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ORIGINAL ARTICLE

Edaphic respiration in an ecosystem submitted to surface soil transposition in the Caatinga

Respiração edáfica em ecossistema submetido a transposição do solo superficial na Caatinga

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ABSTRACT: The research aimed to evaluate the potential of the soil transposition technique in the restoration of a degraded area in the Seridó Desertification Center, through the analysis of edaphic respiration. Seven areas from different microregions of the semi-arid region of Paraíba were selected for soil transposition and allocation to a degraded area. The design was in randomized blocks, consisting of eight treatments: one referring to the control (degraded area) and the others, to soils transported from conserved areas in microregions, and four blocks, totaling 32 experimental units. Monthly analysis of soil respiration measured by absorption of CO_2 with the KOH solution was carried out. With the exception of the soil from the Sousa microregion, all soils transported from the other microregions presented CO_2 values higher than those of the degraded area, demonstrating that the soil transposition technique is efficient for this variable.

RESUMO: *A pesquisa objetivou avaliar o potencial da técnica de transposição do solo na restauração de uma área degradada no Núcleo de Desertificação do Seridó, através da análise da respiração edáfica. Foram selecionadas sete áreas de diferentes microrregiões do semiárido da Paraíba, para a transposição do solo e alocação em uma área degradada. O delineamento foi em blocos casualizados, constando de oito tratamentos, um referente ao controle (área degradada) e os demais, aos solos transportados de áreas conservadas nas microrregiões, e de quatro blocos, perfazendo 32 unidades experimentais. Mensalmente foi realizada a análise da respiração do solo medida pela absorção do CO_2 com a solução KOH. Com exceção do solo da microrregião de Sousa, todos os solos transportados das demais microrregiões apresentaram valores de CO_2 superiores ao da área degradada, demonstrando que há eficiência da técnica de transposição do solo para esta variável.*

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1 Introduction

The irrational use of natural resources and irregular suppression of native vegetation for agriculture, pastureland, and for other purposes, have contributed to the reduction of native vegetation remnants which still exist in the Caatinga. These are the main factors that fragilize the natural environments and effectively reduce the capacity for natural regeneration, compromising the ecosystems' ecological function and contributing to environmental degradation, by making them vulnerable to the desertification process.

In areas where the aforementioned predatory activities have been extremely intensified and where the soils' productive capacity and vegetation resilience are low, incentives should be conducted to ecological restoration projects which aim to recover the integrity of devastated ecosystems.

Different strategies are used for the ecological reestablishment of an area that had its natural resources drained, considering the Caatinga as the most degraded Brazilian biome. Ecological restoration techniques are commonly used for this purpose, such as seedlings transplanting and seeds usage, in search of environmental balance, aiming at the original site's functional and structural processes, including the elimination of disturbance-causing sources, soil intervention, management and elimination of invasive species, and insertion of desired native species (Da Fonseca *et al.*, 2017).

Among the numerous restoration models used in Brazil, nucleation is today one of the most widespread (Reis *et al*., 2007). The nucleation model consists of the use of several techniques which, together, are facilitators in the natural succession process, because they modify the environmental conditions in degraded areas (Corbin; Holl, 2012).

The soil transposition technique is based on removing a soil's surface (the top layer) in an area of native forest, in different stages of forestry succession, plus the litterfall in desirable conditions for restoration purposes, for allocation in a degraded area, where natural restoration is sought through the existing propagules in the transported material. Thus, it is expected that, over time, these areas become nuclei of high species diversity, triggering the successional process (Martins, 2013).

However, several developed studies on this technique seek only to evaluate its potential through the seed bank contained in the transported soil, not considering analysis regarding the presence of organisms that assist in the organic matter decomposition (meso and macrofauna, mycorrhizal fungi, nitrifying bacteria and earthworms), important in the cycling of nutrients, also, in soil restructuring and fertilization (Reis *et al.*, 2010).

