A SCHEME OF PRECISION CARBON FARMING FOR PADDY

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ABSTRACT

Paddy soil used to have a low level of organic matters, generally below 3 %, because of its concerns of producing harmful materials to the crop growth in a less-oxygen decomposition process. On the other hand plowing-in composts and organic fertilizers improves the soil condition. If a carbon-capturing paddy management is described in a correct manner, it could become precision carbon farming aiming at both soil improvement and clean development mechanisms. This paper discusses the practice of Aguri Co., Ltd., a paddy grower, towards a new scheme of precision paddy. With the data collected from nine fields with more than 5-year organic management using the real-time soil sensor during 2004 to 2008, total carbon and total nitrogen were analyzed. As expected, increases in total carbon and total nitrogen were observed by more than 1 % and a significant spatial variability of total carbon was also detected, implying that the dynamics of sequestration rate depended on specific field conditions, and also field total carbon qualification issues. A vertical distribution of soil total carbon was investigated in the top 0.3 m with its averages locating at depths of 0.15-20 m.

Key Words: paddy, soil sensor, organic cultivation, total carbon, total nitrogen

INTRODUCTION

Carbon(C) sequestration in soils has recently become the forefront of numerous research efforts to mitigate the global warming since the terrestrial biosphere presents a significant carbon pool in the global carbon cycle, where agricultural soil is increasingly recognized to be an effective means for capture and storage of atmospheric C. Implementing of proper agricultural management can significantly enhance accumulation rate of soil organic carbon (SOC) over time (e.g. Ringius, 2002; West and Post, 2002), thereby sequestering carbon dioxide from atmosphere. In light of the Emissions Trading the gains of additional carbon that captured in soils represent potential carbon credits which indicate an extra source of income for farmers. Thereupon the carbon-capture farming practices that can generate carbon credit without compromising yields are defined as “carbon farming”. Carbon farming practices historically are infeasible as soil carbon vary dramatically within across fields, which brings up important questions of how to quantify carbon on a field scale (Weersink and Joseph, 2003; Christy et al, 2003) when assessing a sequestration program. Standard methods of estimating soil C are mainly laboratory based analysis of soil core samples, which are labor intensive and time consuming that limits applicability for large land areas (Wielopolski, 2005). Hence, there is a need for in situ quantification of C in a rapid and accurate manner. Precision agriculture (PA), which relies on the existence of in-field variability, opportunely offers a solution for carbon farming. The real-time soil spectrophotometer (RTSS) we developed enables the soil spatial variability of fields to be measured, meanwhile provide soil maps and information to support decision making for both researchers and farmers (Shibusawa, 2007).

Complexity of dynamics in carbon and nitrogen cycles sometimes rejects a correct evaluation of soil productivity with environmental concerns as shown in Fig. 1. If a surplus of organic materials is plowed-in, leaching of nitrate nitrogen will come out and methane gas a global warming gas will be generated under a reduction condition of submerged paddy. Therefore the evaluation of carbon pool should be evaluated in spatio-temporal changeable conditions.

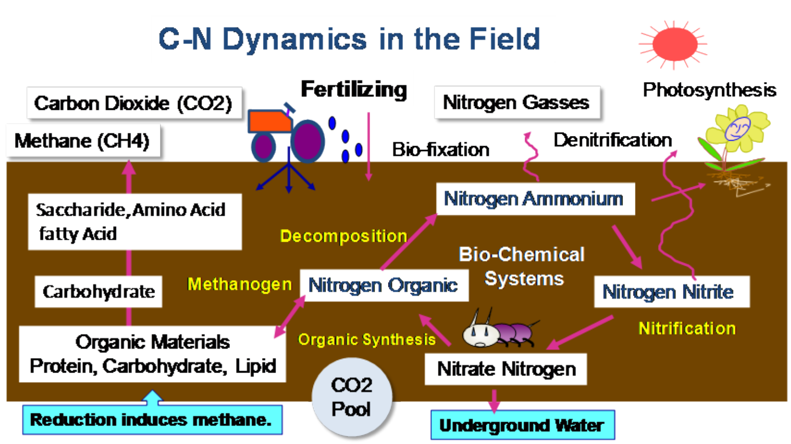


Figure 1. Carbon pool as a target in complexity of soil bio-chemical systems.

