

# Study the Changes in Soil Organic Carbon of Rice-Maize Cropping System in the Top Layer of Alluvisol Soil in Dan Phuong: A Study of C-13 Stable Isotope Composition ( $\delta^{13}\text{C}$ )

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## Abstract

In this study, the experiments on field were conducted to examine the change in the content of soil organic carbon (SOC), its C-13 stable isotope composition ( $\delta^{13}\text{C}$ ) and some main physical, chemical parameters (soil moisture, pH, soil density, content of humic, fulvic, total N, total P, total K) in alluvial soil of Dan Phuong region—Vietnam at a depth of 0 - 30 cm when we changed the regime from 2 maize -1 rice crop to 2 rice - 1 maize crop per 1 year. In addition to analyzing the main parameters in soil, C content and its  $\delta^{13}\text{C}$  value in parts of rice and maize (root, stem and leaf) were also analyzed to assess the contribution of plant residues on soil organic carbon content after harvest. The experiment was carried out in 2016-2017 on the field with the traditional farming method of local farmers along with the tropical monsoon weather conditions of the North-Vietnam. The results showed that SOC had positive correlation with total N, total P parameters and negative correlation with  $\delta^{13}\text{C}$  values of soil samples at two layers (0 - 15 cm and 15 - 30 cm). The average of total dry biomass (stem, stump + roots and leaf parts) per 1 rice and 1 maize crop was 10.64 Mg/ha and 9.09 Mg/ha, respectively. The average of  $\delta^{13}\text{C}$  value of rice ( $\text{C}_3$  plant) was  $-29.78\text{‰}$  and its value of maize ( $\text{C}_4$  plant) was  $-12.61\text{‰}$ . The new plant (rice) contributes to the total soil organic carbon content from 11.31% to 44.14% at the 0 - 15 cm layer and from 6.55% to 11.31% at the 15 - 30 cm layer in one-year experiment period.

## Keywords

Soil Organic Carbon (SOC), C-13 Stable Isotope, Maize and Rice Crop, Soil Properties

## 1. Introduction

In soil science, soil organic carbon (SOC) plays a very important role in soil structure, soil chemical and physical characteristics and soil fertility [1] [2]. In soil-crop ecosystems, SOC storage reflects the net balance between ongoing carbon (C) accumulation resulting from inputs of crop biomass (aboveground, belowground) and/or exogenous organic matter (e.g., manure, straw) and soil C decomposition processes due to microbial oxidation [3] [4].

Stable isotope ratio of  $^{13}\text{C}/^{12}\text{C}$  in SOC expressed in the delta notation ( $\delta^{13}\text{C}_{\text{SOC}}$ )—a natural tracer, is interested in many areas of research on environmental processes such as carbon sinks and photosynthetic mechanisms of plants [5] [6], assessing the carbon reservoir turnover times and soil carbon dynamic in agroforestry ecosystems, methods of fixation and storage of carbon dioxide in soils [1] [6] [7] [8] [9] or exploring soil mineralization processes [10]. Plant species ( $\text{C}_3$ ,  $\text{C}_4$  and CAM plants) differ in their isotopic  $^{13}\text{C}$  values due to isotopic discrimination by their photosynthetic enzymes and the regulation of the diffusion resistance of their stomata.  $\text{C}_3$  plants (rice, wheat, soybean ...) have  $\delta^{13}\text{C}$  average value of  $-27\text{‰}$  ( $-35\text{‰}$  to  $-20\text{‰}$ ),  $\text{C}_4$  plants (sugarcane, corn ...) have  $\delta^{13}\text{C}$  average value of  $-13\text{‰}$  ( $-15\text{‰}$  to  $-7\text{‰}$ ) [11] [12]. For topsoil calculations, SOM has stable carbon isotopic composition comparable to that of the source plant material and changes in the proportion of  $\text{C}_3$  and  $\text{C}_4$  plants will result in a corresponding change in the  $\delta^{13}\text{C}_{\text{SOC}}$ . Therefore,  $\delta^{13}\text{C}$  value of SOM can be used to study C turnover in soils in areas where  $\text{C}_3$  vegetation was replaced by  $\text{C}_4$  plants or vice versa [11].

