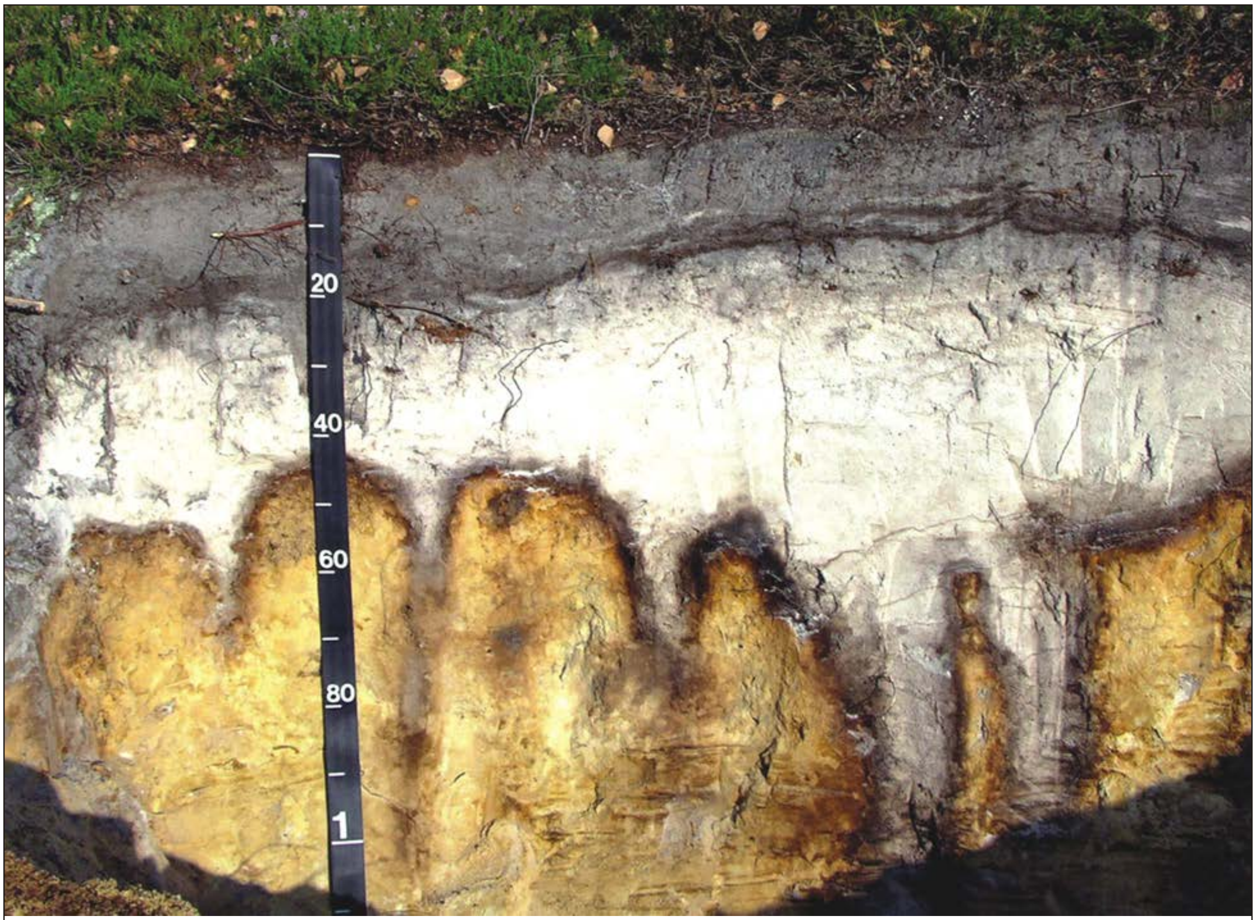

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Research Article
Major Plant Nutrient Release in Jasmine Rice Growing Soils Amended with Biochar and Organic Wastes: An Incubation Study

Teeranuch Opachat, Somchai Anusontpornperm, Suphicha Thanachit and Irb Kheoruenromne

Department of Soil Science, Faculty of Agriculture, Kasetsart University, 10900 Bangkok, Thailand

