International Journal of Agricultural Technology 2022Vol. 18(2):733-744
Available online http://www.ijat-aatsea.com
ISSN 2630-0192 (Online)

Changes in soil properties of Bangkok soil series from rice stubble burning

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Preesong, J. and Yampracha, S. (2022). Changes in soil properties of Bangkok soil series from rice stubble burning. International Journal of Agricultural Technology 18(2):733-744.

Abstract Rice stubble burning, a very improper crop residue management, causes air pollution and soil degradation. Nevertheless, it is typically practiced by today's Thai farmers. The results indicated that the soils in the four plots were all clayey soil, which was an established characteristic of Bangkok soil series. The results showed higher content of soil organic carbon, higher contents of total nitrogen and total sulfur, as well as higher cation exchange capacity of the soil managed with no rice stubble burning at the depth of 0-15 cm. These differences were verified to be the effect of stubble burning on the topsoil because there were no differences detected in the subsoil, not any other factors. Nevertheless, the soil pH and exchangeable Ca of the soil managed by rice stubble burning were higher. Since the level of soil organic carbon was the strongest indicator of soil fertility, it would be communicated to the farmers that managing crop residue by stubble burning would make the soil less fertile than no stubble burning.

Keywords: Crop residue management, Rice stubble burning, Soil properties

Introduction

In Thailand, agriculture in the past rarely required any chemical fertilizer. Crops would produce high yield because of the high fertility of the virgin soil. Therefore, when Thai farmers wanted to increase their rice production, they just grew more rice in more plots, expanding their arable land. However, today, only very limited areas of new arable land in Thailand are available to farmers. The best way to increase crop production is by making the soil of the same plots more fertile. Most arable land areas have been used for continuous cropping for a long time, and the typical way that Thai farmers have managed crop residue has been by burning the crop stubbles might be a reason for the lower fertility, i.e., soil degradation.

In general, soil degradation in cropping systems is driven by suboptimal management practices that induce declines in soil biological, chemical, and

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physical quality, reducing the capacity of the soil to support production (Zingore *et al*., 2015). Crop residue management has a profound influence on the nutrient-supplying power of soils over the short and long term. Usually, crop residue management refers to maintain the soil surface cover and protecting the soil from nutrient losses and erosion. Additionally, it helps in improving different physical, chemical, and biological processes within the soil (Johnson *et al*., 2014). Proper crop residue management helps in adding soil organic matter and provides a nutrient source for soil micro-organisms (Shan and Yan, 2013). The impact of previous crop residue on nutrient availability to subsequent crops has received much attention in crop production-rotation systems throughout the world. Almost all crop residues contain carbon (C), nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), sulfur (S) and micronutrients which are released more slowly by microbial decomposition (Parr and Papendick, 1978).

Rice is a major crop in Thailand. It is grown in around 9.76 million hectares of cultivation area in 2019, which produced 3.84 million tons of paddy rice in that year (Office of Agricultural Economics, 2019). There were around 11.50 thousand hectares of rice cultivation areas in Bangkok at the time of this study, locating in the green space of Bangkok. Most rice cultivation areas were situated in eastern Bangkok areas such as Ladkrabang, Minburi, Khlongsamwa, Nongchok, and Kannayao districts (Office of Agricultural Economics, 2020). After a harvest, a large amount of stubbles would be left in the rice plot. Stubble management options available are such as stubble burning, incorporation into the soil, surface retention, mulching, baling, and physically removing the stubbles (Krishna *et al*., 2004). However, rice stubble burning option was one of the major causes of serious particulate pollution in the air in many regions of Thailand in the last several years (Greenpeace Thailand, 2021). Three greenhouse gasses (GHG), CO_2 (carbon dioxides), N_2O (nitrous oxide), and CH_4 (methane), and thirteen air pollutants, CO (carbon monoxide), NMHC (non-methane hydrocarbons), NO_X (nitrogen oxides), SO_2 (sulfur dioxide), TPM (total particulate matter), PM2.5 (fine particulate matter), PM10 (coarse particulate matter), PAHs (polycyclic aromatic hydrocarbons), PCDD/F (polychlorinated dioxins and furans), BC (black carbon), OC (organic carbon), NMVOC (non-methane volatile organic compounds), and NH_3 (ammonia), were emitted from open-field burning (Gadde *et al*., 2009; Pouliot *et al*., 2017; Peng *et al*., 2016). Kim Oanh (2017) reported that Bangkok was facing an air pollution problem in which rice burning accounted for 24.6 to 37.8% of the seriously high PM 2.5 level (Kim Oanh, 2017).