Furthermore, the cultivation models such as intensive farming, intercropping, crop rotation ( $\text{C}_3$ ,  $\text{C}_4$  plant) and agricultural practices will affect the total SOC budget, nutrient cycling, soil-water relationships, erosion processes and carbon sequestration. Such information is important to determine impacts of land use on the sustainability of cropping systems, and its feedbacks to future climate changes.

The use of stable  $^{13}\text{C}$  isotope techniques to study above issues is not new in the world but it is still quite new in Vietnam. Therefore, in this paper, we applied the  $^{13}\text{C}$  stable isotope technique to study changes in soil organic carbon at 0 - 30 cm depth from maize-rice-maize crop system to rice-rice-maize crop system of alluvial soil in Dan Phuong area. This is a type of soil that accounts for a large proportion of Vietnam agricultural soil which has high C sequestration potential and reduces greenhouse gas ( $\text{CO}_2$ ,  $\text{CH}_4$ ) in agro-ecosystem.

## 2. Materials and Methods

### 2.1. Crop Management

The experimental site was implemented on agricultural soil at Dan Phuong district ( $21^\circ 06' 21.0''\text{N}$ ,  $105^\circ 39' 45.0''\text{E}$ )—a suburban area of Hanoi city, Vietnam for 2 years (2016 and 2017). This area has been growing crop sequence of maize - maize-rice for approximately 10 years.

The experiment site has a tropical monsoon climate with an average annual precipitation of 1721 mm, an average annual temperature of 25.14°C, atmosphere humidity of 75.58% and a mean annual sunshine hour of 1207 h (according to the Report of Center for Agricultural Meteorological Research, Institute of Hydrometeorology and Climate Change). The soil profile of the experimental site was classified as alluvial soil of the Red river or Eutric Fluvisol (FAO, 1990). Rice-rice-maize or maize-rice-maize cropping system was the most important cropping system in the region.

Briefly, rice (Khang Dan 18 variety) and maize (HN88 variety) rotation were planted in plots of 120 m<sup>2</sup> each with 3 replicates. The experiment included 3 treatments in 2017: 1) initial soil condition: maize-rice-maize cropping system no plant return; 2) rice-rice-maize cropping (RRM-NR) no plant return; and 3) rice-rice-maize (RRM-R) with plant return during a 1-year cultivation.

Each cropping season took around 3.5 months. Leaves, stems and roots of maize and rice from the previous crops were ploughed into the soil after harvest. Maize (HN88 variety) was grown with a plant spacing of 25 cm and a row spacing of 75 cm. The chemical fertilizer 16-16-8 (16%N; 16%P<sub>2</sub>O<sub>5</sub>; 8%K<sub>2</sub>O content) was applied for maize at the rate of 500 kg/ha (divided in three times), the 166 kg/ha single fertilizer P<sub>2</sub>O<sub>5</sub> was used 3 days after planting and the single fertilizer K<sub>2</sub>O was applied 45 days after planting at the rate of 166 kg/ha. Rice seedlings (Khang Dan 18 variety) were transplanted by hand with three plants/hill and a spacing of 20 cm × 25 cm. Fertilizer was applied 3 times with total 416 kg/ha chemical fertilizer 16-16-8; broadcast application at the rate of 139 kg/ha 1 - 3 days after transplanting (DAT), 165 kg/ha at 12 - 15 DAT and 122 kg/ha at 40 - 45 DAT. Weed eradication was made at 20 and 50 DAT. Pesticide management of both rice and maize seasons was in accordance with the conventional.

## 2.2. Sampling and Sample Preparation

Soil samples were collected at the beginning and before harvesting crops. Soil samples were taken using a core sampler (6 cm i.d.) to a depth of 30 cm and then it was divided into two layers: 0 - 15 cm and 15 - 30 cm depth. This depth was chosen because it contains most of the root apparatus of rice and maize species. For each crop, three replicates were taken according to a completely randomized experimental design. Each replicate was composed of three subsamples, which were combined. Then, the soil samples were sieved (<4 mm), visible plant debris was removed, and the soils were then air-dried. On the same date, separate samples (50 mm diameter) of undisturbed soil were taken for a bulk density analysis. The samples are spread on stainless steel trays with the use of a stainless-steel spatula, air-dried at room temperature or dried at 40°C - 50°C in a ventilated oven for two days. Dried soils were homogenized in ceramic mortar and sieved through 1 mm mesh sieve to remove bricks, stones, gravel and roots. Samples were then ground and sieved through 100 µm mesh sieve, dried the specimen at

