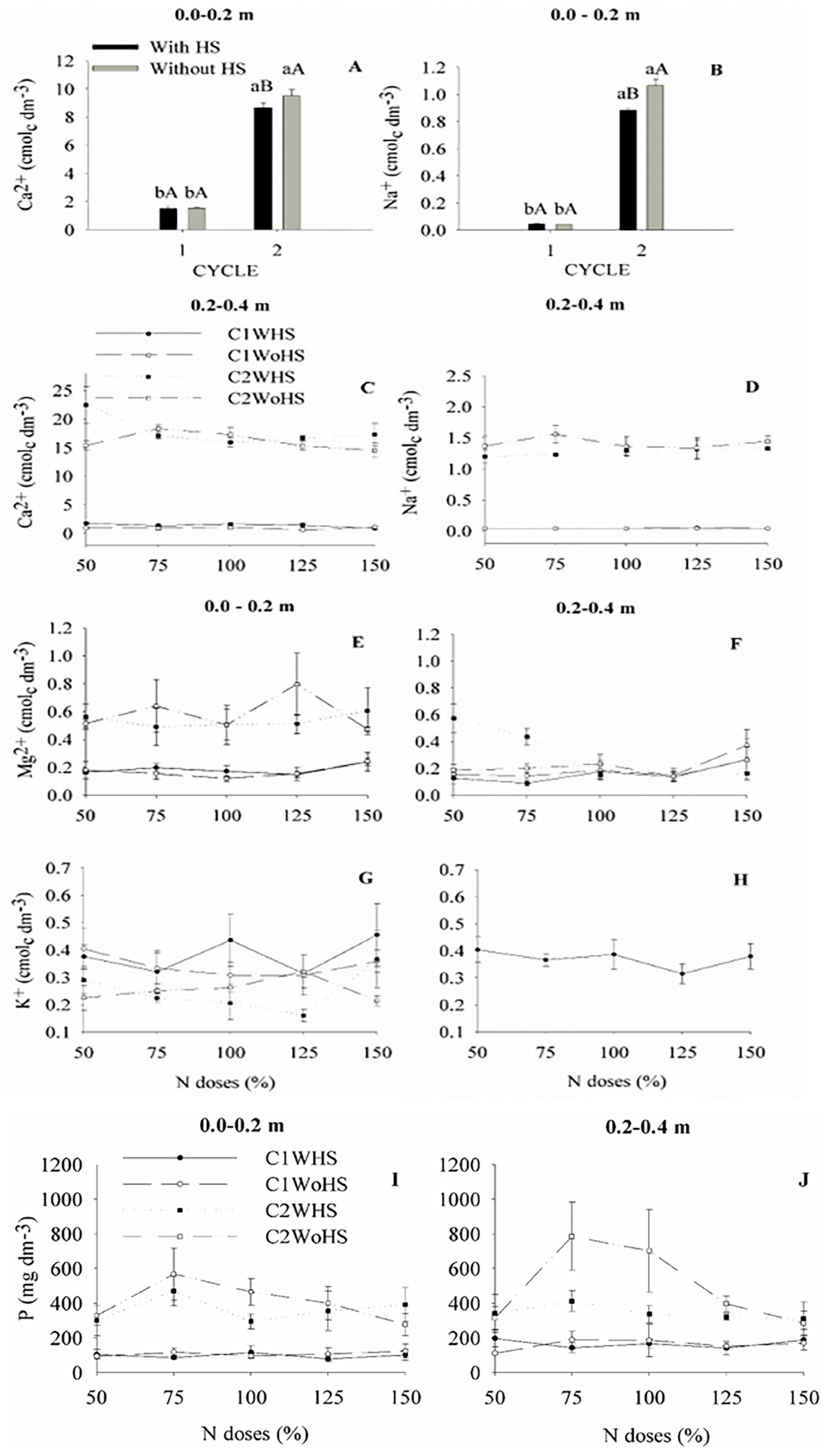

Figure 1. Calcium (A) and sodium (B) contents in the 0-0.2 m layer in the interaction between West Indian cherry production cycle and humic substances (HS), calcium (C) and sodium (D) contents in the 0.2-0.4 m layer, magnesium (E and F), potassium (G and H), and phosphorus (I and J) contents in the 0-0.2 and 0.2-0.4 m layers under cultivation of West Indian cherry fertigated with nitrogen (N) and humic substances (HS). C1WHS, with HS in cycle 1; C1WoHS, without HS in cycle 1; C2WHS, with HS in cycle 2; C2WoHS, without HS in cycle 2. Columns followed by the same lowercase letter between West Indian cherry production cycles and uppercase letter between humic substances do not differ statistically from each other by the F test with $P \leq 0.05$.

