Journal of Sustainable Energy & Environment 8 (2017) 91-94

Evaluating Soil Carbon Stock and Its Changes in Rice Field during 1967-2011 in Central Thailand

Sarawut Saratiean and Amnat Chidthaisong*

Center of Excellence on Energy Technology and Enviornment, The Joint Graduate School of Energy and Environment (JGSEE), King Mongkut's University of Technology Thonburi (KMUTT), 126 Pracha Uthit Rd., Bangmod, Tungkru, Bangkok 10140 Thailand
Corresponding author, Email: amnat_c@jgsee.kmutt.ac.th

Abstract: Soil is one of the most important sinks of carbon. In Thailand, paddy field accounts for more than half of all cultivated area, yet evaluation of the amount of carbon stock and the carbon sequestration potential of paddy field soil is sparse. The objective of this study is primarily to evaluate and analyze the carbon stock and its changes in paddy field soil of central Thailand. The analysis is based on the information available from past data (1967-1998) and the comparison with the current data available since 2011. The results show that the average soil carbon stock for 0-15 cm for 1970-1998 is 54.4 tonC/ha, with the value ranges from 17.25 to 106.95 tonC/ha. In 2011, this average carbon stock was increased to 60 tonC/ha. On the yearly basis, the overall change in soil carbon stock was an increase of 0.12 tonC/ha/yr (0.40% per year), or a total change of 5.91 tonC/ha for average time span of 27 years. Changes in soil carbon stock were found to relate with available potassium (K), but not with other soil properties. We attribute such relationship to the incorporation of rice biomass to the soil along the course of rice cultivation.

Keywords: Soil organic carbon, paddy field, soil properties, central Thailand.

1. Introduction

Increasing concentrations of greenhouse gases in the atmosphere have resulted in elevated global temperatures and brought about climate change [1]. To avoid the adverse impacts of climate change, greenhouse gas emissions need to be mitigated. However, prior to effectively implementing any mitigation measures, accurate and comprehensive quantification of the emissions from sources and of removals by sinks are needed.

Thailand rice planting area accounts for more than 50% of the cultivated land (about 10 million ha are cultivated with rice annually, Bureau of Statistics, 2014). According to the 2nd National Communication to UNFCCC, emissions from the agricultural sector contribute about 23% of the country total emission in 2000 [2]. Within this sector, paddy field alone contributes about 70% to the sectoral total emission. Because of this large contribution, attentions have been paid to finding out the measures to mitigate methane and other greenhouse gases in rice field [3-4]. On the other hand, as it makes up the large fraction of cultivated land in Thailand, roles of paddy soil as carbon sinks is as important as its emission sources. Studies in the past have indicated that long-term continuous rice cultivation in Java (Indonesia) and South Korea have resulted in an increase in soil organic carbon [5]. Pampolino et al. [6] reported that during 15 years of additional continuous rice cropping, topsoil SOC were consistently maintained or increased regardless of N–P–K fertilizer regime. Topsoil SOC increased up to 10% in an experiment with three rice crops per year and removal of all aboveground plant biomass after each crop. Since evaluations of soil carbon stock, sequestration potentials and the relationships between soil carbon and cultivation practices or soil characteristics in Thailand are sparse, the study was carried out to primarily evaluate the carbon stock and its changes. We expected that the results would be useful as the basis for future comprehensive evaluation of soil carbon stock and to enhance the mitigation of greenhouse gas emissions in Thailand paddy fields.

2. Experimental

This study was focused on paddy field in central part of Thailand, since this is the major rice cultivation area of the country. Based on the availability of soil data, the evaluation of carbon stock in this study covered 10 provinces; Nakonsawan, Chainat, Ayutthaya, Supanburi, Saraburi, Patumthani, Angthong and Nakonpathom. In Ayutthaya, two sampling sites; Phakhai (PH) and Tarue (TR) districts were included. Likewise, in Patumthani soil samples were also taken from two sites; Tanyaburi (TY) and Nongsue (NS).