Abstract
Background and Objective: Paddy soils for growing Jasmine rice in Thailand are mostly low fertile and possess some soil constraints of which efficiency of fertilization is low. Biochar and organic wastes can be used to amend these soils and a source of additional major plant nutrients. This study aimed at comparing the mineralization under incubation condition of major plant nutrients among biochar and organic wastes. **Materials and Methods:** Rich husk biochar (RHB), rice husk ash (RHA), cassava starch waste (CSW) and cassava tails and stalks (CTS) were applied into six soils and incubated in laboratory. The experiment was arranged in a Completely Randomized Design with three replications. No amendment application (control), cassava starch waste (CSW), cassava tails and stalk (CTS), rice husk ash (RHA) and rice husk biochar (RHB) were compared. The amounts of available N, P and K were measured at 0, 3, 7, 14, 30 and 60 days during the incubation. One-way analysis of variance (ANOVA) of data was performed with mean separation and Duncan's multiple range test being considered significant at the $p \leq 0.05$ level and highly significant at the $p \leq 0.01$ level using SPSS software. **Results:** CSW and CTS contained high OM content, 727.2 and 663.7 g kg^{-1}, respectively, resulting in high C:N ratio even though they also had high total N content (6.83-7.79 g kg^{-1}). The CSW also had higher total K content (10.18 g kg^{-1}) than did CTS, RHA and RHB (1.3-5.41 g kg^{-1}). Total P quantity in these organic materials varied little and was in a small amount ranging from 0.76-1.28 g kg^{-1}. The RHA and RHB significantly released greater available N and P than did CSW and CTS while the CSW and CTS clearly releasing more available K. Available K was constantly released from these materials throughout the incubation period whereas most of available N was freed within1 month and the amount declined markedly afterwards. Release patterns of N, P and K were similar among soils, indicating that different soil properties played a little part in the availability of major plant nutrients released from these soil amendments. **Conclusion:** This study suggested a potential use of biochar and organic wastes as soil amendments and an enhancement of major plant nutrients in Jasmine rice growing paddy soils.

Key words: Jasmine rice, paddy soil, soil amendment, major plant nutrient, nutrient mineralization

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Corres ponding Author: Somchai Anusontpornperm, Department of Soil Science, Faculty of Agriculture, Kasetsart University, 10900 Bangkok, Thailand Tel: +66 819045925

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Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Thailand is a rice-based country. One of the most famous exported rice in the world is KhaoDawk Mali 105 (KDML 105 cultivar). It is commonly known as Jasmine rice and recognized around the world as having the finest quality and Thailand's principal export product[1]. This rice is mostly grown under rainfed conditions in the northeast of the country, a region characterized by an undulating landscape with generally poor soils and erratic rainfall[2]. Most Jasmine rice growing soils have rather coarse texture to medium nature with inherently low fertility status as affected by soil parent material such as sandstone and siltstone, low organic matter and low available P and K contents. As a result, the average yields for Jasmine rice in northeast Thailand are about 2.33 t ha^{-1}, which is one of the lowest in the world[3], however, this average yield is slightly higher than that of the potential yield (2.28 t ha^{-1})[4]. Plant nutrients and available water content in soils during growth period have been listed as major biophysical constraints to increasing yields[5-7]. Soil amendments can be used to improve paddy soils and subsequently increase rice yield as such rice husk and rice husk biochar[8], rice straw[9], bentonite[10], gypsum and rice-husk-charcoal[11].

Incubation study in laboratory is one of several methods for the investigation of plant nutrient release at a specific time from soil amended with soil conditioner. The study in a sandy loam soil using 20 g kg^{-1} of poultry litter biochar and raw poultry litter showed that a release of phosphorus from poultry litter biochar in neutral soils was at a slower and steadier rate over a longer time period than from raw poultry litter[12]. Nitrogen immobilization occurred in case of application of immature compost (1 month old) resulting in negative values of -0.08 µg N g^{-1} day^{-1} in soil-compost treatments. Net nitrification rate revealed similar patterns as N mineralization with, however, soil-compost (6 month old) treatment resulting in net nitrification rate higher than control[13]. In addition, a study on an Ustoxic Quartzipsamment, rice husk biochar released the highest amounts of mineralized NO_{-3}-N, available P and K while chicken manure releasing the highest NH^{+4}-N[14]. However, there are several agricultural wastes available in substantial amount in Thailand of which they can be used as soil amendment. Some of them contain the amount of plant major nutrients to some degree which can alternatively supply to growing plant and in turn reduce the use of chemical fertilizer. The aim of this research was to compare the mineralization under incubation condition of major plant nutrients among biochar and organic wastes as follow: (1) Cassava starch waste, (2) Cassava tails and stalk, both from cassava starch manufacturing plant, (3) Rice husk ash from rice mill and (4) Rice husk biochar from ethanol plant when applied to 6 paddy soils.