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1E), the treatments referring to the second production cycle of West Indian cherry with and without HS (C2WHS and C2WoHS) showed an increase of around 200% compared to the treatments of the first production cycle with and without HS (C1WHS and C1WoHS). Regarding the application of N doses, there was little variation between treatments, except for the Mg^{2+} content in the 0.2-0.4 m layer, which was higher than in the other treatments at N doses of 50 and 75% in the treatment of the second cycle with HS (C2WHS) (Figure 1F).

The K^{+} content in the 0-0.2 m layer decreased significantly in the treatments referring to the second production cycle (Figure 1G), indicating that there may have been a higher demand for this nutrient by West Indian cherry plants, which caused its reduction in the soil. On the other hand, in the 0.2-0.4 m layer, according to the standard deviations, there was no difference between the N doses and the recommended dose (100%) (Figure 1H).

There was an increase in the Na^{+} contents in the 0-0.2 m layer from the first to the second production cycle of West Indian cherry, with significant differences between the conditions without and with HS application only in the second cycle (Figure 1B). In addition, HS application in the second production cycle of West Indian cherry resulted in a 20.45% reduction in the Na^{+} content (Figure 1B). In the 0.2-0.4 m layer, the Na^{+} contents were considerably higher in cycle 2 of West Indian cherry (Figure 1D).

The P contents in the two soil layers (Figures 1I and 1J) were higher in the treatment of the second production cycle of West Indian cherry and without application of HS (C2WoHS). In the 0-0.2 m layer, the P content in the C2WoHS treatment was 317.97, 278.14 and 12.57% higher when compared to that found in the treatments C1WHS (with HS in cycle 1), C1WoHS (without HS in cycle 1) and C2WHS (with HS in cycle 2), respectively. On the other hand, in the 0.2-0.4 m layer, in the C2WoHS treatment, the P content increased by 446.96, 316.23 and 91.12% when compared to those found in the treatments C1WHS, C1WoHS and C2WHS, respectively.

Soil acidity

The potential acidity (H+Al) in the surface layer was not influenced by N doses (**Figure 2**A). In the 0.2-0.4 m layer of the soil, HS application in the first cycle of West Indian cherry (C1WHS) caused an increase in H+Al, especially at N doses equivalent to 125 and 150% of the recommended dose (Figure 2B). In the second cycle of West Indian cherry, there was inverse behavior between the conditions with and without HS as a function of the established N doses (Figure 2B).

The Al^{3+} contents in the two soil layers analyzed followed stochastic pattern, so it was not possible to identify a trend of behavior of the data as a function of the studied factors (Figures 2C and 2D). As for pH, there was no clear trend of behavior of the data in the 0.2-0.4 m soil layer (Figure 2E).

Cation exchange capacity and base saturation

Regarding the cation exchange capacity (CEC) of the soil, in the 0-0.2 m layer, there were increments of 73.49, 74.91, 57.93, 66.07 and 90.01% at N doses of 50, 75, 100, 125 and 150%, respectively, between cycles 1 and 2 of West Indian cherry (**Figure 3**A). Also in the soil surface layer, for the interaction HS x N (Figure 3C), the treatments without HS at N doses of 75 and 125% had higher CEC when compared to soils with HS and there was an increase in CEC from the first to the second production cycle of West Indian cherry, with significant differences between the conditions without and with application of HS only in the second cycle (Figure 3F). Application of HS in the second production cycle of West Indian cherry resulted in a 10.02% reduction in CEC (Figure 3F). In the 0.2-0.4 m layer, CEC was higher in the second cycle of West Indian cherry, with a more pronounced distinction between the conditions with and without HS at the lowest N dose (50% N) (Figure 3B).

The second cycle of West Indian cherry also allowed higher values of base saturation (V) in the two soil layers analyzed (Figures 3D and 3E).

Micronutrients

As for the Fe^{2+} content, in the 0-0.2 m layer there was a trend of reduction with the increase of N dose in the absence of HS application, regardless of the production cycle, while HS application allowed the maintenance of Fe^{2+} contents up to the N dose of 125% (**Figure 4**A). In the subsurface layer of the soil, except for the N dose of 50%, there was no difference between the conditions with and without HS (Figure 4B).

