**Effect of biomass burning on the macronutrient and micronutrient levels in paddy soil from Chiang Rai Province**

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**Novelty Statement**

Rice straw burning was extensive used for crop residue management in Thailand. It caused to alter pH and some nutrients in the soil. The amount of potassium was increased by the burnt topsoil. The phosphorus level varied between the four types of soil samples and was not significantly affected by rice straw burning. Likewise, the Ca2+ and Mg2+ levels showed no difference between the four types of soil samples.

**Abstract**

This research aimed to study the effect of biomass (as rice straw) burning on the soil nutrients in an agricultural field. The study site was paddy fields in a suburban area at Chiang Rai City, northern Thailand. This preliminary study evaluated the pH, soil nutrients, and electrical conductivity (EC) in a field of cultivated *Oryza sativa* L. strains. Soil samples were burnt straw, non-burnt straw soil both varied a depth. The pH of the non-burnt straw soil at a depth of 10 cm was less acidic than the pH of the other three soil types. Biomass burning after agriculture did not dramatically alter the pH of soil used to grow sticky rice. The proportion of OM in the topsoil of both burnt straw and non-burnt straw soil did not differ. The topsoil also had a high nitrogen composition in the burnt straw (0.11 ± 0.01%) and non-burnt straw (0.10 ± 0.0045%) soils. Meanwhile, combustion resulted in an increased amount of K in the burnt topsoil (96.67 ± 9.07 ppm). The P level varied between the four types of soil samples and was not significantly affected by rice straw burning. Likewise, the Ca2+ and Mg2+ levels showed no difference between the four types of soil samples. Therefore, management of soil preparation before the growing season, such as nutrient determination before planting, is essential to be able to provide the correct amount of nutrient for the actual nutrient requirements of the paddy field rice.

**Keywords:** Burning soil, Macronutrients, Soil chemicals, Glutinous rice, Soil fertility

**Introduction**

Thailand is still an agricultural-based country and so needs good soil management to protect the plant genetics and soil fertility of the agricultural land. Several studies have supported the use of crop rotation as well as manure addition to increase the soil fertility (Bernard *et al.* 2021). Conversely, forest fires occur from human activities, including plant gathering, animal hunting, slash and burn land preparation, plant cultivation, and early burning (Haines *et al.* 2021; Willcox 2010). The effect of forest fire and early burning in agricultural fields is difficult to cope with as it causes a bulked soil and loss of porosity that can adversely influence plant growth, including rice growth. The burning area is often expanded to include natural forest that is connected to the agricultural area (Tongkoom *et al.* 2021) and emits considerable levels of smoke that is difficult to deal with. In addition, the burning produces various substances, such as gaseous carbon dioxide, ash, and tar. Indeed, Thai farmers have to continually pay for chemical fertilizer to increase their rice yield due to the loss of soil fertility, which then becomes a significant cost component. Despite the alterations in soil chemicals, the burning of rice straw is done to get rid of pests and soil-borne pathogens.

It has been reported that OM composed of humus releases essential acids. Nitrogen is incorporated into the soil in the form of ammonia, ammonium ions, nitrate, and nitrite. Paddy soil from sticky (glutinous) rice fields contains some essential macronutrients and micronutrients, such as nitrogen (N), phosphorus (P), potassium (K), calcium (Ca2+), and magnesium (Mg2+). In a long-term field trial, soil amended with farmyard manure and chemical fertilizer was found to have an increased proportion of carbon in the form of humic acid (HA) (Simonetti *et al.* 2011, Zhao *et al*. 2021). Soil from maize field can also improve with farmyard manure due to increase various substances such as lignin, amino acids, peptides and proteins (Ferrari *et al.* 2011). In the crop rotation, the application of chemical fertilizer and compost increases the O-alkyl-C and aromatic-C contents in the soils (Yanagi and Shindo 2016). The infusion of HA into paddy soils can facilitate the system of water irrigation. Atmospheric gases, including CO2, are sufficient for the development of sticky rice with an increasing annual crop field, but it is the soil nutrients that can be limiting.