The soil data analyzed in the current study were mainly derived from the series of reports from Land Development Department (LDD). The main document was "Characterization of established soil series in central plain region of Thailand, Reclassified according to soil taxonomy 2003" [7]. This document contained the information of carbon content, physical and chemical properties, location with coordinates of samples, and name of soil series. Soil samples were collected between 1970 and 2003. The soil carbon data obtained from this report was compared against those reported by LDD in 2011 [8]. In case where data on soil carbon was not available but organic matter content was given instead, soil carbon was indirectly derived from the relationship mentioned in the report as %OC x 1.724 = %OM [12]. Soil carbon stock through 15 cm soil depth was then estimated as;

Soil carbon stock (gC/m^2) *= soil carbon content (gC/gsoil) x bulk density* ($gsoil/cm^3$) *x soil depth (m) x area* (m^2)

Since bulk density was not measured at all of the sites, this study used the LDD soil database to derive an estimate of the bulk density. The soil survey data provide the information on all soil series in the study areas and only those were identified as paddy soils were selected. Each soil series was represented by a typical profile where its physical and chemical properties were described. The soil bulk density value was based on these properties for each soil series.

When applicable, the change in soil carbon stock was analyzed by analysis of variance (ANOVA).

3. Results and Discussions

Due to its flooded nature and usually its continuous cultivation for a long period of time that is not found in any other crops (e.g. hundreds to thousands of years), paddy soil is considered as one of the agricultural systems with high carbon sequestration potentials [5, 9]. The amount of carbon stored in soil and its sequestration potentials, however, vary greatly depending on various factors such as soil type, environmental conditions, climate, and cultivation practices.

In the current study it was found that among the sites large variations in carbon stock of paddy field soil were observed (Table 1 and Figure 1). The carbon stock of paddy soil measured during 1967-1998 was on average 54.4 tonC/ha, with the value ranges of 17.25-106.95 tonC/ha (Table 1). In 2011, the average carbon stock for all of these 10 sites was 60 tonC/ha. On the yearly basis, the overall change in soil carbon stock was an increase of 0.12 tonC/ha/yr (0.40% per year), or a total change of 5.91 tonC/ha for average time span of 27 years. The highest gain of about 6% (1.54 tonC/ha/yr) and the highest loss of 2.2% (1.74 tonC/ha/yr) were found in Chainat and Angthong, respectively.

Studies in the past have indicated that carbon stock of paddy soil is affected by various factors such as fertilization types and modes. Zhu et al. [9] investigated the effect of different fertilization modes on paddy field soil carbon in South China and found the average increase in soil carbon stock in the rage of 0.5-1% per year. However, in the central plain of Thailand, various kinds of fertilizers were applied and there is no existing statistics to track the amounts and modes of these fertilizers. Thus, it is difficult to relate fertilization with soil carbon stock and its trends. In other studies, soil carbon stock and sequestration rates were found to relate to some soil properties such as clay content, the amount of organic materials applied to soil [11].

In the current study, we analyzed the relationship between soil carbon content and soil properties (Table 2 and Table 3). Firstly, we found that during these time intervals, there was no significant change in any soil characteristics at any sites. The exception was for available P which was increased significantly at $p \le 0.08$. For the averaged carbon content, it was also increased (though not significant) from 1.56% to 1.72%. For soil texture, although it was not changed but its compositions as silt and clay were on average reduced from 33 to 38%, and 54 to 44%, respectively. Thus, there was somehow a loss in silt and clay particle from the top soil layers. In addition, rice cultivation also increased the pH from about 4.8 to 5.5 along these time spans. Secondly, there was no significant relationship between soil carbon stock and any of these soil properties, except available potassium (K) as shown in Figure 2. This positive relationship can be expressed as carbon content = 0.44 (available K) + 9.65, r = 0.68 ($p<0.001$). The rate of soil carbon change is also positively related to the rate of available K change, expressed as carbon content change = 0.0372x + 0.0405 r = 0.72, $p<0.001$.

Table 1. Carbon stock and its changes at different locations of paddy field in central Thailand provinces.