50°C for 24 hours. Finally, samples were subdivided into subsamples for determination pH, soil organic carbon, total N, total P, total K, and carbon stable isotope components in SOC ( $^{13}\text{C}/^{12}\text{C}$  ratio -  $\delta^{13}\text{C}_{\text{SOC}}$ ).

The plant samples were collected at harvesting time for each crop. Random choosing of 10 maize plants or 10 rice clusters of each treatment, rinse and subdivide into 4 parts: root, stem, leave and seeds. Each plant part was cut into 0.5 - 1.0 cm, dried at 40°C - 50°C in a ventilated oven until unchanged weight. Dry mass of each part was determined by weight. The dried plant samples were then grounded and sieved through 100  $\mu\text{m}$  mesh sieve for carbon stable isotope ratio and percent of C.

### 2.3. Physiochemical Soil Analysis

The soil samples were characterized using common methods. The content of clay, silt and sand in the fine soil samples (grains < 2 mm in diameter) was quantified by sedimentation after removing the organic matter in a 30%  $\text{H}_2\text{O}_2$  solution (the  $\text{H}_2\text{O}_2$  treatment was conducted at 80°C in a water bath until no further reaction). Soil pH was examined using 1 M KCl (1:2.5, w/v); The soil bulk density ( $\text{g}\cdot\text{cm}^{-3}$ ) of the 0 - 15 cm and 15 - 30 cm soil layers was measured by collecting undisturbed soil samples using steels metal cores of known volume (5-cm internal diameter and 5-cm length). Three core samples were taken at random from each plot. The total nitrogen (TN) and organic carbon (OC) content of the bulk soil were measured by Elemental Analyzer (EA, EuroVector, Italy); we removed inorganic carbon in soil samples by HCl 1N before determination of soil organic carbon. The humic acid and fulvic acid content were determined based on Walkley-Black method—These organic acids were oxidized with excess  $\text{K}_2\text{Cr}_2\text{O}_7$  solution in sulfuric acid then the excess potassium bicromate content were titrated by  $\text{FeSO}_4(\text{NH}_4)_2\text{SO}_4\cdot 6\text{H}_2\text{O}$  solution, thereby deducing humic and fulvic acid content. Based on the acid insoluble nature of humic acid to separate humic acid and identify humic acid content, and then fulvic acid content was calculated. For determining total phosphorus (TP), we used sulfuric acid and perchloric acid to break down and dissolve phosphorus compounds in the soil samples. After that, we measured of phosphorus content in solution by colorimetric method. The total potassium content in soil was digested by a mixture of hydrofluoric acid and pecloric acid. Determination of potassium content in solution by Atomic Absorption Spectrometric (AAS) method, all analytical measurements were performed in triplicate.

### 2.4. Isotope Analysis of $\delta^{13}\text{C}$ in Soil and Plants by EA-IRMS

Stable carbon isotopic composition— $\delta^{13}\text{C}$  values (the proportion of  $^{13}\text{C}$  with respect to  $^{12}\text{C}$ ), measured for soil and plant samples were used to determine the contribution of plant carbon source to soil organic carbon. The rice and maize plant samples and those of the soil samples were dried at 60°C, ball-milled, passed through a 100- $\mu\text{m}$  sieve, and fumigated with 12 N HCl overnight to re-

move carbonates [13] [14]. The  $\delta^{13}\text{C}$  of plant and soil samples were analyzed using isotope ratio mass-spectrometer (IRMS, Micromass GV Instrument, UK) equipped with an elemental analyzer (EA, EuroVector, Italy) at the Isotopes Hydrology Laboratory, Institute for Nuclear Sciences and Technology, Vietnam.