That seriously high PM 2.5 level in the air was a specific example of rice stubble burning at this time. Most unfortunately, this PM2.5 pollution occurred in the same period of Covid-19 pandemic, and a research study (Kim Oanh, 2017) reported increased rates of Covid-19 infection in areas with high levels of air pollution. In general, burning rice stubbles can cause many other kinds of problem, such as house fire, annoying dust, and smog that can cause road accidents. The rice stubble burning issue that was investigated in this study, however, was on soil deterioration or lack of soil fertility that reduced rice yield (Land Development Department, 2005). Most of the soil in Ladkrabang and Nongchok district was Bangkok soil series (Land Development Department, 2003), which were clayey and fertile, but continuous rice stubble burning might cause this kind of soil to degrade.

Therefore, the primary objective of this research was to determine the differences in essential soil properties between Bankok soil series managed with rice stubble burning and Bangkok soil series managed with no rice burning. To reach this primary objective, the determination procedure was repeated at two soil depths: the depth of topsoil (0-15 cm) and subsoil (15-30 cm). The changed topsoil properties due to stubble burning would be verified by the unchanged properties of the subsoil to the changed soil properties due to stubble burning.

Materials and methods

Soil sample

Soil samples were collected from four plots in Bangkok in February 2020. NC1 and NC2 represented two rice farm plots from Nongchok district, while NC3 and NC4 represented two plots from Ladkrabang district, Bangkok, Thailand. NC1 and NC3 were managed with no rice stubble burning, while NC2 and NC4 were managed with rice stubble burning. As shown in a world map in Fig.1, NC1 (soil collected in December 2019) was at latitude 13˚55'23.3"N and longitude 100˚54'32.6"E, NC2 (soil collected in February 2020) was at latitude 13˚55'46.1"N and longitude 100˚54'25.9"E, while NC3 was at latitude 13˚45'41.6"N and longitude 100˚48'38.8"E, and NC4 was at latitude 13˚46'19.6"N and longitude 100˚49'13.9"E. Even though the times of all sample collection were in an off-rice season in Thailand, the sample collections of NC3 and NC4 were done on days in the rainy season, while the collections of NC1 and NC2 were done on days in the dry season.

Disturbed and undisturbed soil samples were collected from two layers of soil at different depths—topsoil at 0-15 cm soil depth and subsoil at 15-30 cm soil depth. Five samples of each type were collected from five different locations in each plot. The disturbed soil samples were collected by a composite soil sampling method with a soil augur and air-dried after removal of plant fragments like visible roots. Then, the soil sample was ground and passed through a 2mm sieve. The resulting fine powder was then analyzed for its physical and chemical properties. On the other hand, the undisturbed soil samples were collected with a soil core. Four soil samples at two different locations in a plot and at two different depths were collected at every plot. For measuring a soil sample's bulk density, the sample had to be dired in an oven at 105˚C for 24 h first before it could be weighed properly (Land Development Department, 2010).

