

Dual Roles of Soils on Landfill Leachate Treatment and Their Soils Carbon Sequestration

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Abstract

This study aims to verify the hypothesis on the dual roles of soils on landfill leachate (LFL) treatment and their soil carbon sequestration (SCS), blank subtraction technique in a plastic bottle model experiment that had been carried out. Four soils, a Tropaquept soil (S_1) and 3 artificial soils obtained by 25, 50 and 75% sand dilution to be S_2 , S_3 and S_4 , respectively. The LFL and water in two sets of the 4 saturated with the two liquids; separately, were investigated into 4 replicated at 1, 2, 4, 8 and 16 weeks of prolonged aging periods. The ranges of the soil active Fe(III) and the LFL loads studied were 5,200-1,300 ppmFe and 192.0-76.8 ppmC, respectively. The important discoveries were that the (a) Complete treatment of the LFL-C applied in all soils were obtained since 4 weeks, (b) Transformation of the CO_2 -C liberated to carbonate salts, evidenced by strong effervescence during soil Fe(II)-Fe extraction by 1 N HCl were observed and the (c) Transformation of the LFL-C to the less decomposable soil organic carbon, as indicated by positive relationship between the remaining Untreated Carbon (UT-C) and Fe(II)-Fe remained and the decrease of CO_2 -C liberation in treated LFL-C soils. The application of this dual roles on the LFL management should be a sound global warming mitigation recommendation.

Keywords: Landfill Leachate Treatment; Carbon Sequestration; Soil Organic Carbon Transformation

1. Introduction

Climate change created by global warming that have arisen from the excess emission of CO_2 , the most important greenhouse gas, from industries and modern human activities might be the most important current global environmental problems (IPCC, 2007). NOAA (2015) reported that during 1990-2014 the atmospheric CO_2 was increased by 36% as that was tremendously increased at the end of this 21 century, showing that global warming temperatures has will increase with the range of 1.8-4.0°C. Numerous Intergovernmental

Summits and Conferences had been dedicated to this problem since the Kyoto Protocol in 1988 the recent Paris Summit in 2015 and the XXI Climate Change Conference. With more intensive researches being called for governing the two main approaches of (a) reduction of anthropogenic emission of CO_2 and (b) the intensification of CO_2 absorption (IPCC, 2013; Usoltsev *et al.*, 2014 and Vachnadze *et al.*, 2016). Present researches in this both approaches, are taking more intensively, there are still going on processes to the solutions (Yaniria *et al.*, 2013; Fan *et al.*, 2015; Paola *et al.*, 2016; and Xinhui *et al.*, 2017).

The Landfill leachate (LFL) experiment is in the first category in support of the reduction of anthropogenic emission, which play an important environmental role by dual mitigations as (a) organic wastewater treatment, for aquatic ecosystem conservation, and (b) on the Carbon sequestration into soil organic matter (SOM) for the global warming problem. Though many recent LFL researches are still being carried out (Guodong *et al.*, 2015; Fatma and Kamel, 2016; Naveen *et al.*, 2016 and Hua *et al.*, 2017), the dual approaches as in this hypothesis on the dual roles of soils on landfill leachate (LFL) treatment and their soil carbon sequestration (SCS), blank subtraction technique in a plastic bottle model experiment that had been carried out. The Successful utilization of soil facultative aerobes in initially aerobic soil for the community wastewater treatment by Alternate Flooding and Drying Soils in Plant had been reported Intaravicha *et al.*, 2013). The Prolonged aging might have created some transformation of the soluble wastewater to more stable organic compounds within the anaerobic soils. Not only the physical (capillary force) and microbiological (anaerobic respiration, AAR) mechanisms but also such physic-chemical (transformation) one, as soil aggregate formation (Vogel *et al.*, 2014 and Wiesmeier *et al.*, 2014) and humification at least by 2 theories: (a.) the sugar-amine and (b.) polyphenol amine proposed by Stevenson (1982), Since aminization must be performed prior to ammonification, the anaerobic process of Organic Nitrogen (O.N.) mineralization (Alexander, 1961) and phenols occurrence in LFL (Huo *et al.*, 2009) had already been reported, should be involved for this hypothesis elucidation. The soil anaerobes in the initially aerobic soil having high enough active Fe(III) at saturation with the LFL might be more beneficial by these reasons: (a) No mosquitoes, disturbing insects and bad smell problems in standing flooding water longer than a week, (b) Maximum storage within the soil pores at initial state was possible and (c) AAR could be going on as in submerged paddy lands, though at the lower rate. To minimize errors from the analytical method used by some possible

interferences, Blank Subtraction Technique (BST) successfully used in quantitative chemical analysis in set by subtraction of data in the treated set (TS) by that of the blank set (BS), was introduced. To verify the dual roles of the soil, this experiment was investigated.