Location	C stock (1967~1998) (tonC/ha)	C stock (2011) (tonC/ha)	Time span (years)	Stock Change (tonC/ha)	Stock Change/year (tonC/ha/yr)	Annual change (% per year)
Ayutthaya_PH	55.89	70.78	41	14.89	0.36	0.65
Ayutthaya_TR	24.15	53.69	44	29.54	0.67	4.08
Supanburi	17.25	31.54	34	14.29	0.42	1.88
Nakonsawan	47.12	55.58	13	8.46	0.65	0.53
Nakonpathom	84.87	67.78	13	-17.08	-1.31	-1.55
Chainat	45.88	65.9	13	20.02	1.54	3.36
Saraburi	40.36	25.61	37	-14.75	-0.39	-0.99
Angthong	76.59	50.52	15	-26.07	-1.74	-2.27
Patumthani_TY	106.95	92.85	30	-14.1	-0.47	-0.44
Patumthani_NS	44.50	88.43	30	43.93	1.46	7.59
Average	54.36	60.27	27	5.91	0.12	0.40

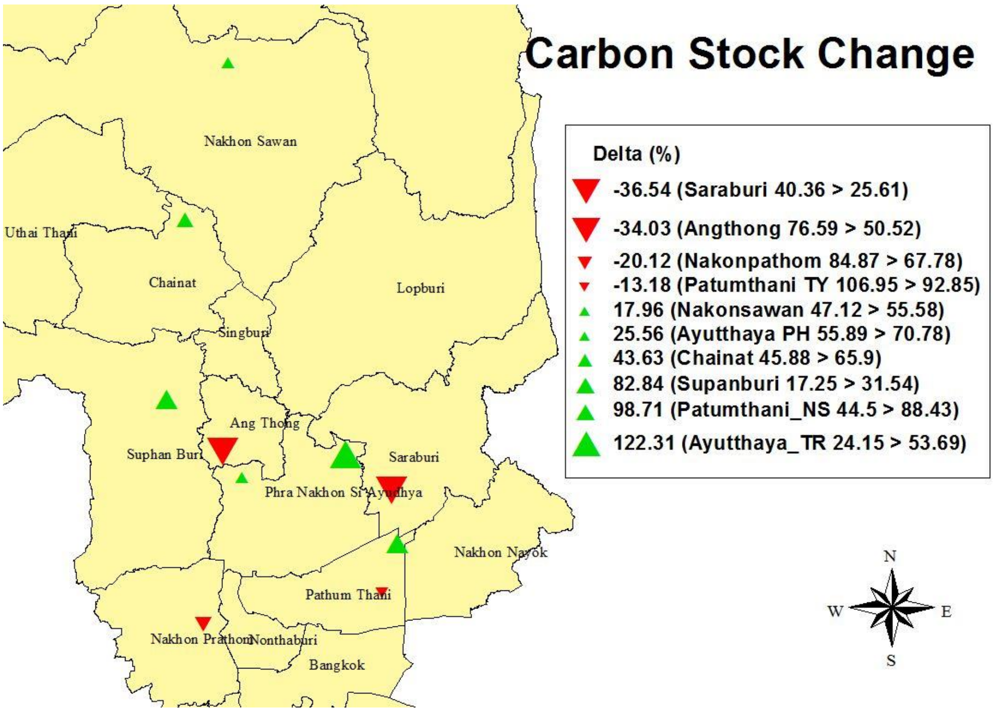

Figure 1. Magnitude and distribution of soil carbon stocks and its changes in Central Thailand provinces.

Raheb and Heidari [10] also found the positive relationship between available K and organic carbon content in paddy field soil but they did not discuss the source of such relationship. We hypothesized that the relationship could be explained by addition of rice biomass (e.g. straw, stubble and rice root) into soil. Dobermann and Fairhurst [13] reported that rice straw content relatively high amount of potassium. Removal of straw from the field which is widespread in many countries such as India, Bangladesh, and Nepal has resulted in the depletion of soil K at many sites. In Thailand, in the past it was a common practice that rice biomass after harvest was incorporated into soil. Yan et al. [11] observed increases in soil organic carbon in paddy soil in China and they suggested that increase rice productivity (mainly due to an increase use of fertilizer), especially root biomass plays an important role in SOC increase. Minasny et al. [5] also reported that root carbon has a longer residence time in soil than shoot C, and root activities also enhance soil organic matter protection via physical and chemical mechanisms. A continued addition of carbon through rice roots would be one of the reason of relationship between soil carbon stock and potassium content found in the current study.