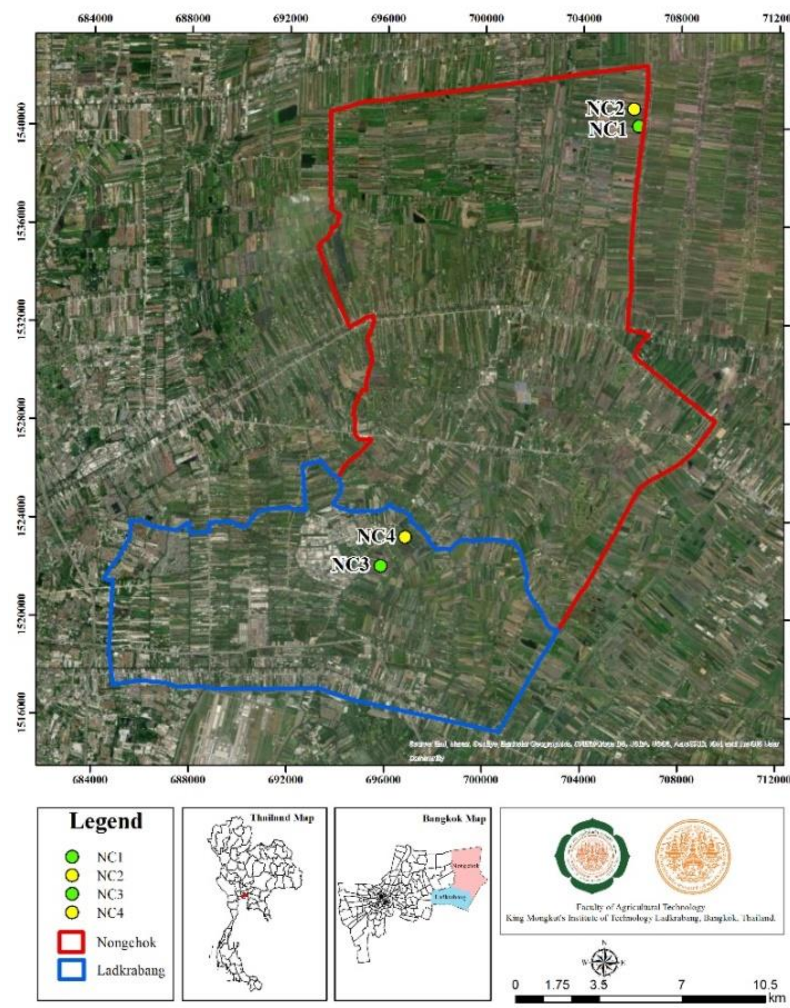

Figure 1. Map of experimental plot location

Experimental design

The experimental design was a 2×2 factorial arrangement in randomized complete block design (RCBD) with 2 replications. Factor A was two rice stubble management such as non-burned rice stubble field and burned rice stubble field. Factor B was two soil depth such as 0-15 and 15-30 cm soil depth.

Soil analysis

The air-dry disturbed soil samples were analyzed for pH (soil: water, 1:1), electrical conductivity (EC soil: water, 1:5) (Richards, 1954) and soil organic carbon (SOC), total nitrogen (TN) and total sulfur (TS) using a CNS analyzer (LECO Corporation, 2016). Available phosphorus (P) was determined colorimetrically after extraction by the Bray II method at 1:10 ratio of soil to solution and determined using a spectrophotometer at wavelength 882 nm (Bray and Kurtz, 1945). Exchangeable potassium (K), exchangeable calcium (Ca), exchangeable magnesium (Mg) and exchangeable sodium (Na) were extracted by 1 *M* ammonium acetate pH 7 (Soil Chemical research center, 2001). Extractable iron (Fe), extractable manganese (Mn), extractable zinc (Zn) and extractable copper (Cu) were extracted by 0.005 *M* DTPA pH 7.3 (Lindsay and Norvell, 1978). Exchangeable cation and micronutrients were measured by the coupled plasma optical emission spectrometer (ICP-OES). Cation exchange capacity (CEC) were extracted by 1 *M* ammonium acetate pH 7 and then distilled using a distillation apparatus (IITA, 1979) and Soil texture were determined using the pipette methods (Gee and Bauder, 1986).

Statistical analysis

Data were subjected to analysis of variance (ANOVA) and differences among between treatment means were compared by Duncan's multiple range test (DMRT) at 0.05 significance level ($P \leq 0.05$). Due to the soil collecting peroide in Nongchock and Ladkrabang district was different in dry and rainny season, respectively. The means of non-burned rice stubble field and burned rice stubble field in Ladkrabang and Nongchock district which collected in the same peroide were compared using a pair T-test.