The impact of biomass burning can degrade the soil nutrients whether or not the topsoil layer directly loses soil fertility. The objectives of this study were to analyze the chemical profiles, in terms of the soil N, K, P, Ca2+, and Mg2+ contents, of the top soil at the surface and at 10 cm depth in an agricultural field (paddy field) with and without rice straw burning.

**Materials and Methods**

**Soil samples**

A field survey was performed in Chiang Rai Province, in northern Thailand between January–March 2019. Burnt and unburnt straw soils (5 kg each sample) were collected separately and kept in plastic bags until analyzed. Burnt straw soil was obtained from areas where the rice biomass had been burnt and had combustion residue on the soil surface, whereas the unburnt straw soil was obtained from areas of paddy fields without crop burning. The paddy fields had grown the Thai Hommali, RD6, riceberry, and RD2-MJU rice varieties.

**Preliminary study**

Soil samples were put into aluminum boxes and dried in a hot air oven at 100 °C for 7 d. The dried soil was first sieved and then ground in a mortar. The obtained ground soil powder was preliminary studied using a NPK soil chemical test kit (Hanna instruments, Inc.). Briefly, each ground soil aliquot (3 g) was added in 7.5 mL of extract solution and left at room temperature for 5 min. The extracted soil nutrients were analyzed using most of the obtained suspension. The NPK results were interpreted as trace, low, medium, and high levels. The electrical conductance (EC) was measured in µS/cm using an EC/TDS meter.

**Soil chemical analysis**

Soil pH was measured from a 1:1 (v/v) soil: water suspension using a pH meter. The OM was analyzed using the Walkley and Black method. The proportion of total N was determined using the Kjeldahl method. Available P was extracted using a BrayII solution and measured with a spectrophotometer. The available K, exchangeable Ca2+, and exchangeable Mg2+ were extracted with 1 M ammonium acetate pH 7.0 and analyzed by atomic absorption spectrophotometry (AAS).

**Statistical analysis**

All data are expressed as the respective mean and standard error (SE). The significance of differences between groups was tested by one-way ANOVA using the SPSS IBM version 20 software and accepting significance at the p < 0.05 level.

**Results**

The preliminary data observed the effect of habitual rice straw burning on the soil environment. In this study the soil types were classified into burnt straw and non-burnt straw. The consequences of burning have a negative effect on the soil pH and the levels of nitrogen (N) potassium (K), phosphorus (P) and electricity conductance (EC). Thai Hommali rice (KDML105) is the main rice variety cultivated in the area of Chiang Rai City, and this variety has a higher nutrient content and, especially, fragrance level than KDML105 rice. The pH of soil from the KDML105 paddy fields was slightly acidic in both the burnt straw and non-burnt straw soil samples (Table 1). The soil accumulated by N and K elements. The RD6, riceberry, and RD2-Maejo rice varieties are usually called Khao-Neaw or glutinous rice, and are a popular consumable meal for northern Thai people. Seemingly, the soil from cultivation of both the RD6 and riceberry rice varieties did not show any significant effect from rice straw burning. However, the soil EC was lower in the burnt straw soils than in the unburnt straw soils and the cropping of RD6 showed an obvious difference in EC value. The effect of burning RD6 rice straw was to cause a reduced N and K content in the soil. The RD-2 MJU rice strain showed comparable nutrients, where the burnt straw soil had low N, trace P, and K contents. This cropping was valuable due to the high N, trace P, and low K levels in farmyard.

Soil samples were classified into the four treatments of burnt straw (surface and at a depth of 10 cm) and non-burnt straw (surface and at a depth 10 cm), and are summarized in Table 2. An effect of straw burning on the soil changed the surface soil pH, increasing it (less acidic) to about 4.76 ± 0.20, whereas at a depth of 10 cm there was no significant effect of rice straw burning on the soil pH, which remained less acidic than at the surface.

