B-6. 2. 3 Quantitative Analysis of Soil Organic Carbon Turnover by Using Natural Abundance of Carbon Isotopes

Contact Person Tadakatsu Yoneyama
Plant Nutrition Diagnosis Laboratory,
National Agriculture Research Center,
3-1-1 Kannondai, Tsukuba, Ibaraki 305-8666, Japan
Tel: +81-298-38-8814, Fax: +81-298-38-8814,
e-mail:yoneyama@narc.affrc.go.jp

Total Budget for FY 1996 - FY 1998 7,485,000 Yen **FY 1998** 2,493,000 Yen

Abstract The carbon content and natural ^{13}C abundance ($\delta^{13}C$) of soil organic carbon from Japan, the Philippines and Thailand were successfully analyzed by on-line ANCA-SL mass spectrometer. Japan soils from cultivated fields had $\delta^{13}C$ values of -24‰ from Hokkaido, -22‰ ～-18‰ from Main Island, Shikoku and Kushu, suggesting some C input by C_4 plants (highly likely by *Miscanthus sinensis*). In Miyako Island, the Philippines, and Thailand, transfer to sugarcane cultivation from forests markedly decreased C content and increased $\delta^{13}C$ values of soil organic carbon from C_3 plants-derived carbon (-27‰ ～ -24‰) to C_4-dominant carbon (-17‰ ～-14‰) within 25 years in Miyako Island, 10 ～ 50 years in the Philippines, and 8 ～ 20 years in Thailand.

Key Words Natural ^{13}C abundance ($\delta^{13}C$), Carbon isotopes, Soil organic carbon, Carbon turnover, C_3 plant, C_4 plant

1. Introduction

Carbon fluxes among atmosphere, terrestrial plants and soil organic carbon as well as carbon exchange between atmospheric CO_2 and oceanic carbonate are important components in the global carbon cycling. However, due to lack of information of carbon contents and turnover of organic carbon in varied soils, carbon fluxes from terrestrial plants to the soil and carbon release as CO_2 from the soil to the atmosphere have not been precisely evaluated yet.

One important solution to this difficulty is the recent development of the tracer analysis of organic carbon turnover in soils. ^{14}C-labelled plant organic materials were incorporated, and the loss of ^{14}C from the soil was traced in some soils[1)]. Another tracer method is the use of natural ^{13}C abundance of soil organic carbon[2,3,4)]. In this project, carbon content and natural ^{13}C abundance of soils collected in Japan, the Philippines and Thailand were analyzed.

Organic carbon in plant tissues is fixed from the atmospheric CO_2 by photosynthetic reactions. Thus produced organic carbon is supplied to the soil by the vegetation as litters and residues. These plant organic matters are decomposed through the respiratory metabolism. Microorganisms decompose low-molecular carbon compounds to CO_2 and simultaneously synthesize their body components like as proteins (immobilization). Some insects like termites can decompose high-molecular compounds like lignins. The organisms who can decompose lignins largely inhabit in tropical and semi-tropical lands. In temperate and boreal lands, plant litters and residues are partly decomposed and accumulate to the high contents of soil organic carbon.

Carbon atoms in natural materials are composed of ^{13}C and ^{12}C. The percentage of ^{13}C in total carbon is around 1.10. The natural ^{13}C abundance ($\delta^{13}C$) is expressed by equation (1) by permil (‰) unit.

$$\delta^{13}C\ (‰) = (R\ sample\ /\ R\ standard\ -\ 1) \times 1{,}000 \qquad (1)$$

where R is ^{13}C / ^{12}C. As standard, PDB (Pee Dee Belemnite) is commonly used.

The $\delta^{13}C$ value of atmospheric CO_2 is around -7‰ and those of plant organic carbon range from -9‰ to -30‰. Interestingly, $\delta^{13}C$ values of plant organic carbon are grouped into two: one group ranges from -22‰ to -30‰ (the average, -27‰), and the other range from -9 ‰ to -15 ‰ (the average, -13‰).[5] The former group belongs to C_3 photosynthetic type and the latter to C_4 photosynthetic type. The decomposition of plant organic materials in the soil does cause a small enrichment (around 1‰) of the organic carbon remained in the soil. Therefore, the $\delta^{13}C$ values of the vegetation are clearly recorded in the soil organic carbon. If we measure $\delta^{13}C$ values of soil organic carbon (δ_s), we can calculate the proportion of C_3-derived C (X) or C_4-derived C (1-X) by equation (2).

$$\delta_s = \delta_{C3} \times X + \delta_{C4} \times (1 - X) \qquad (2)$$

where δ_{C3} is $\delta^{13}C$ value of C_3 plants (= -27‰) and δ_{C4} is $\delta^{13}C$ value of C_4 plants (= -13‰). In the fields, where the vegetation changes from C_3 to C_4 plants, the $\delta^{13}C$ values in soils may be from both C_3 and C_4 values which indicate the exchange of organic carbon in soils in situ.