Results

Physical and chemical properties

The soil physical properties were shown in Table 1. The soil texture is a fine textural class in both soil depth at 0-15 cm and 15-30 cm with non-significant differences in clay percentage. The bulk density at 15-30 cm soil depth was significantly higher than 0-15 cm. The rice stubble management was not affected on both properties. The soil chemical properties were shown in Table 1 and Table 2. The electrical conductivity (EC) and total sulfur (TS) in non-burned rice stubble fields were significantly higher than burned rice stubble fields at the 0.01 and 0.05 significant levels, respectively (Table 1). Soil organic carbon (SOC), total nitrogen (TN), and cation exchange capacity (CEC) at 0-15 cm soil depth was significantly higher than 15-30 cm soil depth at the 0.01 significant level. An interaction between the rice stubble management and soil depth was found in SOC and TN at the 0.05 and 0.01 significant levels, respectively. Exchangeable calcium (Ca) in burned rice stubble fields was significantly higher than that of non-burned rice stubble fields. Exchangeable Ca and extractable Fe at 0-15 cm soil depth were higher than that of 15-30 cm soil depth and significantly different at the 0.01 level. Exchangeable Mg at 15-30 cm soil depth was significantly higher than 0-15 cm soil depth at the 0.05 level.

Table 1. Effect of burning rice stubble and soil depth on some chemical and physical properties

Factor	Clay	BD	pH	EC	CEC	SOC	TN	TS	Available P
	(%)	(kg/cm^3)		(mS/cm)	(cmol/kg)	(g/kg)	(g/kg)	(g/kg)	(mg/kg)
Rice stubble management (R)									
Non-burned	64.32	1.35	5.75	0.39a	38.15	2.22	0.22	0.41a	11.66
Burned	58.99	1.29	5.57	0.28b	34.01	2.15	0.22	0.28b	4.07
Soil depth (D)									
0-15 cm	60.38	1.22B	5.53	0.33	40.17A	2.73 A	0.26 A	0.38	9.54
15-30 cm	62.93	1.41A	5.79	0.34	32.17B	1.64 B	0.17 B	0.31	6.19
F-test									
R	ns	ns	ns	*	ns	ns	ns	**	ns
D	ns	**	ns	ns	**	**	**	ns	ns
R x D	ns	ns	ns	ns	ns	*	**	ns	ns
CV (%)	11.20	7.16	12.88	25.68	18.73	2.92	5.07	23.23	100.13

1/ ** is significantly differenced at $p \leq 0.01$. 2/ * is significantly differenced at $p \leq 0.05$.
3/ ns is not significantly differenced at $p \leq 0.05$.
4/ values followed by the same uppercase and lowercase letter in the column of each factor.

Table 2. Effect of rice stubble management and soil depth on exchangeable K, Ca, Mg and Na, extractable Fe, Mn, Zn and Cu

Factor	Exchangeable (mg/kg)				Extractable (mg/kg)			
	K	Ca	Mg	Na	Fe	Mn	Zn	Cu
Rice stubble management (R)								
Non-burned	271	1,805b	989	416	208	54.05	4.35	4.26
Burned	240	2,128a	988	382	218	71.44	2.95	4.26
Soil depth (D)								
0-15 cm	231	2,200A	897B	380	252A	65.86	4.94	4.35
15-30 cm	280	1,733B	1,080A	418	173B	59.63	2.36	4.16
F-test								
R	ns	*	ns	ns	ns	ns	ns	ns
D	ns	**	*	ns	**	ns	ns	ns
R x D	ns	ns	ns	ns	ns	ns	ns	ns
CV (%)	49.24	11.81	14.46	30.44	25.93	59.18	74.36	19.81

[1]/ ** is significantly differenced at $p \leq 0.01$. [2]/ * is significantly differenced at $p \leq 0.05$.
[3]/ ns is not significantly differenced at $p \leq 0.05$.
[4]/ values followed by the same uppercase and lowercase letter in the column of each factor.