The  $^{13}\text{C}/^{12}\text{C}$  isotope ratio is expressed in the delta notation ( $\delta^{13}\text{C}$ ) that was expressed as:

$$\delta^{13}\text{C}(\text{‰}) = \left( \frac{R_{\text{sample}}}{R_{\text{standard}}} - 1 \right) * 100 \quad (1)$$

where:

$R_{\text{sample}}$  is the mole ratio of the  $[^{13}\text{C}]/[^{12}\text{C}]$  in the sample;

$R_{\text{standard}}$  is the mole ratio of the  $[^{13}\text{C}]/[^{12}\text{C}]$  in the standard.

The standard was Vienna Pee Dee Belemnite (VPDB this is biogenic calcite found in PeeDee formation in South Carolina (USA) and it was prepared and supplied by IAEA in Vienna, Austria.

With respect to the different cropping treatments, the  $\delta^{13}\text{C}$  values of the SOM were used to calculate the proportion of new C ( $f_{\text{new}}$ , *i.e.*, the C derived from current maize/rice residues) and old C ( $f_{\text{old}} = 1 - f_{\text{new}}$ , soil C present prior to tillage, *i.e.*, C in the initial soil) using a mass balance equation [11]:

$$f_{\text{new}} = \frac{\delta_{\text{new}} - \delta_{\text{old}}}{\delta_{\text{veg}} - \delta_{\text{old}}} * 100\% \quad (2)$$

where:

$\delta_{\text{new}}$  represents the  $\delta^{13}\text{C}$  values of organic C in soil fractions after 1 years of tillage,

$\delta_{\text{old}}$  represents the  $\delta^{13}\text{C}$  values of organic C in the initial soil, *i.e.*, the soil samples prior to tillage,

$\delta_{\text{veg}}$  represents the  $\delta^{13}\text{C}$  values of the mixed samples, including plant materials (maize and/or rice leaves, stems and roots) in both cropping treatment.

## 2.5. Statistical Analysis

Pearson's test was used to evaluate the correlation coefficient and differences in means of the soil characteristics: soil humidity, bulk density, pH, humic, fulvic, SOC, TN, TP, TK and  $\delta^{13}\text{C}$  from two depths (0 - 15 and 15 - 30 cm) among three treatments. The statistical analyses were done with SPSS 20.0 software.

## 3. Results and Discussions

### 3.1. The Yield and Carbon Content of the Crops and $\delta^{13}\text{C}$ Values in Plants Samples

Results of seasonal analysis of maize and rice samples (stump + roots, stem and leaf parts) in the study area for 2 years from 2016 to 2017 were showed in **Table 1**. The average of total dry biomass (stem, stump + roots and leaf parts) per 1 rice crop of 3 models was 10.64 Mg/ ha for 2 years. The average of total dry biomass (stem, root and leaf parts) per 1 maize crop of 3 models was 9.09 Mg/ha for

2 years. The average of  $\delta^{13}\text{C}$  values of rice and maize parts were  $-29.78\text{‰}$  and  $-12.61\text{‰}$ , respectively. These results are completely suitable with the world research on the  $\delta^{13}\text{C}$  value of  $\text{C}_3$  plants—rice and  $\text{C}_4$  plants—maize. The different in  $\delta^{13}\text{C}$  value of these plants is the signature for carbon sequestration study.

### 3.2. Soil Properties of Two Layers

We conducted sampling and analyzing some soil properties according to the depth before and after harvest of some maize-maize-rice and rice-rice-maize cultivation models. The average analysis results of soils in 2016 and 2017 at 2 depths (0 - 15 cm and 15 - 30 cm) of the MRM, RRM-NR and RRM-R models were presented in **Table 2** and **Table 3**. Results showed that there were minor changes in the parameters of pH, SOC, TN, TK and  $\delta^{13}\text{C}$  between 2016 and 2017 of MRM model. In 2017, for the 0 - 15 cm soil layer, the soil organic carbon content increases gradually when shifting from maize-rice-maize and rice-rice-maize cultivation in both forms of no plant return and plant return on the fields (increase from 0.702% to 0.748% and 0.855%, respectively). For the 15 - 30 cm soil layer, the SOC content increased insignificantly from 0.36% to 0.40%. The results also showed that, when shifting to 2 rice crops in a year, the soil pH decreased (5.12 - 5.07 - 4.75) and the isotopic component  $\delta^{13}\text{C}$  of SOC decreased relative to the amount of straw left in the field ( $-24.43\text{‰}$ ,  $-24.70\text{‰}$ ,  $-26.00\text{‰}$ ). In other words, the value of  $\delta^{13}\text{C}$  in the SOC is correlated with the isotopic value  $\delta^{13}\text{C}$  of the plant grown on that soil (the average value of  $\delta^{13}\text{C}$  of maize and rice grown in Dan Phuong were  $-12.61\text{‰}$  and  $-29.78\text{‰}$ , respectively).