2. Research Objective

In this project, we tried to collect soils from tropical and semi-tropical areas in Japan, the philippines and Thailand. A particular attention was paid on the vegetation change from forests (C_3 plants) to the cultivation of sugarcane (*Saccharum* sp.) (C_4 plant). Since sugarcane plants are continuously grown for long years, and carbon supply to the soil by weeds neighbouring sugarcane plants is small. We also developed a simple and quick analytsis method of soil carbon content and $\delta^{13}C$ value by on-line ANCA-SL mass spectrometer. By this method one soil sample is analyzed every 6 min, which is very in contrast to the hours analysis by the conventional method. The information of soil carbon content and $\delta^{13}C$ value reported is first to quantify carbon turnover in the soil in Asia.

3. Research Method

(1) Collection of soil samples

In October 1996, forest top soils (0-20 cm) and sugarcane cultivated soils were collected in Miyako Island, Okinawa, Japan. The soils were yellow soil, gray lowland soil and dark red soil. The years of sugarcane cultivation ranged one to about 100 years. Some soils from cultivated fields through Japan were also collected.

In September 1996, soils of Luzon Island and in September 1997, soils of Negross Island in the Philippines were collected from forests and sugarcane fields. The years of continuous sugarcane cultivation ranged 4 to about 180 years.

In October 1997, soils of the north-east area and in November 1998, soils of the central and western areas in Thailand were collected from forests and sugarcane fields. The years of sugarcane cultivation ranged from one to 30 years in the north-east area and from 12 to 40 years in central and western areas. In the Philippines and Thailand, soils were collected from different depths (0-10, 10-20, 20-30 cm and in some sites further 30-40, 40-50, 50-60