Except for the Mn^{2+} contents in the 0.2-0.4 m layer (Figure 4D), which were higher in the first production cycle of West Indian cherry, the contents of this micronutrient in the soil surface layer (Figure 4C) showed a behavior similar to that of Al^{3+} in the two soil layers analyzed (Figures 2C and 2D), following a stochastic pattern, so it was not possible to identify a trend of behavior of the data as a function of the studied factors.

Regardless of HS application, the Zn^{2+} contents in the 0-0.2 m layer were higher from 100% of the recommended N dose applied in the second cycle of West Indian cherry (Figure 4E). This same dose was

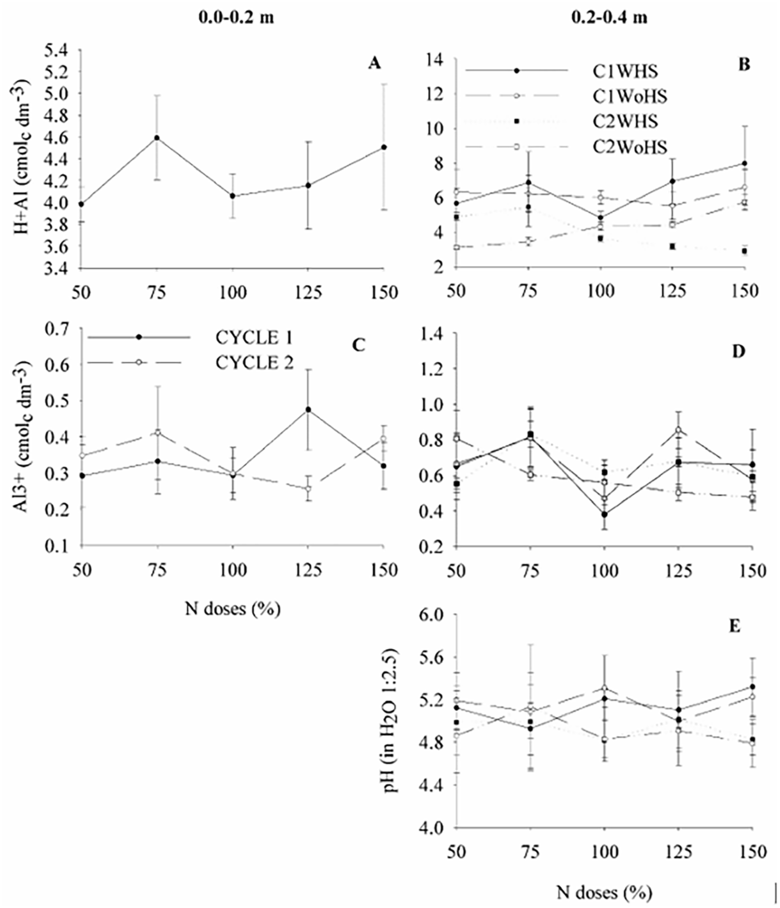


Figure 2. Potential acidity (H+Al) (A and B), aluminum contents (Al^{3+}) (C and D) in the 0-0.2 and 0.2-0.4 m layers and pH in the 0.2-0.4 m layer (E) under cultivation of West Indian cherry fertigated with nitrogen (N) and humic substances (HS). C1WHS, with HS in cycle 1; C1WoHS, without HS in cycle 1; C2WHS, with HS in cycle 2; C2WoHS, without HS in cycle 2