Hence, this study investigated the feasibility of carbon farming in Japanese paddy fields through a pioneering PA study and attempted to identify potential inputs for carbon-capture activities. Specifically, the aims of this study were to: (1) Use a real-time soil sensor to map and quantify the total carbon (TC) and total nitrogen (TN) in fields; (2) Examine whether total carbon and total nitrogen may change (increase) over time; (3) Examine whether the identified changes are statistically significant; (4) Investigate the spatial distribution and variability of total carbon and total nitrogen within and across fields; (6) Determine the sampling depth for total carbon and total nitrogen by the real-time soil sensor.

Nitrogen was considered in this study due to its importance in forming soil organic matter to fix carbon in the soil. More importantly, successful carbon farming should not compromise the productivity of agriculture, and nitrogen is an important element for the growth and development of all crop plants; therefore, we used total nitrogen as an index of productivity.

MATERIALS AND METHODS

Experimental Site

The study was conducted in Matsuyama city in Japan, where a number of small paddy fields are managed by an agricultural company, Aguri, which is one of the pioneers of Japanese PA models and has been conducting farm management by real-time soil sensor since 2004.

According to the Duke gold standard, changes in soil carbon typically cannot be clearly determined between the first year that farming systems are ameliorated to the next when assessing a sequestration project; the changes may not be measurable or may be caused by other factors, so a period of at least 5 years is recommended. Hence, nine of Aguri's 65 fields were chosen, since soil information has been collected annually for these nine fields by real-time soil sensor after harvesting for 5 years since 2004, as shown in Table 1.

Table 1. Information of data collected from the selected fields by the real-time soil sensor (RTSS).

		Sampling Size by RTSS				
Field NO.	Area(a)	2004	2005	2006	2007	2008
49	22.41	391	324	318	334	329
50	21.78	567	453	434	467	474
120-1	11.2	230	204	196	221	207
120-2	11.2	186	155	155	160	149
131	14.7	261	220	224	242	224
147	11.37	233	203	203	216	201
148	8.93	235	211	207	231	220
149	15.67	278	229	226	247	238
157	23	443	282	280	295	279

Real-time Soil Sensor

The fundamental concept embodied in precision agriculture is to understand within/between-field variability of soil characteristics through the on-the-go soil sensing technologies and mapping strategies. The RTSS (SAS1000, made by Shibuya Machinery Co. Ltd) presented herein is one of such sensor, which measures the soil C based upon reflectance spectroscopy (Fig. 2).

The RTSS acquires soil data through a sensor units housing where core systems of optical analysis are equipped. A light source through a single optical fiber inside the sensor units housing illuminates the soil and reflected radiation is collected for analysis by a spectrometer that has linearly arrayed photo-diodes of 256 channels for visible lights range at 400 to 900nm and 128 channels for near infrared lights range at 900 to 2400nm. This system acquires spectra data as the tractor is running across the field at speeds of 1-4km/h. Soil maps are made by measuring on equally spaced intervals, typically at 2-4 second per data, and then interpolating the results between intervals (Shibusawa, S. et. al, 2007).

Figure 2. Real-time soil sensor (RTSS) used in the experiment.

Calibration and Mapping

When the RTSS gathering reflectance data from the target fields, a number of soil samples from same position were also collected for chemical analysis. The spectrum from each sample location was matched with laboratory analysis to create a calibration model where partial least squares regression (PLS) was employed to predict soil parameters. The original spectrum data were treated with Savitzky-Golay smoothing method and 2nd derivative pretreatment within which the best performed one in terms of cross validation error were selected for usage in making fields maps. The field maps are created by simply applying the selected calibration to the whole set of field spectra (Christy et. al, 2003).

Statistical Analysis of Changes in Total Carbon and Nitrogen

In order to find out whether the changes in TC and TN are statistically significant, one-way analysis of variance (ANOVA) was performed using statistical package for the social sciences (SPSS). ANOVA is a powerful statistical procedure to test for differences among several independent groups, which therefore generalizes t-test to more than two groups.

Soil Sampling and Analysis in Depth

In order to determine the optimal sampling depth for soil carbon, vertical distribution of C and N concentrations in the soil were also examined in this study. Samples were collected from one of the paddy field in Matsuyama site in December of 2008. Six samples in each of the 10 points distributed equably were taken at 0-5, 5-10, 10-15, 15-20, 20-25 and 25-30cm depths using a metal stick. In the laboratory, samples were carefully weighed and dried to a constant weight and reweighed. TC and TC were measured by dry combustion method using a Sumigragh NC-80 analyzer and calculated by calibration of acetanilide.

RESULTS AND DISCUSSION

Quantified Total Carbon and Total Nitrogen in the Fields from 2004 to 2008

Based on the analysis of the spectral data collected by the real-time soil sensor, we obtained total carbon values measured from 12,082 points in total in the nine fields in Matsuyama from 2004 to 2008. The changes in quantified total carbon and total nitrogen of all fields and years on average were summarized in a line graph (Fig. 3).