The analysis of soil quality indicators, such as edaphic respiration, becomes an important tool for understanding these organisms' performance in the soil system. For Silva et al (2010), the measurement of CO_2 release from the soil is crucial in the carbon cycle in ecosystems and, by quantifying the level of activity of soil microorganisms, is possible to understand the speed of organic matter decomposition and soil quality.

This respiration refers to the release of CO_2 into the atmosphere, or O_2 consumption, as a result of metabolic processes of living soil organisms. According to Araújo *et al* (2011), the produced CO_2 is the sum of all metabolic activities and has the purpose of monitoring ecosystems and disturbances in degraded areas. In addition, for Souto *et al* (2009), studies on edaphic respiration help to explain many processes that occur in the soil and are important for studies that seek ecological restoration through nucleation techniques, because it allows evaluating the real potential of soils used for the restoration of degraded areas.

In this way, based on the soil edaphic respiration analysis, the referred study aimed to evaluate the potential of the soil transposition technique in the restoration of a degraded area in the Desertification Center of the Seridó.

2 Material and methods

Experimental area

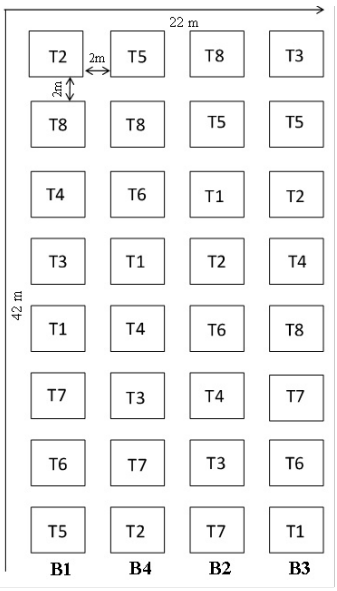
The research was developed at Fazenda Cachoeira de São Porfírio (06º 48' 32.1" S; 36º 57' 17.4" W), with an altitude of 271 m, in the town of Várzea, microregion of the Western Seridó, state of Paraíba. The climate, according to the Köppen classification, is BSh (semi-arid), reaching an average annual temperature of 25 ºC and average annual rainfall of less than 800 mm (Ferreira et al., 2014). The geographical relief is gently undulated, with a large presence of rocky outcrops, and the predominant soil is the Dystrophic Fluvic Neosoil. The vegetation is the hyperxerophilic caatinga, which settles on stony and erodible soils, with a sparse arboreal-arbustive aspect (Barroso, 2017).

The experiment implementation ground shows signs of intense anthropic activity relating to deforestation, extensive cattle ranching and cotton cultivation, which have depleted the soil and the natural regeneration capacity of the vegetation by chemicals over time, reducing the presence of plant species, except for the herbaceous species – panasco grass (*Aristida longifolia* H.B.K.) and white mallow (*Sida cordifolia* L.) – that predominate in the área.

Methodological Procedure

Seven areas were selected for soil transposition, all of them from microregions which include the semi-arid region of Paraíba. The areas of the selected microregions have similar characteristics regarding edaphic and climatic conditions, being enclosed in the droughts polygon, also similar in the phytophysiognomy and vegetation conservation.

The experimental arrangement was made in randomized blocks, consisting of eight treatments: one referring to the control, and the other seven treatments, to the transported soils; four repetitions allocated in plots of nine square meters, equidistant in two meters, occupying a total area of 924 m² (Figure 1).



Tratamentos:

1: Controle – área degradada;
2: MSO – microrregião do Seridó Ocidental Paraibano;
3: MPS – microrregião de Patos;
4: MSA – microrregião de Sousa;
5: MCR – microrregião de Catolé do Rocha;
6: MPO – microrregião de Piancó;
7: MIA – microrregião de Itaporanga;
8: MCS – microrregião de Cajazeiras.

Figure 1. Croquis/Sketch with the distribution of treatments in the experimental area, town of Várzea, Paraíba.
Figura 1. Croqui com a distribuição dos tratamentos na área experimental, município de Várzea, Paraíba.