MATERIALS AND METHODS

Soil properties and samples: Soil samples at a depth between 0-30 cm were collected from paddy fields in the area of jasmine rice growing region, northeast, Thailand. There were 6 jasmine rice growing soils chosen for this study. Their properties presented in Table 1. There were two saline sodic soils (SD1 and SD2) classified as Typic Natraqualfs, one saline soil (SS) classified as a Typic Endoaqualf, two normal paddy soils (NP1 and NP2) classified as Typic Kandiaquults and one soil located on the transitional area between low terrace and middle terrace, so called upland paddy soil (UP), classified as Typic (Aquic) Paleustult[15].

Table 1: Properties of soils selected prior to the experiment

Properties	SD1	SD2	SS	NP1	NP2	UP
pH_w (1:1)	5.40	6.70	5.20	4.50	4.80	4.70
Organic matter (g kg^{-1})	5.29	12.60	12.60	2.32	10.42	2.73
Electrical conductivity, ECe (dS m^{-1})	12.57	13.63	3.56	0.21	0.36	0.35
Cation exchange capacity ($cmol_c$ kg^{-1})	5.25	10.00	3.00	2.25	3.25	3.75
Sodium adsorption ratio	20.85	25.76	11.54	0.44	0.40	0.39
Base saturation percentage	105.50	143.10	60.30	39.60	27.40	39.50
Total nitrogen (g kg^{-1})	0.21	0.35	0.21	0.35	0.21	0.07
Available nitrogen (mg kg^{-1})	6.53	8.40	6.53	6.53	6.53	9.33
Available phosphorus (mg kg^{-1})	7.27	10.72	6.71	3.76	11.15	1.70
Available potassium (mg kg^{-1})	67.75	92.64	20.34	13.23	13.88	8.26
Exchangeable potassium ($cmol_c$ kg^{-1})	0.09	0.19	0.03	0.04	0.03	0.06
Exchangeable calcium ($cmol_c$ kg^{-1})	1.51	7.04	0.94	0.48	0.46	1.07
Exchangeable magnesium ($cmol_c$ kg^{-1})	1.14	1.68	0.25	0.13	0.11	0.19
Exchangeable sodium ($cmol_c$ kg^{-1})	2.86	5.39	0.59	0.24	0.29	0.16
Exchangeable sodium percentage	54.48	53.90	19.67	10.67	8.92	4.27
Textural class	SCL	SCL	SCL	SL	SL	SCL

SCL: Sandy clay loam, SL: Sandy loam

Table 2: Selected properties of biochar and organic wastes used in the experiment

Properties	Cassava starch waste	Cassava tails and stalk	Rice husk ash	Rice husk biochar
pH_w (1:5)	6.56	6.62	8.69	7.80
OM (g kg^{-1})	727.20	663.70	25.70	30.90
ECe (dS m^{-1})	1.98	1.23	0.87	0.25
CEC ($cmol_c$ kg^{-1})	57.10	29.10	9.60	12.00
Total N (g kg^{-1})	7.79	6.83	2.01	1.14
Total P (g kg^{-1})	1.00	0.76	1.28	1.06
Total K (g kg^{-1})	10.18	5.16	5.41	1.31
Total Ca (g kg^{-1})	4.68	4.44	3.80	2.36
Total Mg (g kg^{-1})	2.64	1.16	1.05	0.59
Total S (g kg^{-1})	0.65	0.87	0.54	0.50
Total Na (g kg^{-1})	0.28	0.13	0.21	0.10
Total Si (g kg^{-1})	28.40	12.50	13.10	33.40
Total Zn (mg kg^{-1})	11.30	8.80	19.40	11.90
Total Fe (mg kg^{-1})	115.00	3762.00	1.576	481.00
Total Mn (mg kg^{-1})	45.90	93.80	234.00	202.00
Total Cu (mg kg^{-1})	3.13	5.31	5.31	5.31

Comparing between SD1 and SD2, the former soil contained lower amount of organic matter than did the latter soil and it was also the case for NP1 and NP2. The UP soil is used for growing Jasmine rice as well but has experienced water deficit occasionally during dry year. SD1, SD2 and SS soils are considered a salt affected soil which distributed vastly in Jasmine rice growing area of the country where better rice quality (higher aromatic 2-AP content) but lower grain yield was produced. NP1, NP2 and UP soils are highly leached soils, having very low plant nutrient reserve and organic matter content with the exception of NP2 that the content of organic matter is clearly higher than the others.