**Table 1.** The average results of rice and maize samples in 2016-2017 of 3 models.

Plant type	Plant parts	Total dry biomass/1 crop		Carbon content/1 crop		$\delta^{13}\text{C}_{\text{VPDB}}$	
		(Mg/ha)	SD	(Mg/ha)	SD	‰	SD
Rice 2016	Stump + Roots	2.66	0.11	1.10	0.04	$-29.85$	0.16
	Stem	5.82	0.33	2.42	0.13	$-29.55$	0.18
	Leaf	2.96	0.07	1.21	0.03	$-29.98$	0.17
Total		<b>11.44</b>		<b>4.73</b>			
Rice 2017	Stump + Roots	2.13	0.15	0.87	0.06	$-29.76$	0.13
	Straw	5.19	0.41	2.15	0.17	$-29.70$	0.15
	Leaf	2.52	0.25	1.03	0.10	$-29.83$	0.14
Total		<b>9.84</b>		<b>4.05</b>			
Maize 2016	Stump + Roots	1.56	0.09	0.66	0.04	$-12.81$	0.21
	Stem	4.21	0.19	1.83	0.08	$-12.95$	0.19
	Leaf	3.17	0.19	1.31	0.08	$-12.61$	0.17
Total		<b>8.94</b>		<b>3.80</b>			
Maize 2017	Stump + Roots	1.66	0.10	0.69	0.04	$-12.50$	0.08
	Straw	4.29	0.14	1.81	0.06	$-12.47$	0.19
	Leaf	3.28	0.18	1.35	0.07	$-12.33$	0.24
Total		<b>9.23</b>		<b>3.85</b>			

**Table 2.** The annual average results of 0 - 15 cm soil layer in Dan Phuong.

Sample code	Time	Humidity	Buck density	pH	Humic	Fulvic	SOC	TN	TP	TK	$\delta^{13}\text{C}$
		%	(g/cm <sup>3</sup> )		C (%)	C (%)	C (%)	N (%)	P <sub>2</sub> O <sub>5</sub> (%)	K <sub>2</sub> O (%)	(‰)
0 - 15 MMR 2016	2016	22.06	1.26	5.20	0.063	0.131	0.650	0.103	0.187	2.36	-24.49
		±0.78	±0.05	±0.12	±0.027	±0.049	±0.041	±0.003	±0.004	±0.15	±0.05
0 - 15 MMR 2017	2017	23.79	1.21	5.12	0.103	0.122	0.702	0.100	0.282	1.94	-24.43
		±4.08	±0.03	±0.37	±0.026	±0.056	0.052	0.009	±0.090	±0.39	±0.19
0 - 15 RRM-NR	2017	25.71	1.23	5.07	0.141	0.140	0.748	0.109	0.309	1.77	-24.70
		±6.98	±0.04	±0.22	±0.032	±0.041	±0.087	±0.014	±0.107	±0.35	±0.26
0 - 15 RRM-R	2017	25.47	1.23	4.75	0.157	0.156	0.855	0.120	0.288	2.01	-26.00
		±6.95	±0.04	±0.35	±0.040	±0.046	±0.153	±0.013	±0.054	±0.51	±1.14