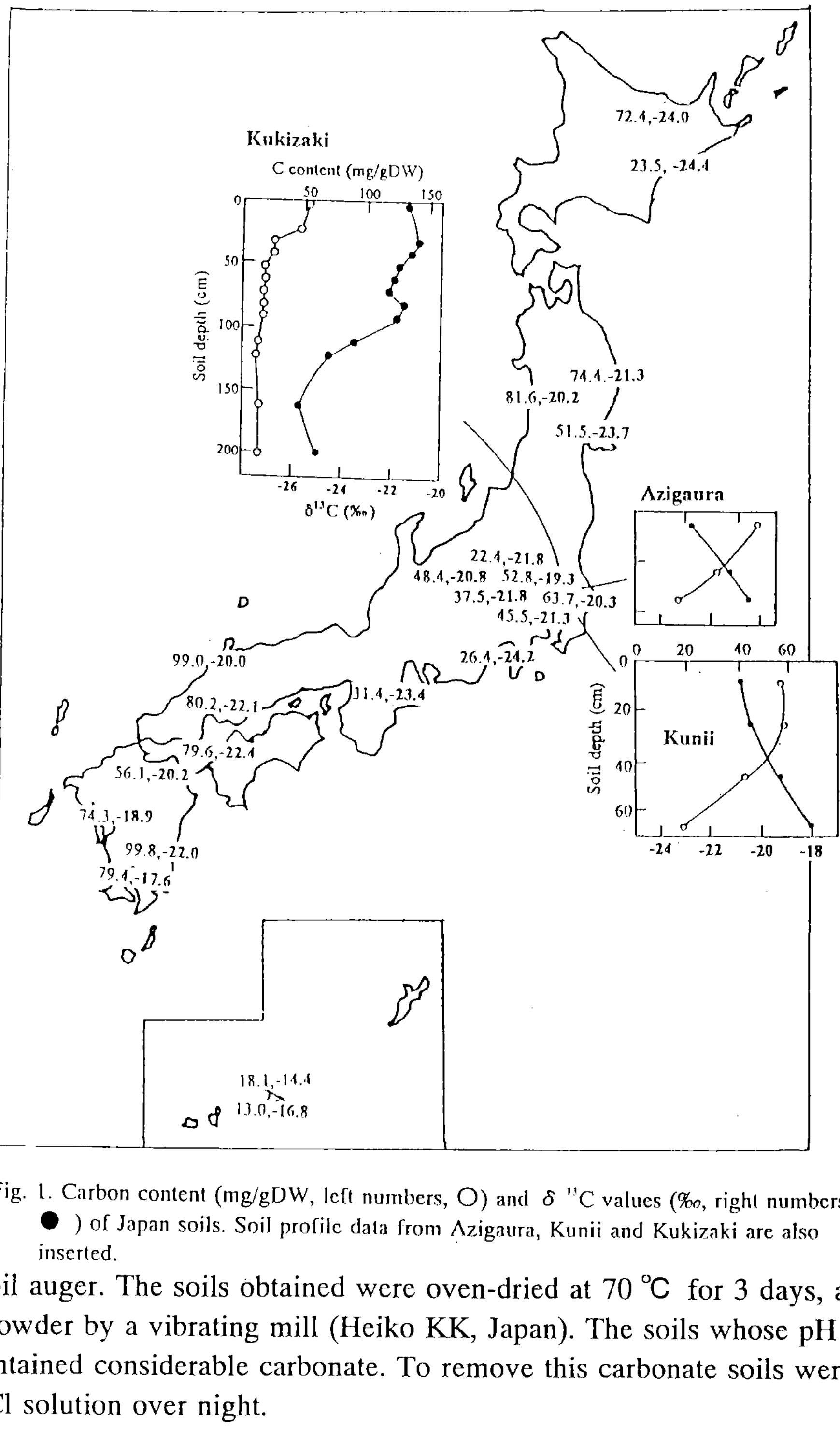

Fig. 1. Carbon content (mg/gDW, left numbers, O) and δ ^{13}C values (‰, right numbers, ●) of Japan soils. Soil profile data from Azigaura, Kunii and Kukizaki are also inserted.

cm) by soil auger. The soils obtained were oven-dried at 70 ℃ for 3 days, and ground to the fine powder by a vibrating mill (Heiko KK, Japan). The soils whose pH were more than 7 contained considerable carbonate. To remove this carbonate soils were treated by the 0.5 M HCl solution over night.

(2) Analysis of C content and δ ^{13}C values

On-line ANCA-SL mass spectrometer (Europe Scientific, UK) was employed for the analysis of carbon content and δ ^{13}C values of soils. By this method, one sample soil was analyzed in 6 min. Soil fine powders were weighed into tin capsules as much containing 100 to 1000 μ g carbon per capsule.

4. Results and Discussion

Fig. 1 shows the C contents and δ ^{13}C values of cultivated soils in Japan. The organicC contents ranged 22 to 100 mg / gDW except for Okinawa, where around 15 mg/gDW.