The treatments are composed of soils from the following microregions: microregion of Western Seridó (MSO); microregion of Patos (MPS); microregion of Sousa (MSA); microregion of Catolé do Rocha (MCR); microregion of Piancó (MPO); microregion of Itaporanga (MIA) and microregion of Cajazeiras (MCS), also, a control treatment (experimental area). Table 1 indicates the results of the chemical and physical tests of the soil + litterfall collection areas.

In each micro-region, an area in advanced successional stage was selected. Subsequently, four 9-square meter plots were delimited for each area, so the entire topsoil surface was collected, as well as the litterfall inside, to a depth of 3.0 cm (Figure 2).

Afterward, the soils have been transported to the experimental area. Each plot was clean and the soil was completely removed in the depth of 3,0cm, so the microregions' collected soils could be relocated to the experimental area, according to the treatments distribution (Figure 3).

Microbial activity, measured by CO_2 capture by a KOH solution, subsequently titrated with HCl, according to the methodology described by Grisi (1978), was determined monthly and quantified in all 32 plots. A glass container with 10 ml of 0.5 N KOH solution was used. In each treatment, a container with the solution was left centrally in the middle of the plot, totaling 32 containers in the day (6:00 am to 6:00 pm), and the same amount in the night period (6:00 pm to 6:00 am), counting 24 hours of sampling.

The containers, after uncapped, were immediately covered with 26 cm high and 23.5 cm in diameter PVC buckets covering a soil area of 415.78 cm^2 to expose the containers only to the air coming from the soil. The buckets' edges were buried in the soil.

During the evaluation period, the CO_2 released into the system was captured by an alkaline solution of 0.5 N potassium hydroxide to establish an acid-base balance system, in which OH- and CO_3^{2-} ions predominate. After 12 hours, corresponding to the day or night period, the containers have been collected and immediately closed – in order to avoid gas exchange with the environment – and taken to the Laboratory of Mineral Plant Nutrition from the Forestry Engineering Academic Unit/CSTR/UFCG, for titration. In each evaluation, a container with the solution was kept hermetically sealed and used as a control (witness) which remained in the laboratory.

The quantification of CO_2 released from the soil was done by titration with a standard acid solution (HCl 0.1N) after precipitation of the carbonate ion present in the samples, including in the control samples. Two drops of phenolphthalein (1st turn) were used in the samples titration, and at the turning point, two drops of methyl orange (2nd turn) were added, until the titrated solution reached an orange color (Souto *et al.*, 2009). The mass of CO_2 released per unit area and time was obtained by considering the total mass released in the period of stay (length) in the area and the area of the bucket, using the following equation:

$$mCO2 = \frac{352 \times (\Delta Va - \Delta Vc) \times Nb \times Na}{3 \times P \times AB} \times 10^4$$

Considering:

$mCO2$ = CO_2 mass in $mg.m^{-2}.h^{-1}$;

ΔV_A = volume difference between the spent HCl in the first and second stage of the sample titration (mL);

ΔV_C = volume difference between the spent HCl in the first and second stage of the control titration (mL);

N_A = HCl concentration, in n-eq/L;

N_B = KOH concentration, in n-eq/L;

P = period of sample stay (length) on soil (hours);

AB = bucket covered área (cm^2).

Table 1. Phisical-chemical description of transported soils from each microregion, Paraíba state.
Tabela 1. Caracterização físico-química dos solos transportados de cada microrregião, do estado da Paraíba.