2. Materials and Method

Soil particles, Electrical Conductivity and pH of a Tropaquepts (S_1) by Jackson (1958); SOM by Walkley and Black (1934); O.N. (ppm) by $SOM \times 0.05 \times 10,000$; amorphous Mn (MnIV) by Asami and Kumada (1959); free Fe(III)-Fe by Mehra and Jackson (1960) and active Fe(III)-Fe by Mckeague and Day (1966) were used for this soil characterization. Some important properties of the 3 artificial soils were calculated from the % sand added. Chemical Oxygen Demand (COD), pH, EC, Salinity and Chlorine Cl^- by the Standard Method of Water and Wastewater (APHA, 2005) were used for the LFL characteristics identification. At equilibrium, the equivalent amounts of O_2-O , Organic Carbon (OC) and Fe(II)-Fe should be identical (Ewing *et al.*, 1962). The equivalent weights of both Oxygen (O) and OC will be at $16/2=8$ and $12/4=3$ respectively. The calculated OC was, therefore, equal to $COD \times 3/8$ mg/L or $\mu g C/mL$. Similar to that of the OC that was calculated from the measured COD, the CO_2-C emission should also be calculated unbiasedly from the Fe(II)-Fe remained, using 55.85 be the Fe equivalent weight also regarded as atomic mass number (amu), since Ponnampurna (1965) reported that only one electron is accepted in the soil reduction process. The CO_2-C produced and remained was, therefore, calculate by the Fe(II) value $\times 3/55.85$ ppmC.

A Tropaquept (S_1) and 3 more artificial soils produced by dilution the S_1 with acid treated sand at 25% (S_2) 50% (S_3) and 75% (S_4) were used in this study. The Flow rates of the LFL: 5, 4, 3 and 2 mL 10 g soil which were very close to the saturation points of the 4 soils samples (for S_1 , S_2 , S_3 and S_4 respectively). The treatment and possible transformation of the saturated soils after aging for 1, 2, 4, 8 and 16 weeks had been investigated in this model

Table 1. The Tropaquept (S₁) soil properties and that of the LFL

S ₁ soil properties		The LFL properties	
Indicator	Value	Indicator	Value
Clay (%)	66	Biological Oxygen Demand (mg O ₂ /L)	180
Silt (%)	20	Chemical Oxygen Demand (mg O ₂ /L)	1,024
Sand (%)	14	Organic Carbon (mg C/L)	5.59:1
pH	5.2	C: N	0.02
Electrical Conductivity (mS/cm)	0.47	Fe ⁺⁺ (mg/L)	8.9
Organic Matter (%)	1.74	pH	25.3
Organic Carbon (ppm)	10,093	Temperature. (°C)	3.51
Active O.C.(ASOC, ppm)	7,771	Dissolve Oxygen (mg O ₂ /L)	>1,999
C: N	11.6: 1	Total Dissolve Soils (mg/L)	16.8
Active C:N ratio	8.93: 1	Electrical Conductivity (mS/cm)	9.9
Free Fe(III)-Fe (ppm)	18,637	Salinity. (ppt)	4,490
Active Fe(III)-Fe (ppm)	5,200	Cl ⁻ (mg/L)	
Active Mn(IV)-Mn (ppm)	155		