**Table 3.** The annual average results of 15 - 30 cm soil layer in Dan Phuong.

Sample code	Time	Humidity	Buck density	pH	Humic	Fulvic	OC	TN	TP	TK	$\delta^{13}\text{C}$
		%	(g/cm <sup>3</sup> )		C (%)	C (%)	C (%)	N (%)	P <sub>2</sub> O <sub>5</sub> (%)	K <sub>2</sub> O (%)	(‰)
15 - 30 MMR 2016	2016	20.08	1.44	7.16	0.025	0.092	0.366	0.080	0.137	2.43	-22.45
		±1.95	±0.06	±0.61	±0.005	±0.025	±0.032	±0.020	±0.013	±0.14	±0.41
15 - 30 MMR 2017	2017	20.23	1.49	6.97	0.044	0.082	0.360	0.081	0.147	2.01	-22.29
		±1.76	±0.06	±0.34	±0.016	±0.011	±0.024	0.024	±0.017	±0.59	±0.34
15 - 30 RRM-NR	2017	22.28	1.47	7.29	0.039	0.094	0.362	0.102	0.183	2.61	-22.95
		±2.33	±0.05	±0.44	±0.012	±0.022	±0.021	±0.026	±0.037	±0.37	±0.55
15 - 30 RRM-R	2017	22.50	1.45	7.40	0.056	0.087	0.400	0.109	0.183	3.03	-23.30
		±2.97	±0.05	±0.18	±0.012	±0.026	±0.041	±0.023	±0.051	±0.46	±0.77

Using SPSS 20.0 software for statistical analysis of the correlation between soil moisture content, density, pH, humic, fulvic, SOM, TN, TP, TK and  $\delta^{13}\text{C}$ . Results of soil analysis at a depth of 0 - 15 cm (**Table 4**) showed that the OC content was positively correlated with the parameters of TN, TP, and fulvic and inversely correlated with  $\delta^{13}\text{C}$  and pH parameters. The results in **Table 5** also showed the positive correlation between OC and TN, TP parameters, and inversely correlated with the  $\delta^{13}\text{C}$  parameter. This correlation was consistent with the trend of shifting crops from cultivating of 2 corn crops + 1 rice crop/1 year to cultivating of 2 rice crops + 1 corn crop/1 year.

### 3.3. The Soil Organic Carbon and Its Relation with $\delta^{13}\text{C}$ Values

The variation of SOC content of 3 models (*MMR*, *RRM-NR*, *RRM-R*) in 2 soil layers in 2017 was presented in **Figure 1** and **Figure 2**. The results showed that the SOC content tends to decrease during the time of winter-spring season in both depths 0 - 15 cm and 15 - 30 cm and gradually increase during summer-autumn season and reach the highest value in September. **Figure 1** and **Figure 2** also showed that the content of SOC changes significantly mainly in

the soil layer 0 - 15 cm. This was the topsoil that contains most of the plant residues after harvest.

The SOM content and its relation with  $\delta^{13}\text{C}$  in SOM was shown in **Figure 3** in. The results showed that SOM content in the 0 - 15 cm soil layer was higher from 2 to 2.5 times than SOM content of the 15 - 30 cm layer and the  $\delta^{13}\text{C}$  value of upper layer was depleted than the  $\delta^{13}\text{C}$  value from 2‰ to 3‰. The depleted  $\delta^{13}\text{C}$  value and the increasing SOC content of the topsoil were due to SOC being decomposed from rice straw and rice roots after harvest (the average  $\delta^{13}\text{C}$  value of rice was  $-29.78\text{‰}$ ). At a depth of 15 - 30 cm, the concentration of SOC was lower than that of the surface layer and the  $\delta^{13}\text{C}$  value of SOC was enriched because this layer was not replenished regularly with plant matter except deep plant roots. In addition, many published works on SOC kinetics show that  $\delta^{13}\text{C}$  values tend to be enriched at deeper layer due to the natural isotope fractionation of the microbial decomposition process of microorganisms and the evaporation process of  $^{12}\text{C}$  light isotope of gases such as  $\text{CO}_2$  and  $\text{CH}_4$ .

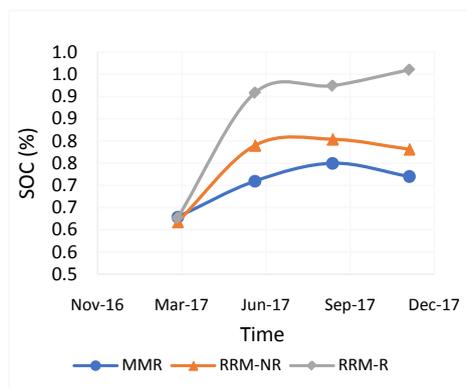
**Table 4.** Pearson Correlations of soil parameters at 0 - 15 cm layer of 3 treatments.