Changes in Total Carbon and Total Nitrogen

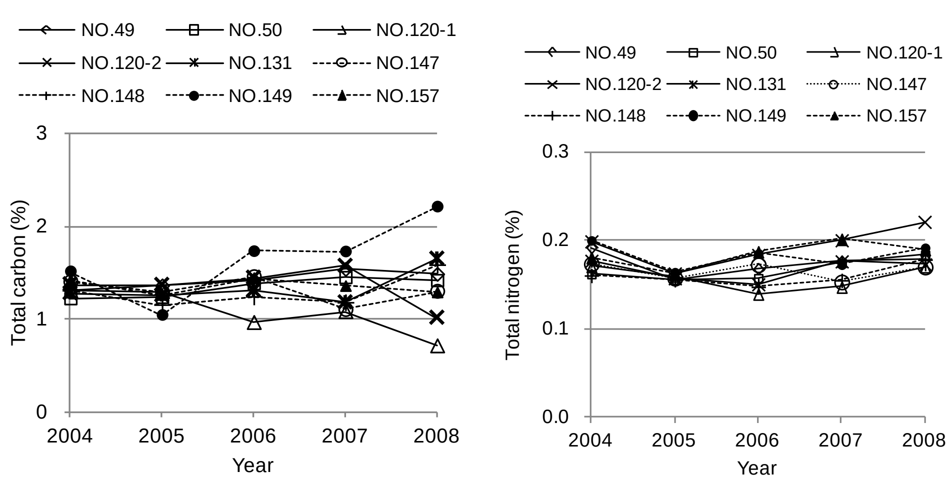


Figure 3. Total carbon and total nitrogen measured in 9 fields from 2004 to 2008

To examine whether these changes were statistically significant, we compared them with the ANOVA results. Since ANOVA is only suitable with normally distributed variables for meeting the “Homogeneity of Variance (HOV) test” at the 0.05 level, firstly we performed HOV tests, where the P-value in each data set satisfied the requirement. Therefore, the ANOVA test can be conducted for every group of total carbon and total nitrogen data. If the P-value was less than 0.05, differences between groups were statistically significant, and a larger F-ratio implied a larger variation among group means.

The F-ratio and ANOVA P value of each field over the years were found to be less than 0.05, indicating significant differences over the years and confirming the temporal variability of total carbon and total nitrogen in the Matsuyama fields. Similarly, significant differences across fields in each year can be seen, implying a significant spatial variability.

Soil Maps

The temporal and spatial variability in total carbon and total nitrogen can be more intuitively observed through soil maps produced for each field in each year. Figure 4 showed an example which demonstrates the most representative field that has continuous increase in total carbon and total nitrogen (No. 149), in which spatial variability of total carbon and total nitrogen changed year by year, and their spatial average increased with year.

Distribution of Total Carbon and Total Nitrogen with Depth

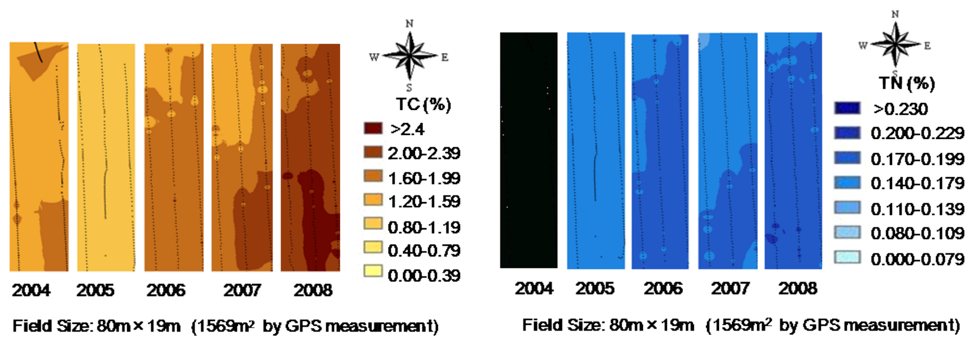


Figure 4. Soil maps of total carbon (left) and total nitrogen (right) from 2004 to 2008.

The analysis of TC and TN with depth clarified the distributions of concentration in the top 0.3 m of surface sol of the paddy fields in Matsuyama. According to the soil depth variation in Fig. 5, total carbon and total nitrogen concentration were strongly stratified with soil depth, as well as C/N ratio. The highest concentration was observed in the top 0.05 m, and the concentrations of both total carbon and total nitrogen became lower at deeper soil depth. The top 0.15 m of soil included 67 % of the whole carbon in the top 0.3 m of soil. Similar results were also reported in previous studies, for example, Dick (1983) and Lai et al. (1990).