experiment. The saturation incubation was aimed for the future recommended technology that is developed as the maximum storage of the wastewater, to be treated and the Soil Organic Matter (SOM) formation, simulation. The blank sets used tap water instead of the LFL, that is the 2 kinds of water, the LFL and the fresh tap water. With 10 grams each of the 4 aerobic soils and 4 rates of each of the water samples : 5, 4, 3 and 2 mL of S₁, S₂, S₃ and S₄, respectively in a 120 mL polyethylene (P.E.) bottle, with 8 replications for 2 sets of 4 for water and 1 N HCl extractions. The total experimental units prepared were, therefore, place into the 2×4×5×8 or 320 bottles which were incubated indoor at room temperature. During the sampling day (1, 2, 4, 8 and 16 weeks of each aging duration), the untreated OC (UT-C) was determined indirectly from COD × 3/8, after 30 mL H₂O adding, 30 min horizontally shaking and 10 min 13,000 rpm centrifuging. For the Fe(II)-Fe, the produces and the remained were determined colorimetrically by the o-phenanthroline method (Herrera *et al.*, 1989), after 30 mL of 1 N HCl, as 30 min horizontally shaking and 10 min 13,000 rpm centrifuging of the extraction procedure recommended (Amari and Mengel, 2006), respectively. The Simple linear relationship (Gomez and Gomez, 1984) of the possible relevant C indicators (Y_i) and

aging periods (X_j) and the soil active Fe(III) were also studied. If the correlation coefficient (r) were significant or higher the intercept (a) and slope (b) would also be reported. If the relationship was not significant the mean (\bar{x}) and standard deviation (SD) will be presented.

3. Results and Discussion

3.1 Properties of the soil and LFL

Table 1 presented the important properties of both the S₁ and the LFL. This S₁ is a strong acid with heavy clay soil but rich in nutrients for microbial activities. The LFL were very rich in OC but might pose microbial activity problems owing to its strong alkalinity and salinity. With very high concentrations of Cl⁻ must be removed by AgNO₃ solution before the COD determination since Cl⁻ will also react with the K₂Cr₂O₇ used in this method.

3.2 Change of the UT-C produced and remained

Since all of treated C is not directly changed to the soil organic matter, the untreated C should be the first indicator of interest. The change of this UT-C is after prolonged saturation period from 16 weeks or about 4 months was reported (Table 2).

Table 2a (TS) and 2b (BS) were directly determined but Table 2c was obtained by the

Table 2. Change of UT-C after aging for 16 weeks of saturation

Soil No.	Saturation duration (weeks)					r	a	b
	1	2	4	8	16			
a. From soil + LFL (µg C/g soil)								
#1	33.6	33.6	16.8	16.8	16.8	-0.703**	30.1	-1.061
#2	32.6	32.4	16.6	15.6	11.9	-0.817**	30.0	-1.327
#3	31.7	22.7	17.0	15.9	15.7	-0.691*	25.4	-0.774
#4	30.7	20.4	15.4	15.4	15.4	-0.620*	23.6	-0.676
b. From soil only (µg C/g soil)								
#1	0	16.8	32.6	17.1	16.6	0.169 ^{ns}	\bar{x} = 16.6	SD=11.5
#2	0	16.2	32.6	15.7	16.2	0.169 ^{ns}	\bar{x} = 16.1	SD=11.5
#3	0	15.6	31.7	15.7	15.7	0.170 ^{ns}	\bar{x} = 15.7	SD=11.2
#4	0	15.4	30.7	15.4	15.2	0.168 ^{ns}	\bar{x} = 15.3	SD=10.9
c. Treatment efficiency (%) for the LFL only								
#1	82.5	91.3	108.2	100.2	99.9	0.454 ^{ns}	\bar{x} = 96.4	SD=9.8
#2	78.8	89.5	110.4	100.1	102.8	0.529 ^{ns}	\bar{x} = 96.3	SD=12.3
#3	72.5	93.8	112.8	99.8	100.0	0.391 ^{ns}	\bar{x} = 95.8	SD=14.7
#4	60.0	93.5	119.9	100.0	99.7	0.356 ^{ns}	\bar{x} = 94.6	SD=21.8

r = The correlation coefficient, where “a” is the (y)-intercept and “b” is the slope

* = The confidence level at 95%

** = The confidence level at 99%

ns = No significant different

\bar{x} = Mean or average

SD = Standard deviation

BST which would be treatment efficiency (TE) of the pure effect of Land Filled Leachate Organic Carbon (LFLOCTE) by: LFLOCTE (%) = 100(LFLOC load – UT-C in TS – UT-C in BS)/ LFLOC load. Since the LFL-C input was 384 µg/mL, applications of 5, 4, 3 and 2 mL per 10 g soil for the respective soils, the LFLOC load will be $5 \times 384/10$, $4 \times 384/10$, $3 \times 384/10$ and $2 \times 384/10$ or 192, 153.6, 115.2 and 76.8 µg C/g soil for the S₁, S₂, S₃ and S₄ respectively. It was clearly seen from Table 2a, that negative trends of change of UT-C (Y, ppmC) in all soils after prolonging saturation periods (X, weeks), in the TS having r values: -0.703**, -0.817**, -0.691** and -0.620** and the b values : -1.061, -1.327, -0.777 and -0.676 UT-C/wk for S₁, S₂, S₃ and S₄ respectively.