	Humidity	Bulk density	pH	Humic	Fulvic	SOC	TN	TP	TK	$\delta^{13}\text{C}$
Humidity	1									
Bulk density	-0.192	1								
pH	-0.302	0.589*	1							
Humic	0.702**	-0.339	-0.439	1						
Fulvic	-0.318	-0.483	-0.394	0.160	1					
OC	-0.505	-0.200	-0.351	0.158	0.560*	1				
TN	-0.046	-0.327	-0.743**	0.400	0.661**	0.597*	1			
TP	-0.271	-0.424	-0.294	0.267	0.600*	0.576*	0.458	1		
TK	-0.640*	0.332	0.055	-0.701**	-0.165	0.253	0.070	-0.214	1	
$\delta^{13}\text{C}$	0.361	-0.017	0.414	-0.154	-0.377	-0.897**	-0.562*	-0.339	-0.361	1

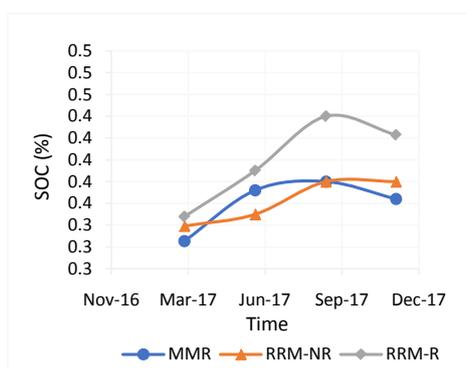
\*\* Correlation is significant at the 0.01 level (2-tailed). \* Correlation is significant at the 0.05 level (2-tailed).

**Tables 5.** Pearson Correlations of soil parameters at 15 - 30 cm layer of 3 treatments.

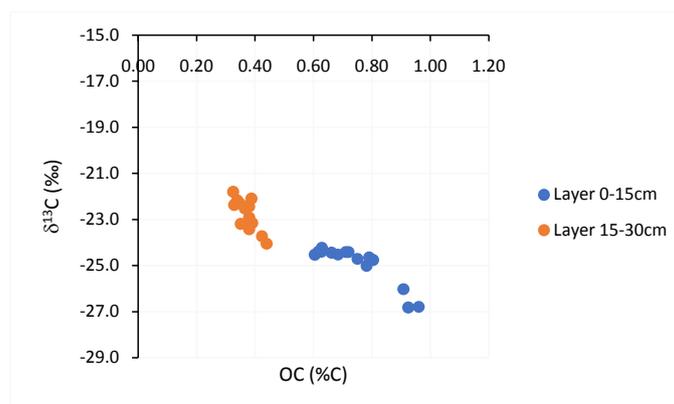
	Humidity	Bulkdensity	pH	Humic	Fulvic	SOC	TN	TP	TK	$\delta^{13}\text{C}$
Humidity	1									
Bulkdensity	-0.667**	1								
pH	-0.394	0.311	1							
Humic	0.135	0.185	0.143	1						
Fulvic	0.222	0.002	0.068	0.126	1					
OC	-0.189	-0.045	0.222	0.467	-0.023	1				
TN	0.063	0.031	0.159	0.557*	0.336	0.685**	1			
TP	-0.059	0.063	0.345	0.407	0.040	0.610*	0.852**	1		
TK	0.097	-0.337	0.508	0.376	-0.119	0.393	0.233	0.307	1	
$\delta^{13}\text{C}$	0.080	0.144	-0.260	-0.302	0.297	-0.776**	-0.661**	-0.729**	-0.502	1



**Figure 1.** The change in SOC content in 0 - 15 cm layer of 3 models: MMR, RRM-NR, RRM-R in 2017.



**Figure 2.** The change in SOC content in 15 - 30 cm layer of models: MMR, RRM-NR, RRM-R in 2017.



**Figure 3.** Relation of SOC &  $\delta^{13}\text{C}$  in 3 treatments of the Dan Phuong alluvial soil in 2017.

### 3.4. Carbon Sequestration Potential of Rice-Maize Crop Systems

Applying the formula (2) to calculate the amount of C accumulated in the soil layers when shifting the 2 maize - 1 rice crop model to 2 rice - 1 maize crop model with no plant return and plant return in Dan Phuong alluvial soil, the results are obtained in **Table 6**.