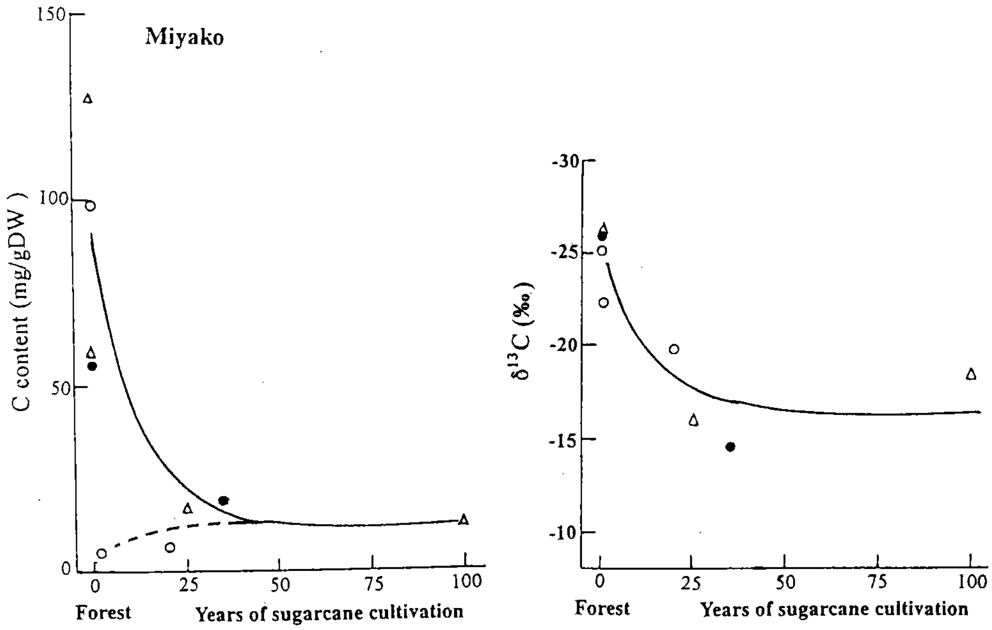

Fig. 2. Carbon content and $\delta^{13}C$ values of top soils of forests and sugarcane fields in Miyako. ○: Yellow soil, ●: Gray lowland soil, △: Dark-red soil.

Their $\delta^{13}C$ values were between -22 ‰ to -18 ‰ except for some sites with around -24‰ (Hokkaido and Shizuoka) and around -15 ‰ (Okinawa). Soil profile analysis at Ajigaura, Kunii and Kukizaki of Ibaraki prefecture (their soils are volcanic ash, Ando soil, up to the depth of around 100 cm) showed that their $\delta^{13}C$ values were between -22‰ and -18‰ , although their crops were wheat or sweet potato (C_3 plants). The soils lower than 100 cm depth at Kukizaki, $\delta^{13}C$ values showed around -24‰, typical C_3 plants. From these analysis of $\delta^{13}C$ values of Japan soils, some C_4 plants likely *Miscanthus* sp. prevailed inte nsively inAndo soils, and their residues have last even after long time C_3 crop cultivation since *Miscanthus* sp. residues contain lignin.

Fig. 2 showed the organic C contents and $\delta^{13}C$ values of top soils from forests and sugarcane cultivated fields with different years in Miyako Island. The organic C contents in forest varied between 5 and 120 mg / gDW, but after shift to sugarcane fields. C content consistently decreased to around 10 mg / gDW. The $\delta^{13}C$ values of forest soils were around -25‰, typical value of C_3 plants and after 25 years the values reached to around -17‰. These results indicate incorporation of sugarcane carbon (-13‰) and quick decomposition of forest carbon (-25‰) but some persistence of forest carbon still after 100 years sugarcane cultivation.

Fig. 3 indicate the variation of C contents and $\delta^{13}C$ values in Philippine soils at forest and sugarcane fields. The C contents of forests were 30 to 65 mg/gDW. Suddenly after transfer to sugarcane fields, they went down to below 20 mg/gDW, and after 50 years they have been stabilized to 15 mg/gDW. The $\delta^{13}C$ values of organic carbon of forest soils was around -27‰, typical value of C_3 plants, and went down to -14‰ (typical C_4 plant) after 50 years. The reach to -14‰ apparently occurred after 10 years in some soils and 50 years in other soils. At present, we cannot find the exact reason, but probably the organic matter decomposition activity of organisms may vary depending on soil nature or environments.

The C contents and $\delta^{13}C$ values of Thai top soils are shown in Fig. 4 for the north-east area (upper) and the central and western areas (lower). The soils in the north-east area are