Experimental design: The topsoil samples were sieved through a 2-mm mesh after removing all roots and organic debris. They were stored in plastic buckets with tight closing lids, which kept them at field moisture content before the experiment. All biochar and organic wastes used in the experiment were hand crushed and sieved through 0.5 mm. Properties of these materials were given in Table 2. The experiment was arranged in a Completely Randomized Design with 3 replications. Five soil amendment treatments were employed as follows: No amendment application (control), cassava starch waste (CSW), cassava tails and stalk (CTS), rice husk ash (RHA) and rice husk biochar (RHB). All soil amendments were applied at 3.13 t ha^{-1} as based on the recommendation rate for growing field crop in Thailand. The plant major nutrients mineralization of biochar and organic wastes amended soils was investigated.

Soil incubation and mineralization: Incubation of soil with biochar and organic wastes was carried out between January-March, 2016, according to the incubation method developed by Mohammed[16], to determine the released rates and amounts of N, P and K, all in available form. The incubation was carried out in a 100-mL glass bottle. Topsoil samples were amended with desired biochar and organic wastes. The soil was thoroughly mixed with the amendments and adjusted to 60% of field capacity with deionized water. Each of the incubation bottles was closed with para-film, on which three holes were made with a pinto allow gaseous exchange with the atmosphere. Then, the treated soil samples were incubated in laboratory at 30°C for the required periods (1, 3, 7, 14, 30 and 60 days). To prevent the development of anaerobic conditions, the incubation bottles were aerated every 3 days by opening the para-film throughout the incubation period. At each interval, the losses in weight of the incubation bottles were checked and deionized water was added to the samples, keeping them at the original weight. The samples of each week's incubation were analyzed to examine the contents of available N, P and K. Each time of the analysis was immediately done after mixing the soil and soil amendment together. At the end of each specified incubation period, the incubation bottles were re-randomized. Available N was determined by the steam distillation method as outlined by Keeney and Nelson[17]. Available P was extracted from the soil by the Bray II solution and subsequently the content was determined by the molybdenum blue method[18]. Available K was extracted from the soil with 1 mol L^{-1} NH_4OAc at pH 7.0 and the content was measured by an atomic absorption spectrophotometer (American Society of Agronomy)[19].

Statistical analysis: One-way analysis of variance (ANOVA) was used to test for significant differences of all parameters. Mean separation and Duncan's multiple range test were considered significant at the $p \leq 0.05$ level and highly significant at the $p \leq 0.01$ level using Statistical Package for the Social Sciences (SPSS) software (version 22.0 for Windows, IBM Armonk, NY).