There was a significantly higher OM content in the surface soil than at 10 cm depth in both soil types, and the OM was numerically (but not significantly) slightly higher in the burnt-straw surface soil than in the unburnt straw surface soil. This was due to the abundance of soil chemicals as both types of soil were still fertile after harvesting. Also, it is likely that the low fire intensity and short fire period was insufficient to reduce the POM content. At a depth of 10 cm the soil OM content was significantly lower than at the surface, due to the bulk of other substances of a low organic value, and represented a low fertility for plants. The total %N was broadly in accord with the OM content, being mostly accumulated at the surface soil layer and slightly decreased in the lower soil layer. However, the %N is also related to the action of soil microorganisms in the nitrogen nutrient cycle that produce substantial amounts of nitrate, nitrite, and ammonium ions. Fires often affect (increase) the transformation of organic N into ammonium and nitrate ions, which are easily absorbable by plants (Úbeda *et al* 2005) because ammonium ions and ammonia gas are released from the OM on heating, which then stimulates the nitrification process (Wan *et al* 2001).

Although, the P levels were not significantly increased in the burnt straw soil compared to the unburnt straw soil, they were numerically higher. However, the P levels in soil will vary depending on the soil management. In this study, the P was at a high concentration in the burnt straw soil (6.67 ± 3.19 and 4.70 ± 2.44 ppm at the surface and 10 cm depth, respectively).

The K level was significantly higher in the burnt straw soil than the non-burnt straw soil at both levels (surface and 10 cm depth), and was significantly higher at the surface than at 10 cm depth, but remained in the medium concentration range. Straw burning at the surface of the soil can alter the K level. In soil, Ca2+ ions tend to be bound in solid molecules, such as CaCO3, CaO, and other compounds, which is useful to adjust soil pH for neutral. The contaminants of carbonate in water need to be removed before its household use. Interestingly, the calcium carbonate level in soil can be measured by AAS. In this study, the highest Ca2+ concentration (1,332.33 ± 90.75 ppm) was found in the non-burnt straw soil at a 10 cm depth (Fig. 1). As for the soil Mg2++content, it also showed no significant difference between the four groups of soil (Fig. 2).

**Discussion**

The amount of soil chemicals is directly related to the magnitude of soil heating and the severity of the fire. Fire intensity can be classified as low, medium, and high with maximum temperatures of 250, 400 and above 675 ◦C, respectively (Reynard-Callanan *et al* 2010). We observed that the soil pH was slightly higher in the burnt straw soil compared to the unburnt straw soil. Because burning of organic matter in soils produces ash which increase pH of soil (Molina et al., 2007). However, a significant increase in the soil pH only occurs in severe burning. (Arocena and Opio 2003; Heydari *et al* 2017). The surface soil contained more organic matter than the depth soil. Therefore, a depth of soil was low fertility for plants. The surface soil has no difference in organic matter between burnt and unburnt soil. Because the both types of soil were still fertile after harvesting. Also, it is likely that the low-intensity fire and the short period fire was insufficient to reduce the OM content. In this study, the percentage of nitrogen (%N) increased after burning which corresponds to several studies (Chungu *et al* 2020; Xu *et al* 2022). It may be due to organic N was transformed to ammonium and nitrate in burning soil (Úbeda *et al* 2005). Potassium is an important marker for biomass burning because a large ratio of this element is contained in the plants and litter (DeBano and Conrad, 1978). Therefore, potassium level tends to increase after forest fire.