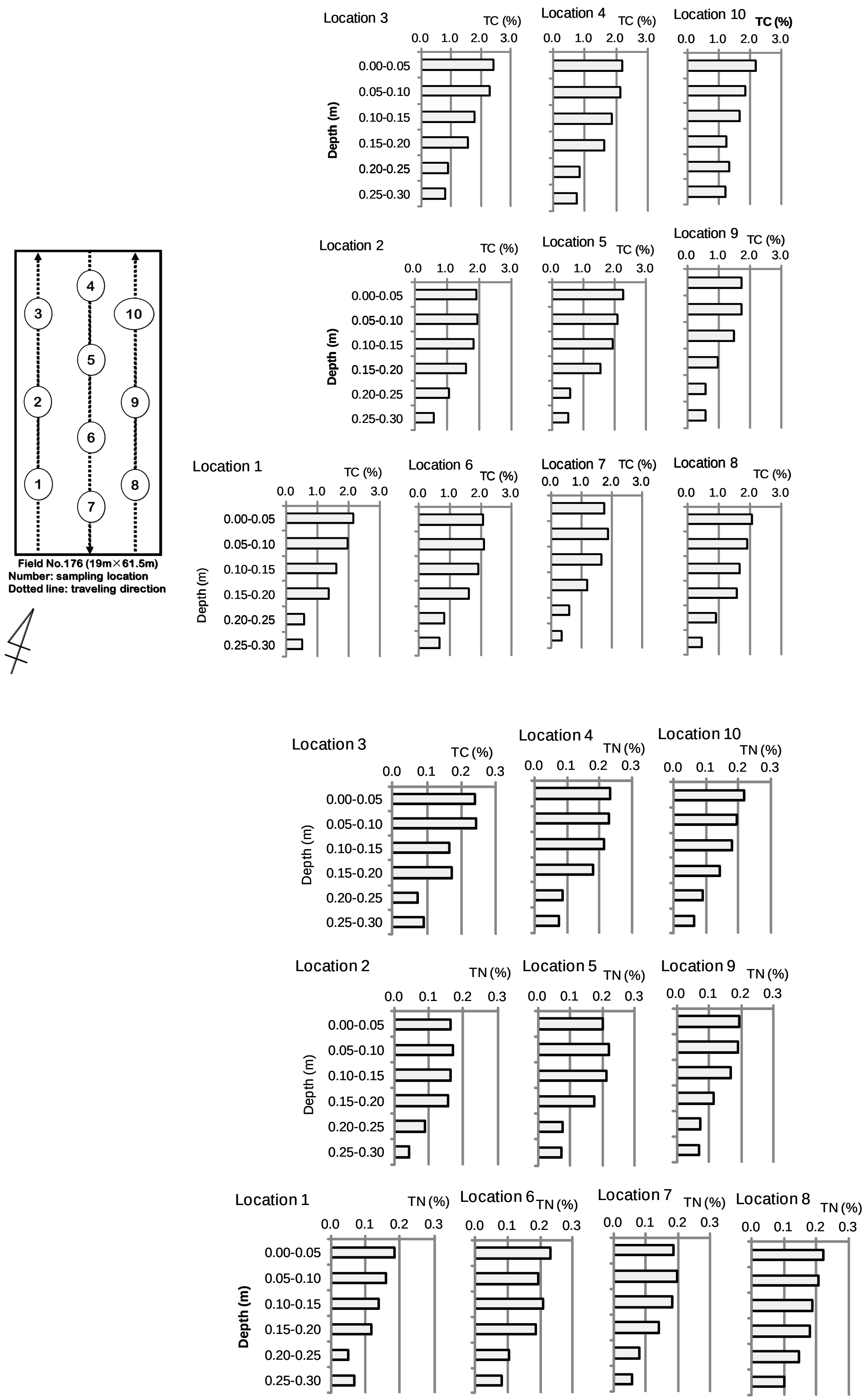
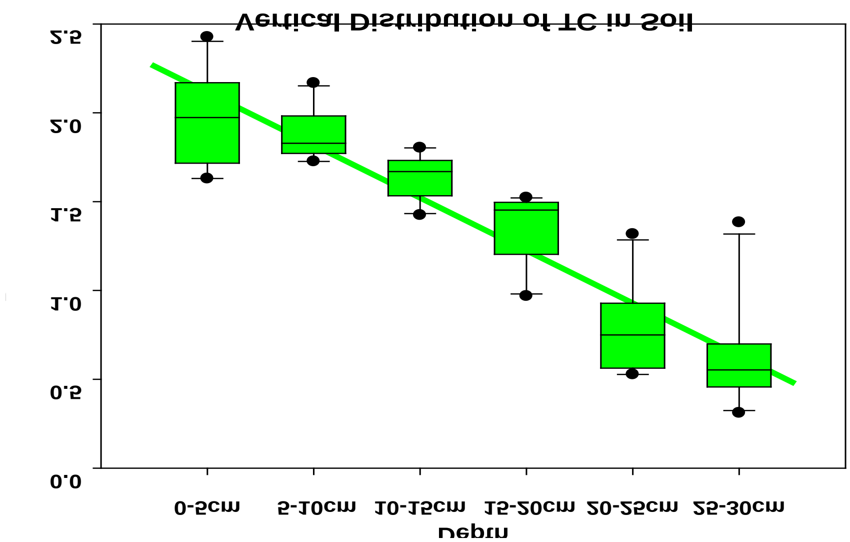