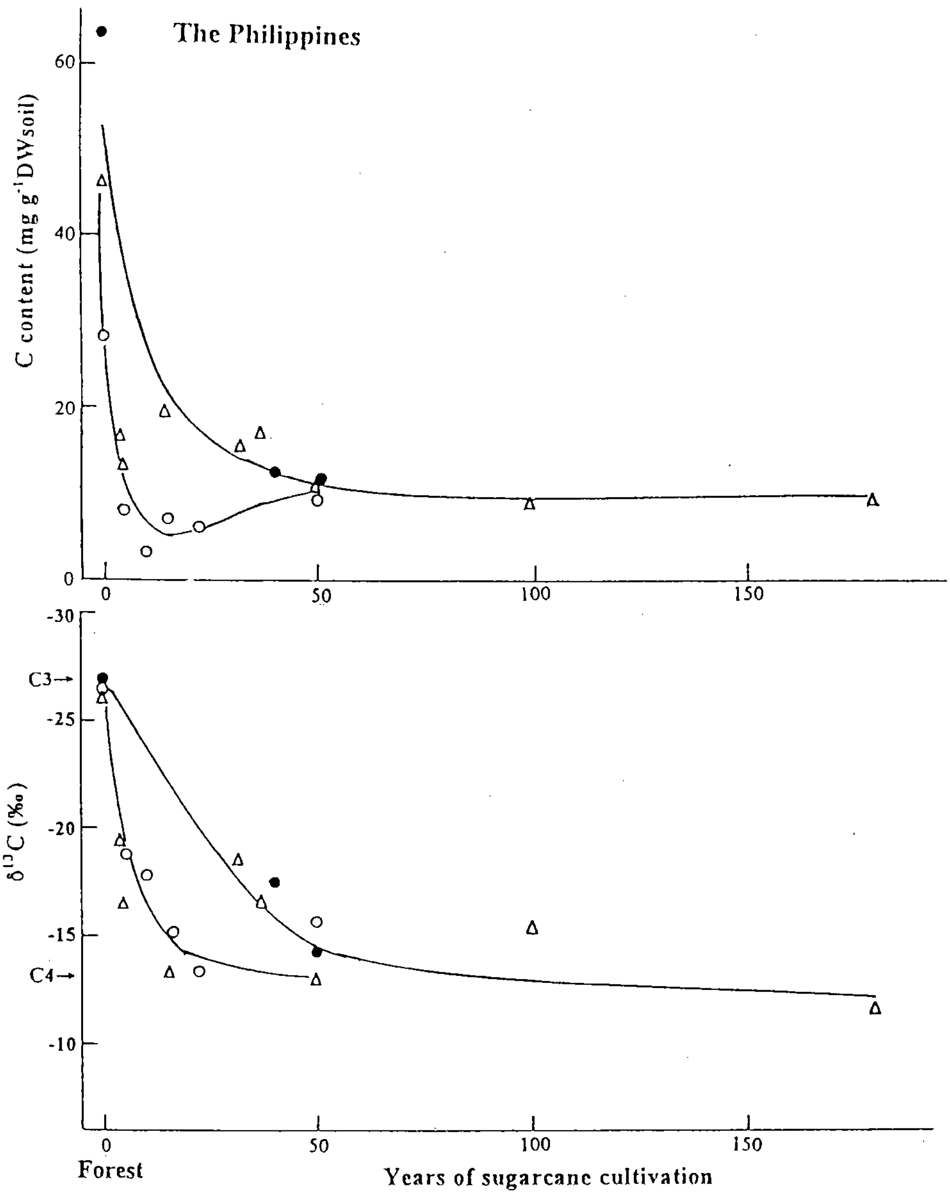

Fig. 3. Carbon content (upper) and δ ^{13}C value (lower) of top soils of forests and sugarcane fields in the Philippines. O: Central Luzon,●: Nasugbu, Luzon, Δ: I

sandy and their C contents were very low about 5 mg/gDW in forests and around 2 mg/gDW in sugarcane fields. The δ ^{13}C values of forest soils were around -27‰, and after 8 years of sugarcane cultivation the δ ^{13}C value reached to around -17‰. The soils in mg/gDW in forest soils and 10-15 mg/gDW in sugarcane fields. Thus the shift of forests to sugarcane field showed small changes compared to the cases in Miyako or Philippine soils. The years of continuous sugarcane cultivation in central and western areas were longer that in the north-east area. The δ ^{13}C values of -27‰ at forests changed to around -17‰ after 20 years sugarcane cultivation.

The data of change in organic C content and δ ^{13}C value when forests (C_3 plants) were shifted to sugarcanes (C_4 plant) cultivation in tropical and semi-tropical areas indicate that C content of top soils suddenly went down and simultaneously δ ^{13}C values also changed from C_3 values (-27‰ ~-24‰) to C_4-dominant values (-17‰ ~-14‰) within 10 to 50 years. About 250 Thai soils are left for analysis of C content and δ ^{13}C values, and data