Variables	Unities	Treatments							
		Control	MSO	MPS	MSA	MCR	MPO	MIA	MCS
Ph	H_2O	5,8	6,6	6,7	6,3	6,6	7,0	6,6	6,6
P	mg dm^3	5	16	4	7	10	71	111	6
K	$cmol_c$ dm^3	0,27	0,22	0,36	0,34	0,56	0,50	0,78	0,44
Na		0,02	0,01	0,01	0,01	0,01	0,02	0,02	0,01
Ca^2		1,10	2,4	6,6	3,8	5,2	9,2	9,3	7,4
Mg^2		1,80	0,5	1,9	0,5	1,9	1,3	2,2	0,9
$H+Al^3$		4,80	1,25	2,87	3,2	3,47	0,0	5,48	3,76
SB		3,19	3,13	8,87	4,65	7,67	11,02	12,3	8,75
CTC		7,99	4,38	11,74	7,85	11,14	11,02	17,78	12,51
V	%	39	71	75	59	69	100	69	70
M.O	g kg	24,97	8,24	26,67	27,06	28,63	54,12	71,38	42,36
Sand		873	897	721	765	640	706	638	701
Silt		55	78	166	160	133	218	235	135
Clay		72	25	113	75	227	76	127	164
Ds	g cm^3	1,48	1,59	1,50	1,54	1,38	1,31	1,33	1,35
Textural Classes		Sandy	Sandy	(Franco) Sandy	White Sand	(Franco) Loamy-sandy	(Franco) Sandy	(Franco) Sandy	(Franco) Sandy

* P, K, Na: Mehlich1 Extractor; Al, Ca, Mg: Extractor KCl 1M; SB=Ca2+Mg2+K++Na+; H+ + Al3+: Calcium Acetate Extractor 0,5 M, pH 7,0; CTC=SB+H++Al+3; M.O.: Walkley-Black Moist Digestion; PST= Percentage of Exchangeble Sodium. Granulometry: Loam and Silt in Boyouccos densimeter, Sand by sieving; Apparent density: volumetric ring method; Real density: balloon with etanol method; MSO: microregion of the Western Seridó; MPS: microregion of Patos; MSA: microregion of Sousa; MCR: microregion of Catolé do Rocha; MPO: microregion of Piancó; MIA: microregion of Itaporanga and; MCS: microregion of Cajazeiras.
* P, K, Na: Extrator Mehlich1; Al, Ca, Mg: Extrator KCl 1M; SB=Ca2+Mg2+K++Na+; H+ + Al3+: Extrator Acetato de Cálcio 0,5 M, pH 7,0; CTC=SB+H++Al+3; M.O.: Digestão Úmida Walkley-Black; PST= Percentagem de Sódio Trocável. Granulometria: Argila e Silte pelo densímetro de Boyouccos, Areia por peneiramento; Densidade aparente: método do anel volumétrico; Densidade real: método do balão com etanol; MSO: microrregião do Seridó Ocidental; MPS: microrregião de Patos; MSA: microrregião de Sousa; MCR: microrregião de Catolé do Rocha; MPO: microrregião de Piancó; MIA: microrregião de Itaporanga e; MCS: microrregião de Cajazeiras.

Figure 2. Demonstration of the transposed soil collection. A) collection of soil + litterfall; B and C) overview of the soil + litterfall collection area and D) bagged material to be taken to the experimental area.
Figura 2. Demonstração da coleta dos solos transpostos. A) coleta do solo + serapilheira; B e C) vista geral da área de coleta de solo + serapilheira e D) material ensacado para ser levado à área experimental.

Figure 3. A) removal of vegetation and soil surface from the experimental plots; B and C) Bags distribution and D) Transported soils deposition in the plots.
Figura 3. A) retirada da vegetação e do solo superficial das parcelas experimentais; B e C) distribuição dos sacos e D) deposição dos solos transpostos nas parcelas.

Soil samples were monthly collected at a depth of 5.0 cm, using a container of known weight to determine the water content in the soil (Tedesco *et al.*, 1995). With the help of a digital thermometer, soil temperatures at the surface and 15.0 cm depth were measured each month. The monthly rainfall data were obtained from a rain gauge located near the experimental area.