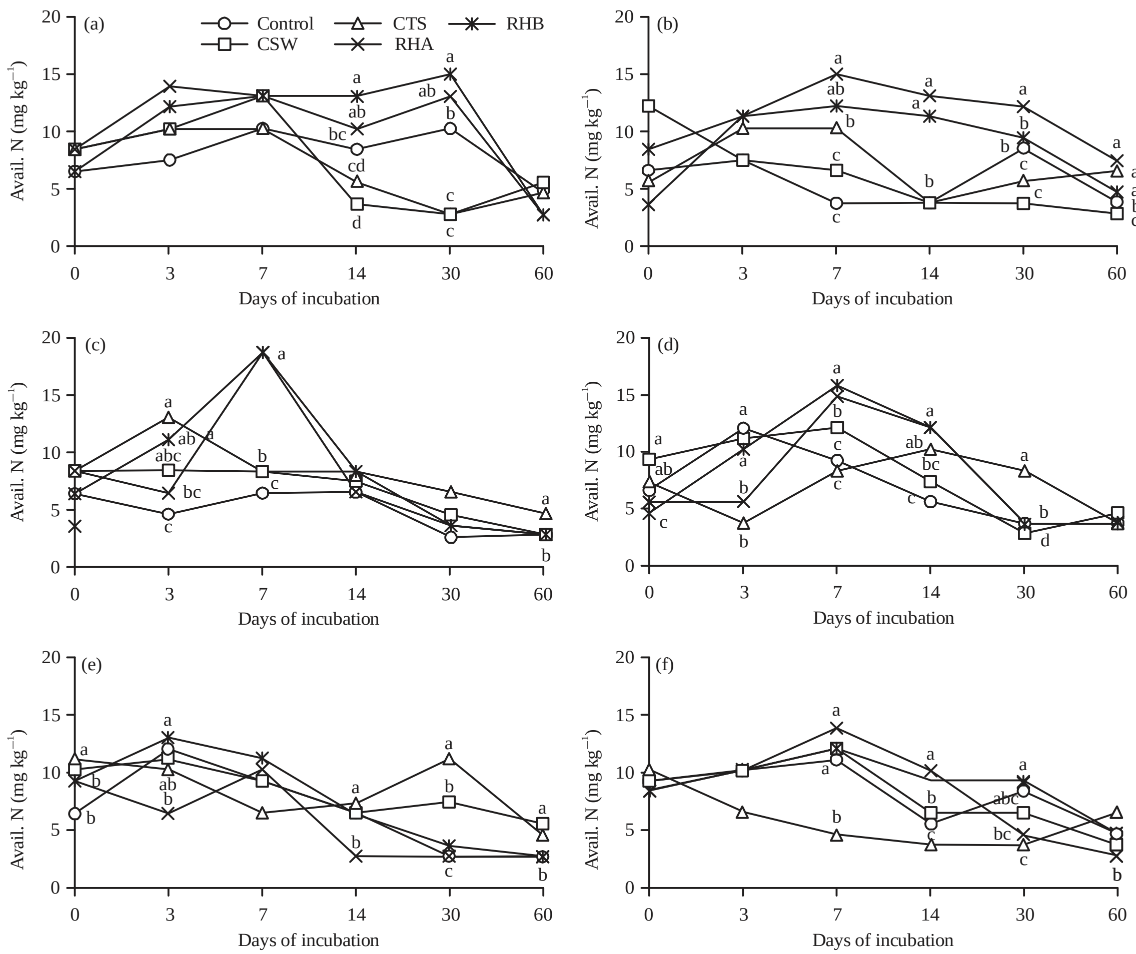

Fig. 1(a-f): Nitrogen release from different soil amendments in different soils under incubation condition

Different lowercase letters on lines grouped under the same measured day are significantly different ($p \leq 0.05$)

RESULTS

Nitrogen release: Different amounts of available N were released from different amended soils and at different times of incubation. Rice husk ash (RHA) followed by rice husk biochar (RHB) generally released the highest amount of available N in all soils (Fig. 1). Significantly different amounts of this available nutrient were found to be released at different times when compared among soils but mostly around 7 days after the incubation. The highly significantly $p<0.05$ highest available N contents released from the first saline sodic soil (SD1) amended with RHB was 13.1 and 14.9 mg kg^{-1} in day 14 and day 30, respectively. These amounts were not different from those released from RHA amended soil whereas the lowest amount was detected when amended with cassava starch waste (CSW) and cassava tails and stalk (CTS). Similar release pattern of this nutrient was also found in SD2. In a saline soil (SS), the equally highest amount of 18.7 mg kg^{-1} released in day 7 was from RHA and RHB with the amount from all wastes and the control clearly decreasing until day 60. In contrast to those problem soils, RHA and RHB still gave the greatest quantity of available N, especially in day 7 and day 14, however, wastes from cassava starch manufacturing plant (CSW and CTS) tended to release more of this plant nutrient in a normal paddy soil (NP1) in day 30 and day 60 than in salt affected soils. In an upland paddy soil (UP), it was rather surprising that the amount of N released from all wastes was barely different from that released from the control.

Phosphorus release: It was very clear that all RHA and RHB amended soils highly significantly released greater amount of available P than did CSW and CTS amended soils and the control from the start of the incubation onwards. It was also cleared that the trend of increasing amount of available P released from using RHA and RHB as soil amendment with