Figure 5. Maps of total carbon and total nitrogen measured in each depth.

Since the real-time soil sensor senses soil only at depths up to 0.3 m, it is important to set a proper sampling depth that can obtain representative information of the target soil properties. As carbon sequestration is most obvious in the top 0.3 m of soil, we considered the optimal sampling depth to be within this range. Figure 6 show the average value with variance of TC and TN sample collected from each depth, by which the optimal sampling depth for soil C, as well as N is recommended to be 15-20cm considering the holistic average value of TN and TC in the top 30cm soil also fell in the same range.



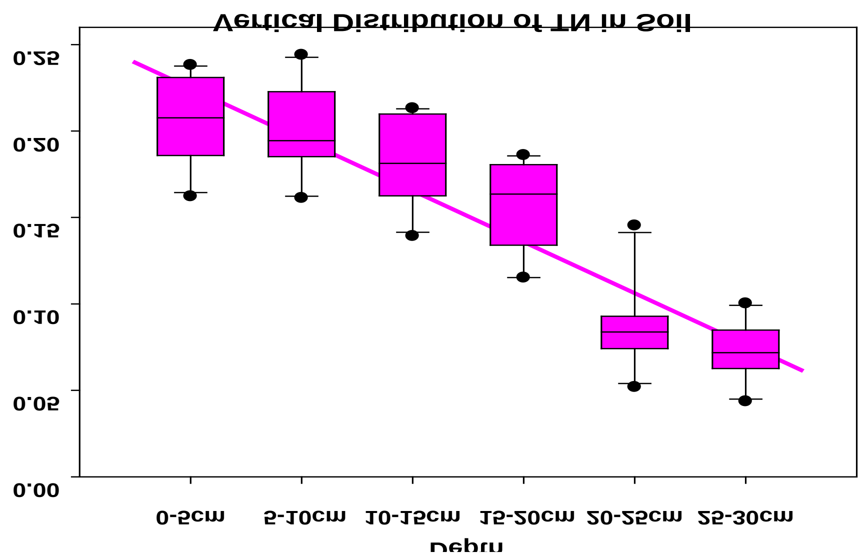


Figure 6. Vertical Distribution of total carbon and total nitrogen.

CONCLUSIONS

Based on the soil information collected by real-time soil sensor from 2004 to 2008, soil total carbon and total nitrogen in nine fields managed by Aguri Co., Ltd. in Matsuyama city were analyzed. As expected, increases in soil total carbon and total nitrogen were observed in a majority of the fields. Statistical analysis verified the significant temporal variability of total carbon and total nitrogen in each field from 2004 to 2008, indicating the potential for carbon sequestration by paddy fields over time. Moreover, a significant spatial variability of total carbon was also detected, implying that the dynamics of sequestration rate depended on specific field conditions, and that a method of quantifying field total carbon is needed. Therefore, further research on the factors that influence the rate of accumulation of soil total carbon should be conducted.

The distributions of total carbon and total nitrogen were strongly stratified in the top 0.3 m of soil following a diminishing pattern. The sampling depth for total carbon and total nitrogen by real-time soil sensor is recommended to be 0.15–0.20 m when assessing carbon farming projects in paddy fields.

In summary, carbon farming for Japanese paddy fields would appear to be feasible, however, effective carbon farming practices would depend on how farmers wish to utilize the information as well as the various factors involved.

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