The total rainfall during the experimental period was 568 mm. Rainfall was concentrated from December 2015 to May 2016, with the highest rainfall occurring in January and March: 280 and 108 mm, respectively, accounting for 68% of the total recorded.

Figure 1 illustrates the monthly averages of precipitation and temperature at the soil surface and at 15 cm depth, for the study period from October 2015 to September 2016.

Statistical analysis was performed using SAS Software 9.3 (2011), and the averages were compared using Tukey's test.

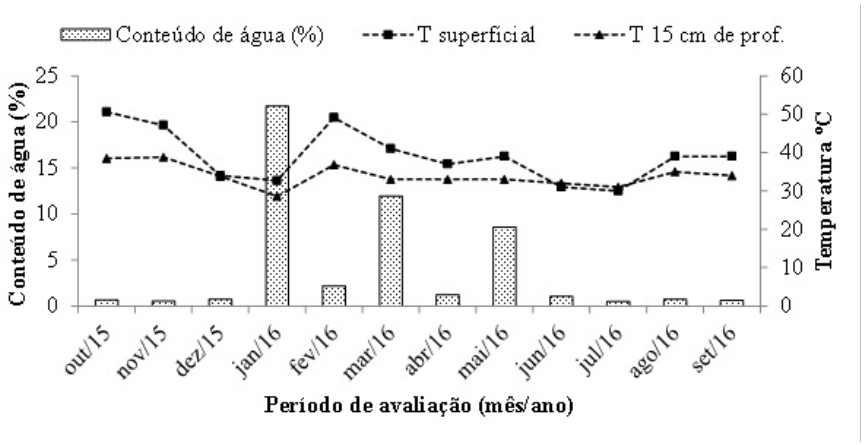


Figure 4. Monthly averages of water in the soil (%); Temperature at the soil surface and at 15 cm depth in the experimental area.
Figura 4. Médias mensais do conteúdo de água no solo (%) e da temperatura superficial do solo e a 15 cm de profundidade do solo na área experimental.

3 Results and Discussion

The soil respiration annual average rate in the day and night shifts was 121.5 and 160.7 mg $CO_2.m^{-2}.h^{-1}$, respectively. The CO_2 liberation in the night shift was higher than the day shift throughout the year, except for the months of November and August, where the values were statistically equal, as described in figure 5.

Several studies conducted in caatinga ecosystems demonstrate that the nighttime influences a higher release of CO_2 by the soil microbiota (Araújo *et al.*, 2009; Araújo *et al.*, 2011; Souto *et al.*, 2013; Correia *et al.*, 2015; Santos *et al.*, 2016).

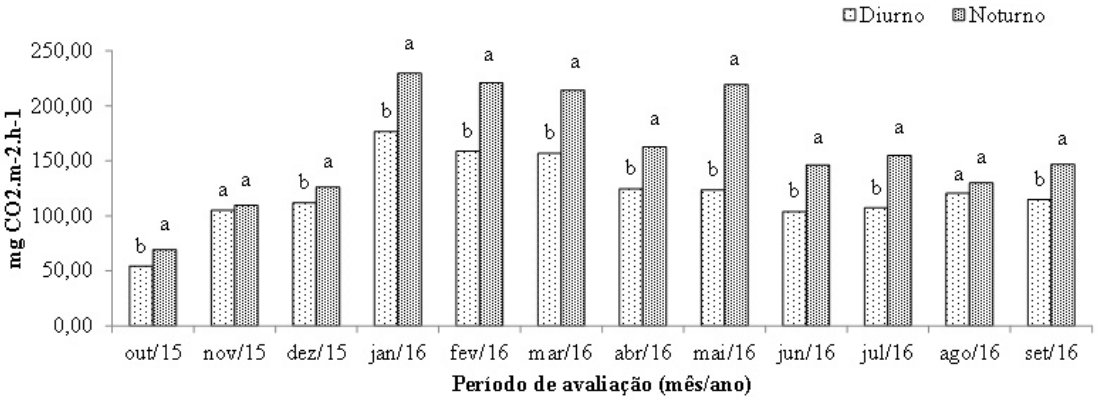


Figure 5. Monthly average values of CO_2 ($mg.m^{-2}.h^{-1}$) released in the day and night shifts, from October 2015 to September 2016. Equal letters in the columns in each month do not diverge by Tukey's test at 5%.