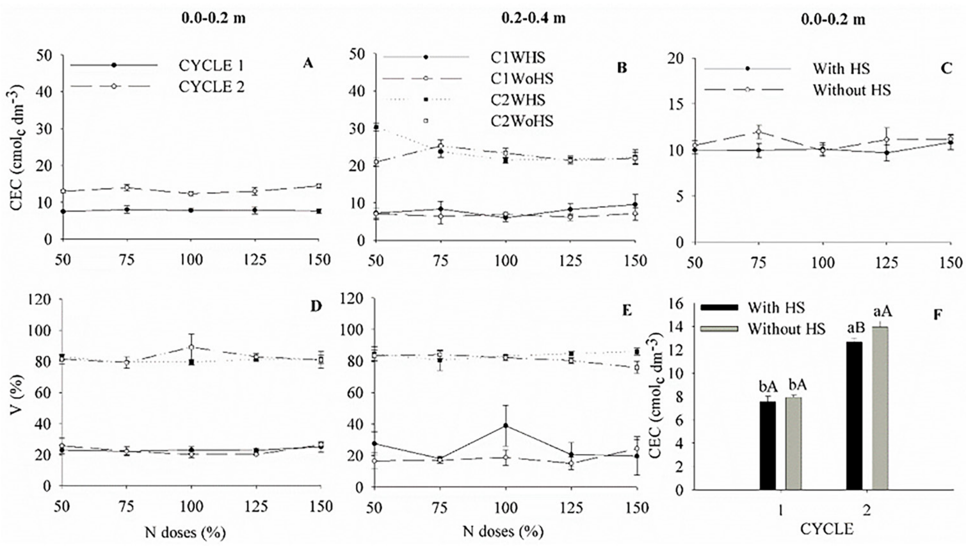


Figure 3. Cation exchange capacity (CEC) (A, B and C) and base saturation (V) (D and E) in the 0-0.2 and 0.2-0.4 m layers under cultivation of West Indian cherry fertigated with nitrogen (N) and humic substances (HS), and CEC in the 0-0.2 m layer (F) in the interaction between West Indian cherry production cycle and humic substances (HS). C1WHS, with HS in cycle 1; C1WoHS, without HS in cycle 1; C2WHS, with HS in cycle 2; C2WoHS, without HS in cycle 2. Columns followed by the same lowercase letter between West Indian cherry production cycles and uppercase letter between humic substances do not differ statistically from each other by the F test with $P \leq 0.05$.

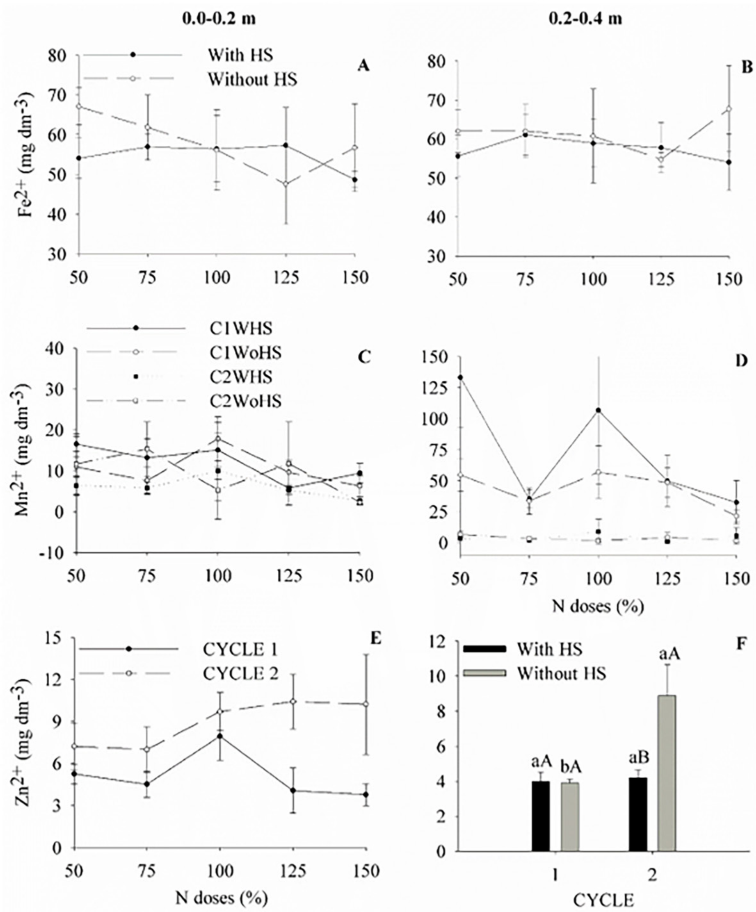


Figure 4. Iron (A and B) and manganese (C and D) contents in the 0-0.2 and 0.2-0.4 m layers, zinc content in the 0-0.2 m layer (E) under cultivation of West Indian cherry fertigated with nitrogen (N) and humic substances (HS) and zinc content in the 0.2-0.4 m layer (F) in the interaction between West Indian cherry production cycle and humic substances (HS). C1WHS, with HS in cycle 1; C1WoHS, without HS in cycle 1; C2WHS, with HS in cycle 2; C2WoHS, without HS in cycle 2. Columns followed by the same lowercase letter between West Indian cherry production cycles and uppercase letter between humic substances do not differ statistically from each other by the F test with P ≤ 0.05.