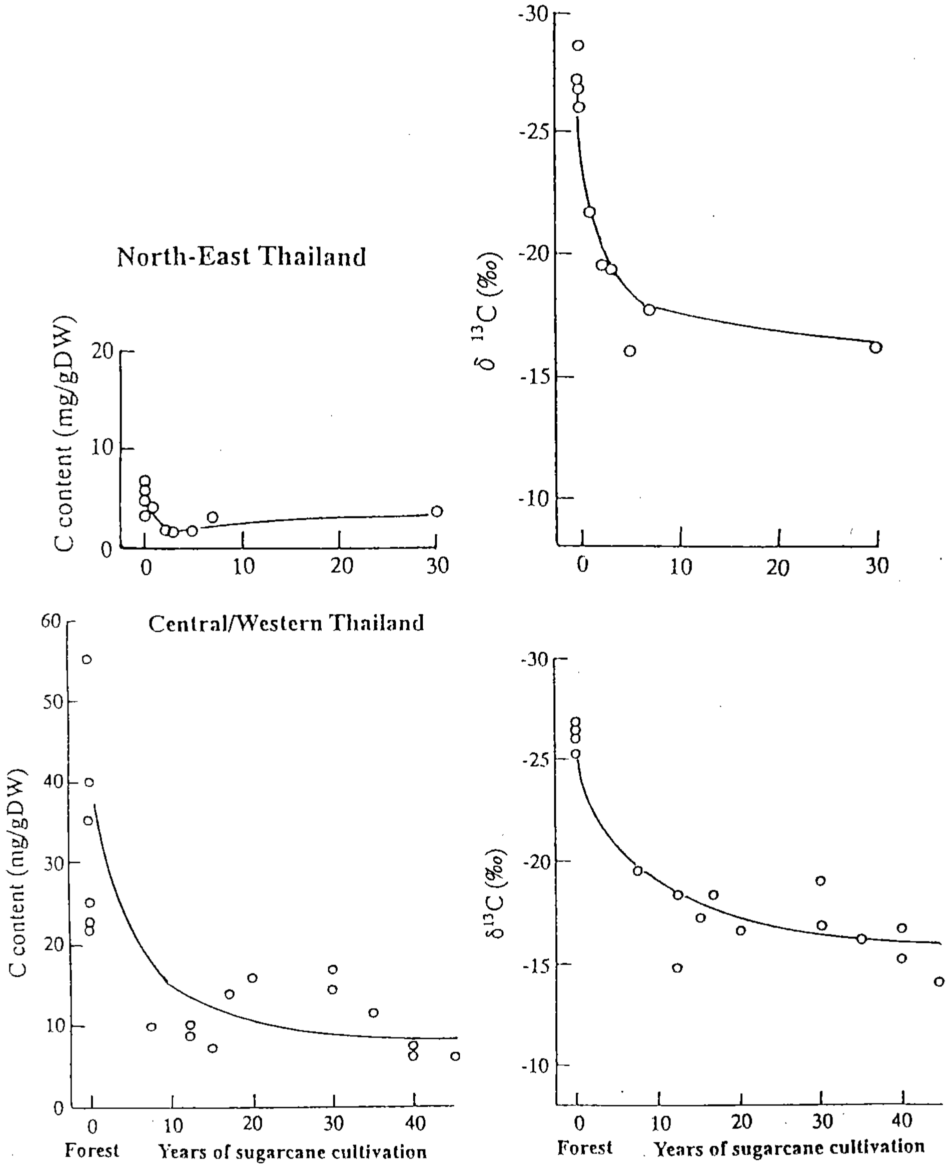

Fig. 4. Carbon content and δ ^{13}C values of top soils of forests and sugarcane fields in North-east (upper) and central and western (lower) Thailand.

analysis on deeper layers of soils are also left. After this, we like to make a global modelling of carbon flows using the new information we have had through this project.

References

1) Scharpenseel, H.W. & Pfeiffer, E.M. (1995) Carbon cycle in the pedosphere. *In* Proceeding of the Tsukuba global carbon cyele worhshop. p. 146-160.

2) Balesdent, J., Wagner, G.H. & Mariotti, A. (1998) Soil organic matter turnover in long-term field experiments as revealed by carbon-13 natural abundance. Soil Sci. Soc. Am, J., 52:118-124

3) Neill, C., Fry, B., Melillo, J.M., Steudler, P.A., Moraes. J.F.L. & Cerri, C.C. (1996) Forest- and pasture-derived carbon contributions to carbon stocks and microbial reapiration of tropical pasture soils. Oecologia, 107:113-119. (1996)

4) Yoneyama, T. (1996) Simulation of vegetation changes from δ ^{13}C values of soil organic carbon. RADIOISOTOPES 45:659-660.

5) Yoneyama, T. (1998) Variation of natural abundance of ^{13}C and ^{15}N in plants and animals. Kagaku to Seibutsu 26:176-183.