In the case of soil carbon loss at some sites (Naknonpathom, Saraburi, Angthong, and Patumthani_TY), we could not find any relationship between soil carbon loss and soil properties. The small number of sample sites with sufficient information of soil carbon, soil bulk density, the lack of accurate information on soil cultivation practices such as fertilization rate and type, may all make such analysis difficult. Thus, it is desirable that systematic soil sampling and soil carbon tracking system be established, so that we could understand the factors affecting soil carbon stock. Such system would be also necessary to plan any activity to enhance soil carbon sequestration in Thailand paddy field soils.

4. Conclusions

This study estimates carbon stock and its changes in paddy field of central Thailand, basing on the available data from the Department of Land and Development. These data included soil characteristics, chemical and physical properties of key soil series found in the rice cultivation areas of central Thailand. Comparisons of soil carbon stock and for soil samples taken during 1967-1998 to that during 2011 were made. It was found that for majority of soil samples, carbon stock has increased at approximately 0.12 tonC/ha/yr (0.40% per year). The key finding is that changes in soil carbon stock is significantly related to available K in the soil. Relationship between soil carbon with other soil properties such as soil particles (%sand, silt, clay), available P, CEC and base saturation was not found. Since other data such as cultivation practice, the amount and mode of fertilizer application, and other soil properties (such as nitrogen content, in situ soil bulk density, etc.) are not available, further efforts may be needed to collect and analyze the relationship between soil carbon and these parameters.

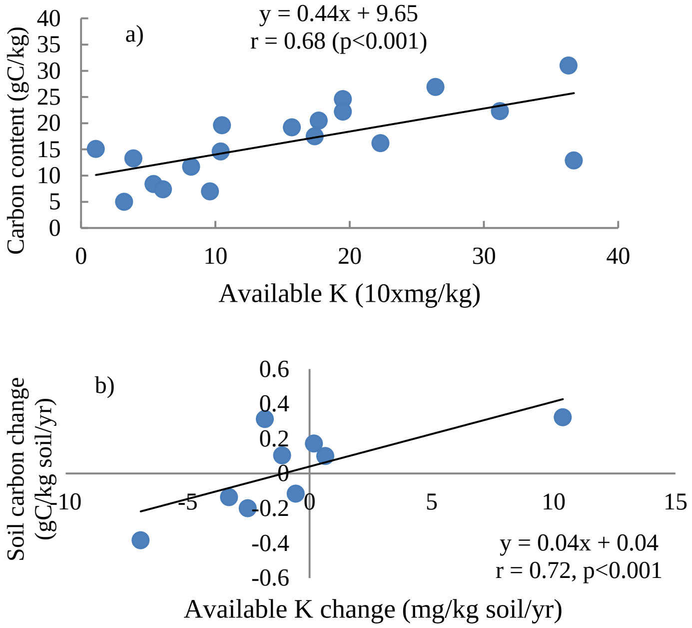

Figure 2. Relationship between a) carbon content and available K and b) rate of changes in soil carbon and available K in paddy soil.

Table 2. Key soil properties for the soil samples taken during 1967-1998 in Central Thailand provinces.