Table 2b and 2c did not show clear trends of changes of UT-C throughout 16 weeks of aging Blank Set, though the positive trends of changes of UT-C were observed in the first 4 weeks. In the BS, the variation of most UT-C were in the ranges ($\bar{x} \pm SD$): 16.6 ± 11.5 , 16.1 ± 11.5 , 15.7 ± 11.2 and 15.3 ± 10.9 mg/L C in S₁, S₂, S₃ and S₄, respectively. The decrease of the mean values (Y, ppmC/wk) within the 4 soils and that of the soil active Fe(III) (X, mg/L Fe)

was highly significantly correlated (r = 0.998**) which could be predicted by equation (1)

$$Y \text{ (mg/L C)} = 14.85 + 3.31 \times 10^{-4} X \text{ (mg/L Fe)} \quad (1)$$

By the BST, the variation of most LFLOCTE (%) ($\bar{x} \pm SD$) in the ranges : 96.4 ± 9.8 , 96.3 ± 12.3 , 96.8 ± 14.7 and 94.6 ± 21.8 %. Correlation study between the mean values of the LFLOCTE (%. Y) and active Fe(III) (mg/L Fe, X) showed highly significant (r = 0.922**), which could be predicted by the equation (2)

$$Y \text{ (%) } = 94.3 + 4.54 \times 10^{-4} X \text{ (mg/L Fe)} \quad (2)$$

The Stimulation of LFLOCTE (%) by soil active Fe(III) which is important Electron acceptor (EA) were clearly discerned by this two equations

Table 2 also illustrated clearly the successes of introduction of the BST for the pure effect of the LFLOCTE (%), that is 60% - 82.5% of LFL-C were treated, since the 1st week, and complete treatment (100% or more) were reached since 4 weeks aging. The OC used as Electron Donor (ED) should come from such non humus fractions (NHF) as weed residues only of the

BS. Undetectable UT-C in the blank at week 1, might be due to the complete absorption of the acidic metabolites produced (Alexander, 1961) by the soil clay and/ or in soil micro pores by capillary forces. The increase in UT-C in the BS (Table 2b) during the first 4 weeks should come from the increase in the decomposers cell proliferation but at much lower rate than that of the TS. The OC in the TS (Table 2a) should be used for the cell proliferation after obtaining kinetic energy from AAR, having OC from the Non Humus Formation (NHF) of the native soil be ED, the soil active Mn(IV)-Mn and active Fe(III)-Fe, after the former was used up, be Electrical Conductivity (EC). The neutralization of the acid soils rapidly, with the alkaline LFL within the 1st week, stimulated much more cell proliferation in the TS, owing to its narrower C:N ratio similarly to that of the manuring

legumes indicated by the peak UT-C obtained in all soils since the week 1 (Table 2a).

The negative trends of this UT-C changes are shown in Table 2a since 2 weeks aging, should not come from no microbial activities but would rather come from transformation of the decomposable OC as ED source to OC as nutrient source for protein production of new cell and/or to be cementing agent for the soil aggregate granulation (Vogel *et al.*, 2014; Wiesmeier *et al.*, 2014) and/or organic compounds with could combine with amines, polymerized and condensed to humus (Stevenson, 1982). The microbial activities in the anaerobic condition was still going on indicated by the UT-C occurrence and the increase in LFLOCTE (%) reaching the complete treatment within 4 weeks.