Comparison of soil properties parameter for non burned rice stubble field and burned rice stubble field

The mean comparison of non-burned rice stubble field and burned rice stubble field at 0-15 cm and 15-30 cm soil depth were shown in Table 3 and Table 4, respectively. Soil pH at 0-15 cm soil depth in burned rice stubble field was moderately acidic (pH 5.73) was a significant difference with non-burned rice stubble field as a strong acidic (pH 5.33). SOC (28.1 g/kg), TN (2.74 g/kg), TS (4.53 g/kg) and CEC (47.29 cmol/kg) were found at 0-15 cm soil depth in non-burned rice stubble field were higher than burned rice stubble field and significantly different at the 0.01 level (Table 3).

Soil pH at 15-30 cm soil depth more alkalinity than topsoil. Soil pH (6.34), SOC (17.90 g/kg) and TN (1.91 g/kg) at 15-30 cm soil depth in burned rice stubble field were higher than non-burned rice stubble field and significantly different. Total sulfur and exchangeable Na at 15-30 cm soil depth in non-burned rice stubble field was 3.61 g/kg and 453 mg/kg, respectively and were significantly higher than burned rice stubble field at the 0.05 and 0.01 level, respectively (Table 4).

Table 3. A pair t-test analysis of soil properties parameter between non-burned rice stubble field and burned rice stubble field at 0-15 cm soil depth

Parameter	Non-burn rice stubble	Burned rice stubble	T-test
Clay (%)	58.90	61.85	ns
Bulk density (g/cm^3)	1.30	1.18	ns
Soil pH	5.33	5.73	**
Electrical Conductivity (mS/cm)	0.37	0.30	ns
Cation exchange capacity (cmol/kg)	47.29	33.49	**
Soil organic carbon (g/kg)	28.10	26.49	**
Total Nitrogen (g/kg)	2.74	2.54	**
Total Sulfur (g/kg)	4.53	3.07	**
Available P (mg/kg)	14.27	4.81	ns
Exchangeable K (mg/kg)	257	207	ns
Exchangeable Ca (mg/kg)	2,045	2,356	ns
Exchangeable Mg (mg/kg)	885	909	ns
Exchangeable Na (mg/kg)	379	382	ns
Extractable Fe (mg/kg)	247	258	ns
Extractable Mn (mg/kg)	47.65	71.60	ns
Extractable Zn (mg/kg)	3.58	6.29	ns
Extractable Cu (mg/kg)	4.21	4.50	ns

[1]/ ** is significantly differenced at $p \leq 0.01$.
[2]/ ns is not significantly differenced at $p \leq 0.05$.

Table 4. A pair t-test analysis of soil properties parameter for non-burned rice stubble field and burned rice stubble field at 15-30 cm soil depth

Parameter	Non-burn rice stubble	Burned rice stubble	T-test
Clay (%)	61.53	64.33	ns
BD (g/cm^3)	1.34	1.42	ns
Soil pH	5.23	6.34	**
Electrical Conductivity (mS/cm)	0.36	0.32	ns
Cation exchange capacity (cmol/kg)	31.76	32.30	ns
Soil organic carbon (g/kg)	14.98	17.90	**
Total Nitrogen (g/kg)	1.56	1.91	*
Total Sulfur (g/kg)	3.61	2.50	**
Available P (mg/kg)	9.04	3.34	ns
Exchangeable K (mg/kg)	287	275	ns
Exchangeable Ca (mg/kg)	1,566	1,901	ns
Exchangeable Mg (mg/kg)	1,093	1,068	ns
Exchangeable Na (mg/kg)	453	383	*
Extractable Fe (mg/kg)	169	178	ns
Extractable Mn (mg/kg)	60.45	71.28	ns
Extractable Zn (mg/kg)	2.33	2.40	ns
Extractable Cu (mg/kg)	4.32	4.01	ns

[1]/ ** is significantly differenced at $p \leq 0.01$. [2]/ * is significantly differenced at $p \leq 0.05$.
[3]/ ns is not significantly differenced at $p \leq 0.05$.