Location	Year	C (%)	Soil particle %Sand	%Silt	%Clay	Texture	pH	P (mg/kg)	K (mg/kg)
Ayutthaya_PH	1970	1.62	3	30	67	C	5	6	223
Ayutthaya_TR	1967	0.7	10	25	65	C	5	7	96
Supanburi	1977	0.5	71	24	5	SL	5.2	3	32
Nakonsawan	1998	1.19	17	47	36	SiL	5	7	NA
Nakonpathom	1998	2.46	1	34	65	C	5	37	195
Chainat	1998	1.33	12	35	53	C	4.8	11	39
Saraburi	1974	1.17	7	41	52	SiC	5.3	2	82
Angthong	1996	2.22	1	19	80	C	5	6	195
Patumthani_TY	1981	3.1	1	35	64	C	4.1	15	363
Patumthani_NS	1981	1.29	1	43	56	C	3.9	6	367

Table 3. Key properties of soil samples taken in 2011 in Central Thailand provinces.

Location	C (%)	Soil particle %sand	%silt	%clay	Soil texture	pH	Avail. P (mg/kg)	Avail. K (mg/kg)
Ayutthaya_PH	2.05	3	30	67	C	5.1	30	177
Ayutthaya_TR	1.46	7	63	30	SiCL	5.1	26	104
Supanburi	0.84	43	40	17	L	6.3	31	54
Nakonsawan	1.51	NA	NA	NA	NA	5.6	4	11
Nakonpathom	1.96	2	35	63	C	5.5	3	105
Chainat	1.75	70	20	10	SL	5.2	9	174
Saraburi	0.74	10	25	65	C	5.5	16	61
Angthong	1.92	5	37	58	C	5.5	34	157
Patumthani_TY	2.69	2	44	54	SiC	5.1	108	264
Patumthani_NS	2.23	13	52	35	Sil	6.2	28	312

References

[1] IPCC, 2013: Summary for Policymakers. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker TF, Qin D, Plattner G.-K., Tignor M, Allen SK, Boschung J, Nauels A, Xia Y, Bex V and Midgley PM (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

[2] ONEP, *Thailand's second national communication under United Nation Framework Convention on Climate Change* (2011) Office of natural resources and environmental policy and planning, Bangkok.

[3] Towprayoon S, Smakgahn K, Poonkaew S, Mitigation of methane and nitrous oxide emissions from drained irrigated rice fields, *Chemosphere* 59 (2005) 1547-1556.

[4] Doi R, Pitiwut S, From maximization to optimization: A paradigm shift in rice production in Thailand to improve overall quality of life of stakeholders, *The Scientific World Journal* (2014) pp. 11.

[5] Minasny B, McBratney AB, Hong SY, Sulaeman Y, Kim MS, Zhang YS, Kim YH, Han KH,. Continuous rice cropping has been sequestering carbon in soils in Java and South Korea for the past 30 years, *Glboal Biogeochemical Cycles* 26 (2012) doi:10.1029/2012GB004406.

[6] Pampolino MF, Laureles EV, Gines HC, Buresh RJ, Soil Carbon and Nitrogen Changes in Long-Term Continuous Lowland Rice Cropping, *Soil Science Society of America Journal* 72 (2008)798-807.

[7] Land Development Department, Ministry of Agriculture and Cooperatives, *Characterization of established soil series in central plain region of Thailand, Reclassified according to soil taxonomy 2003* (2003).

[8] Land Development Department, Ministry of Agriculture and Cooperatives, *Soil Nutrient Data in Thailand* (2011) (Unpublished Manuscript).

[9] Zhu L, Lib J, Taoc B, Hu N, Effect of different fertilization modes on soil organic carbonsequestration in paddy fields in South China: A meta-analysis, *Ecological Indicators* 53 (2015) 144-153.

[10] Raheb A, Heidari A, Effects of clay mineralogy and physico-chemical properties on potassium availability under soil aquic conditions, *Journal of Soil Science and Plant Nutrition* 12 (2012) 747-761.

[11] Yan X, Zhou H, Zhu QH, Wang XF, Zhang YZ, Yu XC, Peng X, Carbon sequestration efficiency in paddy soil and upland soil under long-term fertilization in southern China, *Soil & Tillage Research* 130 (2013) 42-51.

[12] Pribyl DW, A critical review of the conventional SOC to SOM conversion factor, *Geoderma* 156 (2010) 75–83.

[13] Dobermann A and Fairhurst TH, *Better Crops International 16, Special Supplement* (2002) 7-16.