Calcium ions are added in the form of fertilizer for stimulating seedling and growing plantlets but the availability of cationic ions can be reduced by burning management. The high Ca2+ levels in the unburned area reflects that CaCO3 was commonly applied with fertilizer to promote the exchangeable Ca, available P, and exchangeable K levels in the soil (Ozyhar *et al* 2022). Furthermore, calcium peroxide has been used for the treatment of arsenic contamination in the grains of brown rice. Calcium silicate was used as a plant-available silicon to increase the efficiency of N utilization and rice straw biomass (Hyun-Hwoi 2020). In addition, eggshells are used a bioresource fertilizer as they are rich in K, P, and Ca2+ (Borges *et al* 2021). Of the micronutrients in the soil, Mg2+ was found at a lower amount than Ca2+ and did not floccate in the soil suspension. In addition, Mg2+ was also bound in complexes with Ca2+. It is claimed that slashing and burning, which has also been used to manage insect and other pests/pathogens results in changes to the nutrient dynamics and soil structure, where burning strongly affected the physical, biological, and chemical composition of the soil.

**Conclusion**

The management of agricultural wastes in rice fields by burning can vary the trace element concentrations in paddy soils, including, in this study, the K, OM, and total N levels, whereas the P, Ca2+, and Mg2+ levels remained relatively unchanged. Therefore, management of soil preparation before the growing season, such as nutrient determination before planting, is essential to obtain the optimal amount of nutrient supply to match the actual nutrient requirements of paddy field rice.

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**Author contributions**

TC and LN collected soil samples, PK and LN done experiments and TC PK LN wrote equally for this manuscript.

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**Table 1 Preliminary data of burnt and non-burnt soils in suburban paddy fields in Chiang Rai**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Rice varieties** | **Suburban area in Chiang Rai** | **Soil types** | **Soil chemicals** | **Electrical conductance (EC)** |
| Thai Hommali | Thoeng, PaDaet | Burnt straw  Non-burnt straw | pH 4–6, high N, trace P, and low to high K.  pH 4–5, high N, trace P, and low to high K. | 0.16  0.17 |
| RD6 | Chiang Khong, Phan, and Khun- Tan | Burnt straw  Non-burnt straw | pH 4–6, low to medium N, low P, and trace K.  pH 4–5, high N, trace P, and low K. | 0.09    0.17 |
| Riceberry | Phan | Burnt straw  Non-burnt straw | No data  pH 4–5, high N, trace P, and low K. | No data  0.17 |
| RD2- Maejo | PaDaet | Burnt straw  Non-burnt straw | pH 5–6, low N, trace P, and trace K.  pH 4–5, high N, trace P, and low K. | 0.09  0.07 |

**Table 2 Chemical properties of soils: pH, % OM, total N (%N), available P (ppm), and available K (ppm) from paddy fields in suburban Chiang Rai**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Soil type** | **pH** | **%OM** | **%N** | **Available P (ppm)** | **Available K**  **(ppm)** |
| Burnt straw, surface | 4.76 ± 0.20ns | 2.11 ± 0.23a | 0.11 ± 0.01a | 6.67 ± 3.19ns | 96.67 ± 9.07 a |
| Burnt straw, depth of 10 cm. | 5.04 ± 0.21 | 1.64 ± 0.14b | 0.08 ± 0.01b | 4.70 ± 2.44 | 64.00 ± 29.31b |
| Non-burnt straw, surface | 4.51 ± 0.10 | 1.92 ± 0.80a | 0.10 ± 0.004a | 3.67 ± 0.63 | 66.33 ± 11.02b |
| Non-burnt straw, depth of 10 cm. | 5.19 ± 0.22 | 1.52 ± 0.03b | 0.08 ± 0.001b | 3.63 ± 1.99 | 62.67 ± 20.40b |



Fig.1 Calcium levels (ppm) in the surface soil and at a depth of 10 cm in burnt straw and unburnt straw soils. Data are shown as the mean ± 1SEM. Alphabetical was TB, Topsoil burning; DB-10, Burning at depth 10 cm.; TN, Topsoil non-burning; DN-10 non-burning at depth 10 cm.



Fig.2 Potassium levels (ppm) in the surface soil and at a depth of 10 cm in burnt straw and unburnt straw soils. Data are shown as the mean ± 1SEM. Alphabetical was TB, Topsoil burning; DB-10, Burning at depth 10 cm.; TN, Topsoil non-burning; DN-10 non-burning at depth 10 cm.