Figura 5. Valores médios mensais de CO_2 ($mg.m^{-2}.h^{-1}$) liberados nos turnos diurno e noturno, de outubro de 2015 a setembro de 2016. Letras iguais nas colunas, em cada mês, não diferem entre si pelo teste de Tukey a 5 %.

Souto *et al.* (2013) attribute the higher production of CO_2 in the nocturnal period when compared to the diurnal period, due to the lower thermal oscillations, favoring better conditions for the soil microorganisms activities. According to Brady & Weil (2013), microbial activity sensitively responds to soil temperature and is higher when temperatures are, in general, between 20 and 40º C. Souto *et al.* (2009) verified inhibition in CO_2 production when temperatures reached values near 50º C. Fang & Moncrieff (2001) observed that soil respiration was intensified when soil temperature was up to 32 ºC with an ambient temperature near 40 ºC, while at higher temperatures, soil respiration was reduced.

All treatments recorded the highest soil respiration rates in the months with the highest rainfall (Table 2). The treatments referring to the soils of Western Seridó microregion (MSO), Patos microregion (MPS) and Piancó microregion (MPO) recorded the highest rates of CO_2 released in the month of January, with 262.9, 216.7 and 247.8 mg $CO_2.m^{-2}.h^{-1}$, respectively. The control treatment and from the microregions of Sousa (MSA), Catolé do Rocha (MCR), Itaporanga (MIA) and Cajazeiras (MCS) recorded, in February 178.6, 179.5, 211.1, 180.4 and 183.9 mg CO_2. $m^{-2}.h^{-1}$, respectively. The MCR and MCS treatments also recorded, in May, a respiration rate statistically equal to February.

The highest average CO_2 release rate was observed in the month of January, with 203.1 mg $CO_2.m^{-2}.h^{-1}$. The lowest average CO_2 release rate was recorded in October, with 61.7 mg $CO_2.m^{-2}.h^{-1}$ This increase in CO_2 released in the rainy season can be attributed to the superior water content in the soil (Figure 2), which provided substantial growth of the herbaceous stratum in the treatments, allowing for mild temperatures at the soil surface and, consequently, higher microorganisms activity in the soil surface.

Brady & Weil (2013) corroborate this information and explain that higher soil water concentration and lower temperatures enable faster growth of the vegetation cover, providing better conditions for the development of microbial biomass, also favoring a higher release of CO_2 by increasing the microorganisms metabolic activities. Regarding the water content in the soil, these effects are mainly derived from the interaction between water content and soil pore space. According to Smart & Peñuelas (2005), elevations in soil water content, with the incidence of rainfall events, facilitate the expulsion of significant amounts of CO_2 from within the soil, due to water infiltration into the pore spaces.

On the other hand, the decrease in CO_2 release observed in the months from June to November is probably related to the dry season, when soils were dry, with little herbaceous cover and high temperatures on the soil surface, effectively reducing the activity of edaphic organisms. Han *et al.* (2015) observed a positive correlation with the amount of litterfall and high CO_2 release values. The results also showed that with the reduction of litterfall, the soil moisture decreases and, consequently, decreases the microbial activity in the soil.

Table 1. Phisical-chemical description of transported soils from each microregion, Paraíba state.
Tabela 1. Caracterização físico-química dos solos transportados de cada microrregião, do estado da Paraíba.