Table 3. Change of Fe(II)-Fe after aging for 16 weeks of saturation

Soil No.	Saturation duration (weeks)					r	a	b
	1	2	4	8	16			
a. From soil + LFL (µg Fe/g soil)								
#1	2,504	2,382	1,674	1,647	803	-0.952**	2,463	-106.7
#2	1,726	1,617	1,280	988	566	-0.974**	1,704	-75.6
#3	1,100	841	847	584	430	-0.924**	1,004	-39.3
#4	418	412	316	291	281	-0.815**	399	-8.88
b. From soil only (µg Fe/g soil)								
#1	2,563	1,971	1,777	1,621	881	-0.940**	2,344	-93.8
#2	1,567	1,123	997	976	584	-0.880**	1,365	-50.9
#3	874	623	530	418	378	-0.802**	726	-26.0
#4	452	311	293	290	248	-0.709**	375	-9.06

r = The correlation coefficient, where “a” is the (y)-intercept and “b” is the slope
 ** = The confidence level at 99%
 ns = No significant different

Table 4. Change of CO₂-C after aging for 16 weeks of saturation

No.	Saturation duration (weeks)					r	a	b
	1	2	4	8	16			
a. From soil + LFL (µg C/g soil)								
#1	134.5	128.0	88.9	88.5	43.1	-0.952**	132.3	-5.73
#2	92.7	86.9	68.8	53.1	30.4	-0.974**	91.6	-4.06
#3	59.1	45.2	45.5	31.4	23.1	-0.924**	53.9	-2.11
#4	22.5	22.1	17.0	15.6	15.1	-0.815**	21.4	-0.48
b. From soil only (µg C/g soil)								
#1	137.7	105.9	95.5	87.1	47.3	-0.940**	125.9	-5.04
#2	84.2	60.3	53.6	52.4	31.4	-0.880**	73.3	-2.74
#3	47.0	33.5	28.5	22.5	20.3	-0.802**	39.0	-1.40
#4	24.3	16.7	15.7	15.6	13.3	-0.709**	20.1	-0.49

r = The correlation coefficient, where “a” is the (y)-intercept and “b” is the slope
 ** = The confidence level at 99%

3.3 Change of the Fe(II)-Fe produced and remained

The Flooding and/or saturation of aerobic soils will rapidly change microbial aerobic respiration (AR) of the facultative aerobes to anaerobic one, owing to depletion of O₂ entrapped in the soil; using NO₃⁻, MnO₂, Fe₂O₃ or Fe(OH)₃ in the soils to be EA (Ponnamperuma, 1965 and 1976). Because of its very high abundance, Fe(III)-Fe is the most important electron acceptor and very good indicator of the glucose waste water treatment potential of Thai soils (Intaravicha *et al.*, 2013). The production of Fe(II)-Fe in the 4 soils with and without LFL anaerobically incubated at saturation condition for the 16 weeks aging period were present in Table 3.

Highly significantly negative trends of change of the Fe(II)-Fe produced and remained observed were: (a) In the TS, the r values were -0.952**, -0.974**, -0.924** and -0.815** and -106.7, -75.6, -39.3 and -8.88 mg/L Fe/week of the b values in the 4 respective soils and (b) In the BS, the r values were -0.940**, -0.880**, -0.802** and -0.709** and the b values were -93.8, -50.9, -26.0 and -9.06 ppmFe/week in the S₁, S₂, S₃ and S₄ respectively. The role of active Fe(III) (X, ppmFe) on the b values (Y, ppmFe/week) of both the TS (Table 3a) and BS (Table 3b) could also be calculated and presented by these two equations (eq. 3 and 4)

$$TSY = 24.82 - 0.025X \quad (r = -0.999**) \quad (3)$$

$$BSY = 24.82 - 0.021X \quad (r = -0.978**) \quad (4)$$

This clearly indicated that the more active Fe(III) the more Fe(II)-Fe produced and remained. Lower S₁ Fe(III)-Fe reduction in the TS than the BS in the 1 week aging might come from retardation of active Fe(III)-Fe reduction by the active Mn(IV)-Mn which has higher electron acceptor power (Ponnamperuma, 1965). The 155 ppm Mn(IV)-Mn in the S₁ will be equivalent to 5.64 µMn(IV)-Mn which should be about 315 mg/L Fe(II)-Fe which was much higher than the -59 mg/L Fe(II), since equivalent weight of the Mn is 27.47, owing to each molecule of Mn(IV) will accept

2 electrons in the anaerobic reduction process (Ponnamperuma, 1965). The oxidation of the Fe(II)-Fe to Fe(III)-Fe was not possible in this saturation system of incubation as some of the Fe(II) remained might be involved in the soil aggregate formation having the Fe(II) chelate be cementing agent (Jastrow *et al.*, 2007; Schmidt *et al.*, 2011) and/or incorporation into organic molecules of metabolites having catalytic activity (Price *et al.*, 1972) in the polymerization and condensation after combination with amino compounds of the organic metabolites in humus formation theory (Stevenson, 1982). The remaining Fe(II)-Fe in the TS after aging might come from reduction of the active Fe(III)-Fe coincidentally with the Fe(II)-Fe transference and/or transformation to unextractable Fe(II)-Fe extracted by the 1 N HCl. This new formation of the Fe(II)-Fe should, therefore, related to the CO₂-C emitted by the AAR, using O.C. newly diffused from the macropores to the micropores for the ED sources having the soils active Fe(III) be EA.