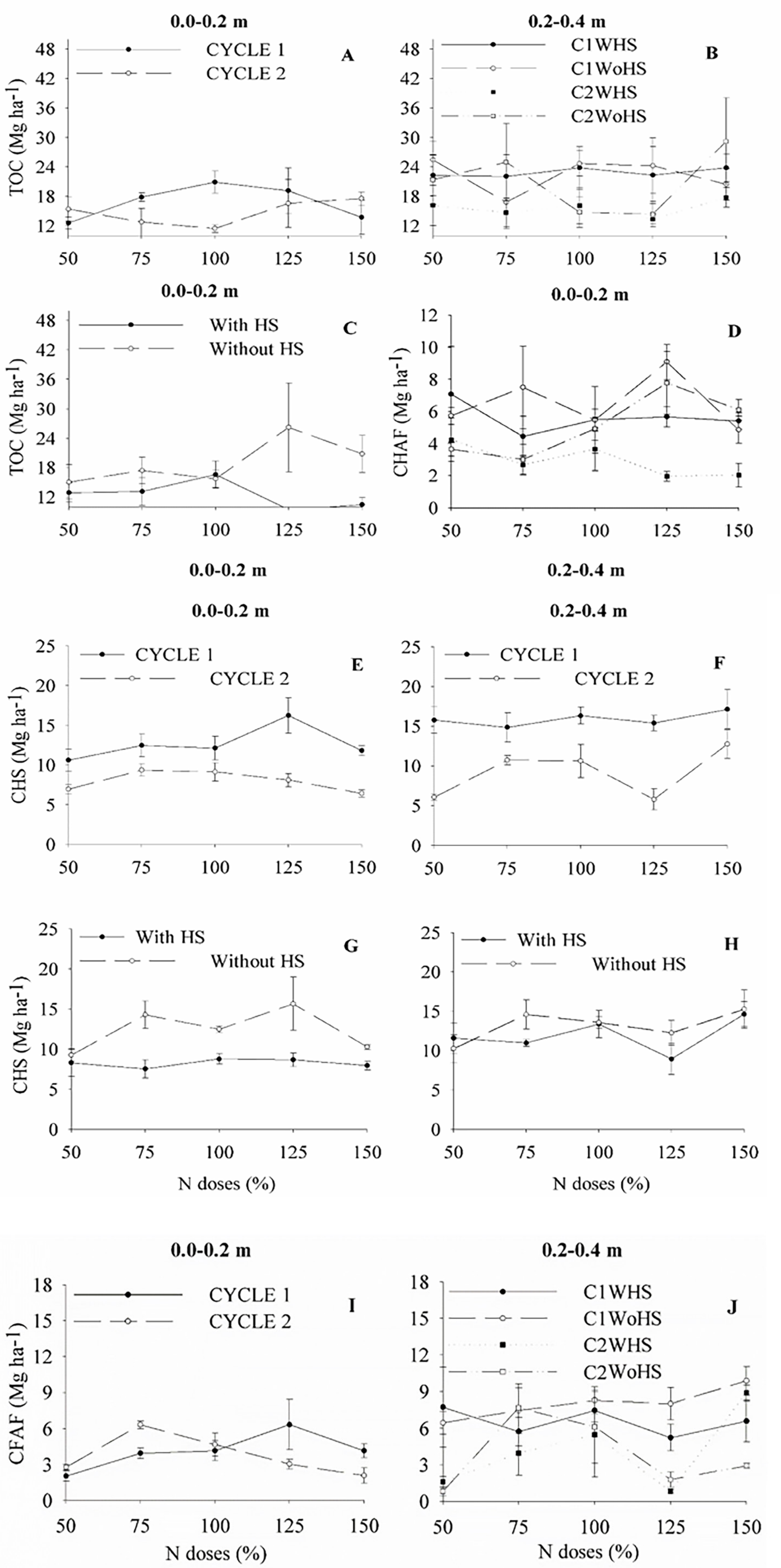
responsible for the highest content of Zn^{2+} in the surface layer during cycle 1 of West Indian cherry, with a reduction in its content at the subsequent doses (Figure 4E). Regarding the Zn^{2+} content in the 0.2-0.4 m layer, the CYCLE x HS interaction indicates that there was an increase of Zn^{2+} from one cycle to the other only in the absence of HS application (Figure 4F).

Stocks of total organic carbon and carbon of humic substances

The total organic carbon (TOC) stocks in the 0-0.2 m layer were higher in the first production cycle of West Indian cherry, with a maximum value for 100% of the recommended dose of N (**Figure 5**A). At this same soil depth, regardless of West Indian cherry production cycle, the absence of HS application allowed higher TOC stocks, especially at the highest doses of N (125 and 150% of the recommended dose of N) (Figure 5C). In the 0.2-0.4 m layer, TOC stocks remained constant in the first cycle of West Indian cherry with HS applications and increasing N doses, and were higher than the stocks of cycle 2 (Figure 5B). HS application resulted in reductions of 82.14% in the TOC stock in the first production cycle of West Indian cherry and 24.52% in the TOC stock in the second cycle (Figure 5L).