**Table 6.** Results of SOM sequestered in 0 - 30 cm layers of Rice-rice-maize crop model with no plant return and plant return in 2017.

Parameters	Units	RRM-NR		RRM-R	
		0 - 15 cm	15 - 30 cm	0 - 15 cm	15 - 30 cm
$\delta^{13}\text{C}_{\text{SOC}_{\text{new}}}$	‰	-25.01	-23.00	-26.78	-23.72
$\delta^{13}\text{C}_{\text{SOC}_{\text{old}}}$	‰	-24.40	-22.52	-24.40	-22.52
$\delta^{13}\text{C}_{\text{R}}$	‰	-29.79	-29.79	-29.79	-29.79
$\text{SOC}_{\text{new}}$	(MgC/ha)	14.88	8.78	18.27	8.75
F	%	11.31	6.55	44.14	16.46
$\text{SOC}_{\text{RRM sequestered}}$	(MgC/ha)	1.683	0.575	8.065	1.440
Total $\text{SOC}_{\text{RRM sequestered}}$	(MgC/ha)	2.259		9.505	

The  $\delta^{13}\text{C}_{\text{SOM}_{\text{new}}}$  value decreased from 1‰ to 1.5‰ when we changed from 2 maize - 1 rice cultivation to 2 rice - 1 maize cultivation in 2017. For the RRM-NR model, the results showed that the average contribution rate of new plants (rice) was about 11.31% at 0 - 15 cm depth, and 6.55% at 15 - 30 cm depth and the total amount of SOM accumulated after 1 year of cultivation on both layers was 2.259 MgC/ha. When leaving rice straw in the field (RRM-R), the average contribution rates of new plants to the total amount of SOM of 0 - 15 cm and 15 - 30 cm layers were accounted for 44.14% and 16.46%, respectively. The average cumulative amount of SOM in the 0 - 30 cm layer was 9.505 MgC/ha at the RRM-R model. This value was 4 times higher than that of the RRM-NR model (2.259 MgC/ha). Thus, if farmers leave plant residues (straw) after each harvest on the field, the amount of C from new plants accumulated in the soil in the form of SOM will increase significantly. This is a way to get more  $\text{CO}_2$  from the air into plant tissues and store  $\text{CO}_2$  as SOC in farmland.

#### 4. Conclusion

Our research on soil organic carbon, C-13 stable isotope and some main characteristics of the alluvial soil at Dan Phuong district—Vietnam was conducted in 2016-2017 when we changed from 2 maize + 1 rice crop model to 2 rice + 1 maize crop model. The annual average of total dry biomass of rice and maize samples (stem, root, leaf parts) was 10.64 Mg/ha and 9.09 Mg/ha, respectively. The average  $\delta^{13}\text{C}$  value of Khang Dan rice was  $-29.78\text{‰}$  ( $\text{C}_3$  plant) and that value of HN88 maize ( $\text{C}_4$  plant) was  $-12.61\text{‰}$ . The amount of C accumulated in the soil in the form of SOM increases with time, the OC content is positively correlated with the parameters of TN, TP, fulvic and inversely correlated with  $\delta^{13}\text{C}$  parameter (0 - 30 cm layer). The top soil layers were regularly provided plant residues, so the  $\delta^{13}\text{C}$  value of SOM was changed corresponding to the  $\delta^{13}\text{C}$  value of plant. The average cumulative amount of SOM in the 0 - 30 cm layer was from 2.259 MgC/ha to 9.505 MgC/ha. This is a nature stable isotope method that can be used to relatively accurately quantify the C sequestration ability of the popu-

lar agricultural farming models in Vietnam and around the world. We need to conduct long-term and deeper research for many years to estimate SOC sequestration in some popular agricultural farming models and find the ways to minimize the number of greenhouse gases in the atmosphere.

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### Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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