3.4 Anaerobic respiration changes in the saturated soils

Since Fe(III)-Fe is the most important EA soil pool of anaerobes previously reviewed, the Fe(II)-Fe produced and remained in Table 3 should be the best indicator of the AAR. At equilibrium equivalent of the Fe(II)-Fe and the CO₂ liberation should be, therefore, identical (Ewing *et al.*, 1962). Equivalent weight of CO₂-C used were 12/4 = 3 while that of the Fe(III)-Fe, according to Ponnamperuma (1965), electron used in the soil reduction is only 1, the Fe(II)-Fe equivalent weight should, therefore, be 55.85/1 = 55.85. Estimation of the CO₂-C liberation in the TS and BS are presented in Table 4

The minimization of the CO₂-C (Y, ppmC) liberated were clearly discerned, as the aging periods prolonged (X, weeks) in all soils by: (a) In the TS: the r values were -0.952**, -0.974**, -0.924** and -0.815**; the a values were 132.3, 91.6, 53.9 and 21.4 ppmC and the b values were -5.73, -4.06, -2.11 and -0.48 ppmC/wk; (b) For the BS: the r values were -0.940**, -0.880**, -0.802** and -0.709**; the a values were 125.9, 73.3, 39.0 and 20.1 ppmC and the b values were

-5.04, -2.74, -1.40 and -0.49 ppmC/wk for the respective 4 soils. Very high CO₂-C liberated in the first 2 weeks of aging might not be emitted, since very strong effervescence during the Fe(II)-Fe extraction by 1 N HCl. Most of the CO₂-C emitted and consequently might be rapidly transformed to H₂CO₃ and carbonate salts of Fe²⁺, Ca²⁺, Mg²⁺ and Na⁺ and stored in the soils.

Since information in the TS are the most practical knowledge for the future LFL treatment technology development, some important discoveries should also be focused and the role of active Fe(III) must not be overlooked. From table 4a (TS) CO₂-C liberated disappearances, which might be accepted as the complete humus formation period (HFP) could be predicted to be about 24, 23, 26 and 45 weeks for the S₁-S₄. CO₂-C liberated in the 1st week, which was the peak AAR, should also another practical importance. The relationship between the active Fe(III) (X, ppmFe) and (a) HFP (Y₁, weeks); (b) the 1st week CO₂-C liberated (Y₂, ppmCO₂-C) and (c) the b values (Y₃, ppmCO₂-C/week) studied were illustrated in eq. (5)-(7)

$$Y_1 = 46.0 - 5.08 \times 10^{-3} X \quad (r = -0.819^{**}) \quad (5)$$

$$Y_2 = -15.2 + 0.028 X \quad (r = 0.999^{**}) \quad (6)$$

$$Y_3 = 1.33 - 1.36 \times 10^{-3} X \quad (r = 0.999^{**}) \quad (7)$$

It could be seen from these 3 equations that (a) the more soil active Fe(III) the less HFP (eq.5) and (b) the more the soil active Fe(III) the faster the AAR at the 1st week (eq. 6) and b values (eq. 7).

4. Conclusion

It could be concluded that the 4 Thai soils that had very high LFLOCTE (%) since week 1 have its aging reaching the plateau of 100% or little bit higher within 4 weeks. The minimization of the CO₂ emission by chemical mechanisms as carbonate salts, are the evidenced of strong effervescences during the soil Fe(II) extraction by 1 N HCl and the transformation to SOM are also the evidenced by the termination of CO₂, which released the

SCS mechanisms deduced. Both the LFLOCTE (%), before 4 weeks of aging, and the HFP were enhanced highly significantly by the soil active Fe(III). The hypothesis proposed was clearly, therefore, verified. The application of this dual roles of soils on the LFL management should be, therefore, a sound global warming mitigation recommended.

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