Discussion

Increasing soil pH after rice stubble burning in topsoil (0-15 cm) and subsoil (15-30 cm) was attributed to ash alkalinity. Ash residues are dominated by carbonates of alkali and alkaline earth metals but also contain variable amounts of silica, heavy metals, sesquioxides, phosphates, and small amounts of organic and inorganic N (Raison, 1979). Burning rice stubble directly reflected to lower organic carbon in topsoil than non-burning plots. According to rice straw is an important organic C source that contains nutrients for optimum crop growth (Sharma *et al*., 2020). Almost all crop residues contain carbon (C), nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), sulfur (S), and micronutrients especially nitrogen and sulfur (Parr and Papendick, 1978). Therefore, total N and S in non-burned rice stubble plots, which can be loss in gas phase were significantly higher than burned rice stubble plots (Table 3). Chaopyao *et al*., (2020) studied the nutrient content of rice stubble in Ladkrabang district and found that rice stubble contains 47.68-60.16 kg C ha^{-1}, 0.82-1.03 kg N ha^{-1}, and 0.33-0.42 kg S ha^{-1}. Burning rice stubble enhances the loss of those nutrients and affects other soil properties such as CEC which significant higher in non-burned soil at 0-15 cm.

Cation exchange capacity (CEC) at a depth of 0-15 cm was significantly higher than 15-30 cm soil depth because of the high clay content and organic matter content. As well-known soil components that contribute to CEC is clay and organic matter (Martel *et al*., 1978; Manrique *et al*., 1991). The cation exchange capacity of organic soils increases markedly with increases in soil pH and increases with greater degrees of humification (Stevenson, 1994). In the same vein, cation exchange capacity decreased down the depths probably because of the decreasing of soil organic matter down the depths. The relationship between clay content (% by weight) and CEC can be highly variable because different clay minerals have different CEC, and the relative proportion of pH-dependant and permanent CEC varies among clay minerals (Miller, 1970). The increased cations exchange capacity during the peak and end of rains might also be due to higher rainfall, which favors rapid decomposition of dead plant materials that lead to the accumulation of soil organic matter (Fatubarin, 1980).

Exchangeable potassium (K), magnesium (Mg), and sodium (Na) at 15-30 cm depth were higher than topsoil caused by parent material of Bangkok soil series is a marine mixed with riverine alluvium under brackish water influence (Land development department, 2005a). Exchangeable calcium, SOC and TS in 15-30 cm soil depth in burned rice stubble fields were higher than in non-burned rice stubble fields may be due to some soil samples were collected during the rainy season. Besides, nutrient contents may dilute or move down to the subsoil. Fatubarin and Olojugba (2014) reported that the chemical properties that were mostly influenced by rainfall patterns are soil organic matter, total nitrogen, soil pH, available phosphorus, exchangeable cations (Ca, Mg and K), and cation exchange capacity (CEC). Rainfall and %Relative humidity showed a significant negative correlation with pH, and %sand and a significant positive correlation with OC, OM, CEC, % clay, and %silt (Osobamiro and Adewuyi, 2018). Organic carbon strongly depends on environmental conditions that influence soil proprieties, such as local climate, temperature, humidity, insulation, topographic profile, land use (Dube *et al*., 2001; Rabbi *et al*., 2015). The high coefficient variation percentage (CV) of available P in non-burned rice stubble fields may be caused by NC1 plot was continuous applied organic fertilizers, which resulting in high available P accumulation. Zhang (2016) reported that the concentrations of total and available P have shown an increasing trend with increasing manure application rate.

It concluded that crop residue management, rice stubble burning made Bangkok soil series showed less fertile than no stubble burning, namely, lower organic carbon content especially in topsoil. Moreover, loss of SOC from burning rice stubble may be related to higher emission of GHG and other air pollution gases.

Acknowledgements

The authors are grateful for the King Mongkut's Institute of Technology Ladkrabang [2563-02-04-014] for providing financial supports to this research.

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(Received: 25 August 2021, accepted: 30 January 2022)