In the 0-0.2 m layer (Figure 5D), HS application in the second cycle of West Indian cherry reduced the carbon (C) stocks of the humic acid fraction (CHAF) mainly at the highest N doses (125 and 150%). In this same cycle, in soils where there was no application of HS, the stocks of CHAF were increasing at the N dose from 75% to 125%. For the cycle 1 of West Indian cherry, there was stochastic pattern in the absence of HS application, while with HS the tendency was maintenance of CHAF stocks with the increasing doses of N (Figure 5D).

In the first production cycle of West Indian cherry,



0.0-0.2 m
A
CYCLE 1
CYCLE 2
TOC (Mg ha-1)
0.2-0.4 m
B
C1WHS
C1WoHS
C2WHS
C2WoHS
0.0-0.2 m
C
With HS
Without HS
TOC (Mg ha-1)
0.0-0.2 m
D
CHAF (Mg ha-1)
0.0-0.2 m
0.2-0.4 m
0.0-0.2 m
E
CYCLE 1
CYCLE 2
CHS (Mg ha-1)
0.2-0.4 m
F
CYCLE 1
CYCLE 2
G
With HS
Without HS
CHS (Mg ha-1)
N doses (%)
H
With HS
Without HS
N doses (%)
0.0-0.2 m
I
CYCLE 1
CYCLE 2
CFAF (Mg ha-1)
N doses (%)
0.2-0.4 m
J
C1WHS
C1WoHS
C2WHS
C2WoHS
N doses (%)

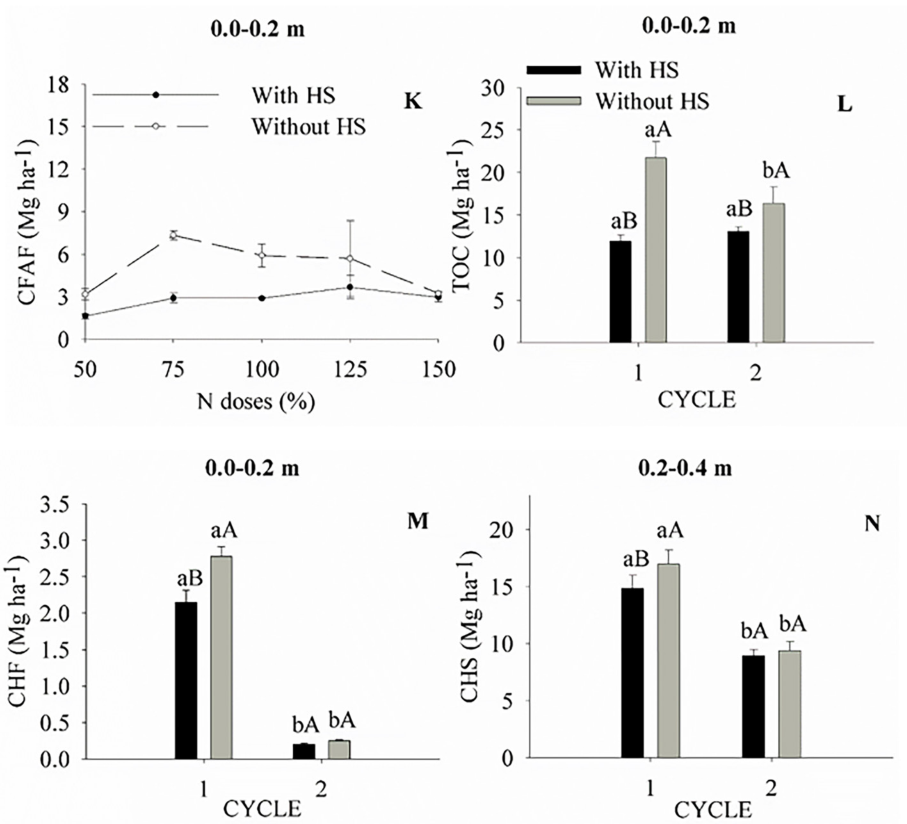


Figure 5. Stocks of total organic carbon (TOC) (A, B and C), C of humic acid fraction (CHAF) (D), C of humic substances (CHS) (E, F, G and H) and C of the fulvic acid fraction (CFAF) (I, J and K) in the 0-0.2 and 0.2-0.4 m layers under cultivation of West Indian cherry fertigated with nitrogen (N) and humic substances (HS), stocks of TOC (L) and C of humin fraction (CHF) (M) in the 0-0.2 m layer, and CHS in the 0.2-0.4 m layer (N) in the interaction between West Indian cherry production cycle and humic substances (HS). C1WHS, with HS in cycle 1; C1WoHS, without HS in cycle 1; C2WHS, with HS in cycle 2; C2WoHS, without HS in cycle 2. Columns followed by the same lowercase letter between West Indian cherry production cycles and uppercase letter between humic substances do not differ statistically from each other by the F test with $P \leq 0.05$.