Month/year	Soil respiration (mg $CO_2.m^{-2}.h^{-1}$)							
	Treatments							
	Control	MSO	MPS	MSA	MCR	MPO	MIA	MCS
Oct/2015	63,39cA	62,33eA	62,48fA	49,89eA	68,09cA	53,84eA	54,44eA	79,47eA
Nov/2015	117,53bAB	107,52dAB	115,41eAB	87,50deB	107,22bcAB	85,23deB	107,07dAB	130,73 cdA
Dec/2015	133,61bAB	113,13dAB	124,66deAB	97,21 cdB	114,50bAB	102,97cdAB	126,33dAB	140,28bcdA
Jan/2016	151,05abD	262,97aA	216,71aBC	167,27abD	230,21aAB	247,80aAB	171,22abD	178,04 abCD
Feb/2016	178,65aA	206,10bA	185,93bcA	179,56aA	211,10aA	192,60bA	180,47aA	183,96aA
Mar/2016	154,08abC	223,39abA	190,48abBC	162,57abC	209,58aA	208,98abAB	165,15abcC	169,70abcBC
Apr/2016	123,45bB	149,08cdAB	142,10deAB	169,40abA	141,34bAB	136,64cAB	142,71bcAB	143,92bcdAB
May/2016	158,78abBC	188,96bcAB	159,99cdBC	166,82abBC	205,04aA	144,68cC	162,27abcBC	184,87aAB
Jun/2016	132,39bA	113,89dA	127,24deA	128,15cdA	107,67bcA	121,17cdA	134,36bcdA	135,12bcdA
Jul/2016	138,16bA	111,31dA	145,28deA	135,12bcA	110,86bcA	140,43cA	144,22bcA	123,90dA
Aug/2016	132,85bA	115,26dA	125,27deA	139,22abcA	114,65bA	103,43cdA	138,16bcdA	133,00cdA
Sep/2016	149,83abA	114,50dA	135,88deA	137,85bcA	114,95bA	122,38cdA	141,64bcdA	129,06cdA
Median/Average	136,15	147,37	144,29	135,05	144,60	138,35	139,00	144,34

Averages followed by the same letter, lowercase in the column and uppercase in the row, do not differ by the Tukey test at 5% probability.
Médias seguidas da mesma letra, minúscula na coluna e maiúscula na linha, não diferem entre si pelo teste de Tukey a 5% de probabilidade.

The microorganisms' capacity to biodegrade organic matter decreases when it is either wet or dry, which may also be one of the reasons why the CO_2 values were lower in the drier months. For Macleod *et al.* (2008), the biodegradation of organic matter by microorganisms is more efficient depending on how humid the organic matter is. Caatinga areas conducted studies that aim to analyze soil respiration shows that low water content and high soil temperatures are limiting factors for superior microbial activity (Souto *et al.*, 2013; Correia *et al.*, 2015).

There was no statistical difference in the values of CO_2 released from the soil for the months of February, June, July, August, September, and October (Table 2). However, in the months of November and December, the highest values were observed in the MCS treatment, with 130.7 and 140.2 mg $CO_2.m^{-2}.h^{-1}$ respectively. In January, the MSO treatment was the one that presented the highest CO_2 release, 262.9 mg $CO_2.m^{-2}.h^{-1}$. Again in March, the MSO treatment showed the highest release, 223.3 mg $CO_2.m^{-2}.h^{-1}$, followed by the MCR treatment, which showed 209.5 mg $CO_2.m^{-2}.h^{-1}$. In April, the MSA treatment was the one that released the highest CO_2 concentration: 169.4 mg $CO_2.m^{-2}.h^{-1}$. In May the MCR treatment presented the highest value: 205.0 mg $CO_2.m^{-2}.h^{-1}$ (Table 2).

In general, the data show that the average annual soil respiration rate was highest in the MSO treatment, with 147.3 mg $CO_2.m^{-2}.h^{-1}$, followed by the MCR, MCS and MPS treatments, which had an average value of 144 mg $CO_2.m^{-2}.h^{-1}$. The lowest respiration rate was observed in the MSA and control treatments, both of which registered an average value of 136 mg $CO_2.m^{-2}.h^{-1}$ (Table 2).