in the 0-0.2 m layer, the highest carbon stock of the fulvic acid fraction (CFAF) was observed at a N dose of 125% (Figure 5I). In cycle 2, the stock of CFAF increased at the N doses from 50 to 75% by approximately 2.3 times, with consecutive reductions up to the maximum N dose (Figure 5I). Similar behavior was observed in the samples collected in the same soil layer (0-0.2 m depth) and without HS application (Figure 5K). There was no clear trend of behavior of the CFAF stock data in the 0.2-0.4 m layer (Figure 5J). In the first production cycle, there was a reduction in the carbon stock of the humin fraction (CHF) (29.43%) with the application of HS (Figure 5M).

The highest carbon stock of humic substances (CHS) was found for the N dose of 125%, in the 0-0.2 m layer of the soil, in the first production cycle of West Indian cherry (Figure 5E). In cycle 2, the CHS stock increased by approximately 1.3 times between the N doses from 50 to 75%, with consecutive reductions up to the maximum dose of N (150%) (Figure 5E), similar to what occurred with the CFAF stock in the same cycle and soil layer (Figure 5I). Between the two production cycles, the first stands out with the highest stocks of CHS, both in the surface layer (Figure 5E) and subsurface layer of the soil (Figure 5F).

In the HS x N interaction, it can be observed that the treatment without HS contributed to greater accumulation of CHS in the 0-0.2 and 0.2-0.4 m layers (Figures 5G and 5H). In the absence of HS application, N doses of 75, 100 and 125% allowed the highest CHS stocks in the 0-0.2 m layer (Figure 5G). Regarding the CHS stock of soils collected in the 0.2-0.4 m layer, the CYICLE x HS interaction indicates that the CHS stock was lower in the second cycle both with and without HS application (Figure 5N).

Regarding fertigation with N, there was no decrease or increase in any soil attribute with increasing fertilizer doses. Some exceptions can be highlighted, such as the P contents in the two soil layers evaluated (Figures 1I and 1J), Fe^{2+} content in the 0-0.2 m layer (Figure 4A) and the carbon stock of the fulvic acid fraction (CFAF) in the surface layer of the soil (Figures 5I and 5K). The P content increases at the first N doses and tends to decrease at the highest doses, indicating a possible relationship between the increase in nutrient availability as a function of urea application and the eventual increase of plant growth, allowing greater absorption of P and, consequently, decrease in its contents in the soil. According to Ferreira Neto et al. (2014), the increase in N dose stimulates P absorption, which demonstrates the synergistic interaction between N and P, in which both nutrients at adequate doses promote increments in plant production greater than those obtained with the application of each nutrient alone (Sattari et al., 2014).

The substantial increase of Na^+ ions in the soils of the present study, observed in the second production cycle of West Indian cherry (Figure 1B), can inhibit the absorption of K^+ by plants and its translocation to the shoots, increase Na^+ in the shoots, reduce K^+, K^+/Na^+ ratio and synthesis of proteins and chlorophyll (Ashraf et al., 2017). In addition, according to the same authors, the increment of Na^+ ions in the soil can increase clay dispersion and consequently decrease porosity, permeability, hydraulic conductivity and soil aeration. However, this effect can be minimized by the increment of other cations such as Ca^{2+} and Mg^{2+} (Figures 1A and 1E), which limits the increase in the values exchangeable sodium percentage.

However, the increase of nutrients in the soil throughout the crop cycles should be limited to what is necessary to meet the growth and development of plants. This is because the additional use of organic and mineral fertilizers in a disorderly manner, with excessive fertilization, can result in imbalances, characterized by excess of some nutrients and/or deficiency of others, which may cause economic losses, due to low production and products with lower nutritional and visual quality, in addition to environmental problems, such as soil and water contamination (Batista et al., 2018).

In general, in the second production cycle of West Indian cherry, the soils showed higher nutrient contents. This characteristic was more clearly represented by the estimated values of cation exchange capacity (CEC) and base saturation (V) (Figures 3B, 3D and 3E). The fertilizations carried out during the first and second production cycles of West Indian cherry may have caused, eventually, the cumulative effect, responsible for the increase of nutrients in the soils collected in cycle 2.

The cumulative effect of nutrients along the production cycles of West Indian cherry shows the importance of constantly monitoring the contents of nutrients present in soils, especially under the cultivation conditions of the semiarid region. In this context, three aspects should be considered: the balancing of nutrient contents in soils, the possible excess of nutrients which may raise the salt content of the soil solution and the cost of unnecessary application of nutrients present in adequate amounts in the soil.

Unbalanced inorganic fertilization usually causes lower crop yields. This can be observed in the study conducted by Zhao et al. (2013), who evaluated the impact of fertilization on corn yield and soil properties in a field experiment over 18 years in northern China, using different sources of fertilizer, and observed that balanced fertilization is important to maintain high crop yield and soil quality. According to Taiz et al. (2017), there may be a decrease in the absorption of a given nutrient due to the excess of another chemical element present in the soil, which is characterized as antagonism.

One of the hypotheses proposed for this study was that the addition of humic (HS) allows the increase of stocks of total organic carbon (TOC) and carbon of soil organic matter (SOM) fractions. The data did not confirm this hypothesis and the opposite was observed in the two soil layers evaluated, especially during the first cycle of West Indian cherry cultivation (Figure 5). Due to the predominance of fragile soils in the region of the present study, it is difficult to raise the stocks, since there is a low efficiency of the chemical and physical stabilization mechanisms of the soil due to its sandy texture (Moradi et al., 2017), with clay contents of 95 g kg^{-1} and 138 g kg^{-1} in the 0-0.2 and 0.2-0.4 m layers, respectively. It is important to highlight that due to the absence of native forests with the same soil class, near the experiment area, it was not possible correct the effect of soil compaction using the bulk density.

The addition of a labile source of C to the soil can intensify the decomposition of C that was already present, by increasing the availability of energy and nutrients needed for microorganisms to decompose the supplied material, a process called priming effect (Liu et al., 2019). Although the mechanisms that favor the priming effect are still little understood due to their complexity, it is commonly proposed that they are microbial activation, stoichiometry and N limitation (Perveen et al., 2019).

Since microorganisms are responsible for the decomposition of SOM, their population in the soil influences the priming effect. In addition, the C/N ratio of the residues supplied assumes significant importance in the decomposition process, since high C/N ratio stimulates the degradation of native C (Liu et al., 2019).

Another factor that directly interferes in this process is the type of substrate, for example, the addition of easily assimilable organic compounds (glucose, fructose and nutrients) little favored the mineralization of SOM when compared to the straw of ryegrass, cellulose and wheat (Rosa et al., 2014).

In some situations, the supply of fresh material does not result in the priming effect, while the supply of C in more complex/insoluble forms can induce the mineralization of SOM. In addition, the more complex the quality of the organic material added, the greater the diversification of extracellular enzymes produced by microorganisms that favor the mineralization of SOM (Fontaine et al., 2003). Thus, possibly, the increase of HS in the present study may have favored the priming effect, resulting in the decrease in SOM, mainly of the C associated with HS.

Additionally, the slow and regular exudation of organic compounds by plant roots can be a mechanism through which plants favor the mineralization of SOM by certain groups of microorganisms (k-strategists), which develop in an environment with low amount of energy and availability of nutrients. Consequently, a maximum of plant energy could be directed to the decomposition of the SOM, favoring the availability of nutrients (e.g. nitrogen) and avoiding their immobilization (Fontaine et al., 2003).

On the other hand, with the increasing doses of N, a trend of increase in the CFAF stock was observed in soils where HS were applied (Figure 5K), showing that the increase in N availability may favor the negative priming effect, that is, the application of C sources (HS) associated with N fertilization can help in the maintenance of C in the soil, reducing the microbial mineralization of SOM (Wang et al., 2014). Corroborating the results found in the present study, Lima et al. (2016) evaluated the contents of total organic carbon (COT) and of the organic matter fractions in an Oxisol cultivated with vegetables under different soil management systems and with different cover crops and verified negative priming effect when the availability of N was high. This negative priming effect can reduce the efflux of CO_2 from the soil and stimulate C sequestration, thereby reducing the consequences of greenhouse gases.

Conclusions

The chemical attributes and the organic carbon stocks in the soil showed a stochastic pattern as a function of the increase in N availability;

For the conditions under which the study was carried out, the application of KS100 results in a decrease in the C stocks of soil humic substances.

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