Excepting the MSA treatment, all the others treatments showed higher CO_2 released levels than the control treatment (degraded area), demonstrating that the transposed soils from the various microregions have desirable characteristics for ecological restoration of the degraded area where the experiment was installed, using the soil transposition technique. For Martins (2013), the soil transposition, in addition to providing the seed bank, works as a source of organic matter, nutrients, microorganisms, micro and mesofauna present in the soil surface and in the litterfall, which will assist in the degraded soil physical-chemical recovery, and, as a consequence, the area revegetation.

Therefore, the increased production of CO_2 by the soils allocated in the degraded area is probably due to the greater presence of edaphic microorganisms coming from them. And the low respiratory activity observed in the control treatment, compared to the other treatments, might be a function of a lower diversity of the microbial population, given the degradation characteristics of this area.

Valentini *et al.* (2015), aiming to assess CO_2 production in a regular forest and a degraded area, observed that the average annual soil respiration in the forest was higher than in the degraded area: 130.6 and 86.7 mg $CO_2.m^{-2}.h^{-1}$, respectively. Correia *et al* (2015), analyzing four areas in different regenerative stages in the semi-arid region of Paraiba, observed that the more conserved an ecosystem was, the higher the CO_2 release. Yan *et al.* (2006), evaluating soil respiration in three forests at different successional stages in the Dinghushan reserve in southern China, found higher CO_2 values in the forest community with more advanced succession. Assis Junior *et al* (2003) verified higher microbial activity in native forest (559.3 mg $CO_2.m^{-2}.h^{-1}$) and agroforestry systems (538.2 mg $CO_2.m^{-2}.h^{-1}$) than in deforested areas (165.1 mg $CO_2.m^{-2}.h^{-1}$).

The low base saturation values and the acid pH of the control treatment differed from the other treatments and this may have been another factor contributing to lower CO_2 release when compared to the CO_2 released in the other areas, since dystrophic soils have low fertility, and considering that acid pH decreases the availability of cationic nutrients in the soil solution, which are essential for the development of the metabolism of soil microorganisms. According to Bittar *et al.* (2013), soil microbial activity is regulated by several abiotic factors, such as pH and soil nutrients.

The linear increase in soil CO_2 efflux is observed over a pH range between 4.0 to 8.0, with a potential decline in CO_2 emission at pH above 9.0 (Reth *et al.*, 2005). As reported by Freitas-Vinhal *et al.* (2012), the content of available nutrients such as P, K, and Mg are important factors that regulate microbial activity and soil dynamics. The same authors observed an increase in microbial activity with the addition of P to the soil.

Observing the physical properties referring to the MSO treatment soil (Table 1), it can be seen that there is a high sand content in the granulometry of this soil when compared to the other treatments. Presumably, the high sand content may have facilitated the gas exchange between the soil and atmosphere, which increased the release of CO_2 from the soil, especially when there was a bigger water volume in the soil. In this study, as already observed, all treatments demonstrated higher CO_2 production in rainy seasons, that is, with higher water content in the soil. Besides, the MSO treatment was the one that showed the highest values in this period.

A study by Bauer *et al.* (2006) revealed that CO_2 efflux showed a negative correlation with soil density and clay fractions. However, sand fractions were positively correlated with CO_2 efflux. The same authors found, in sandy loam soil, that density and texture were related to CO_2 efflux when the water content was relatively high.

4 Conclusion

Edaphic respiration in most of the transposed soils is higher than in the degraded area, demonstrating that there is na advantage of the soil transposition technique when the purpose is to restructure degraded soils.

Edaphic respiration is a bioindicator to quantify the degraded areas' recovery responses. Also, it was effective in this study's analysis when comparing soils from different preserved areas in a degraded one.

The highest production of CO_2 occurs during the night and rainy seasons, favored by lower temperatures and higher water content in the soil.

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