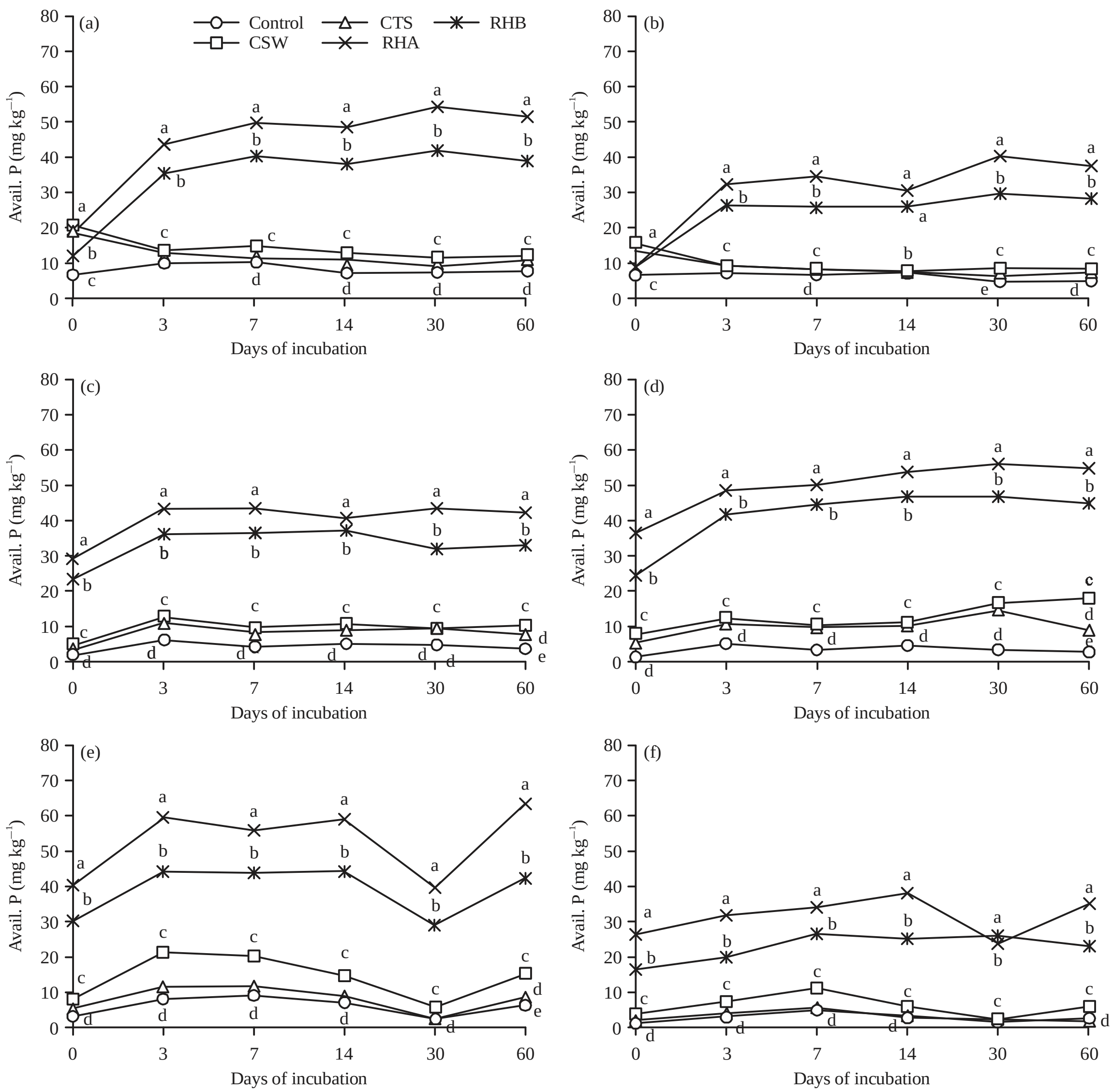

Fig. 2(a-f): Phosphorus release from different soil amendments in different soils under incubation condition

Different lowercase letters on lines grouped under the same measured day are significantly different (p$\leq$0.05)

time of incubation was recorded in all soils, indicating that more of available P would be released further after 2 months when incorporated in these paddy soils. The highest amount of this nutrient mineralized was 63.8 mg kg^{-1} at day 60 in NP2 amended with RHA (Fig. 2). In saline sodic soils (SD1 and SD2), this major nutrient was significantly available more at day 3 while in other soils the availability being statistically greater from the time of measurement. RHA freed slightly higher content of available P than did RHB when used to amend all soils at all the time investigated. Although, CSW and CTS were inferior to RHA and RHB in the context of available P release, both soil amendments still tended to release this nutrient greater than, to a slight extent, the control with no soil amendment addition, particularly in the case of CSW in almost all soils.

Potassium release: It was cleared that biochar and organic wastes used in this study released different amounts of available K with quite similar pattern in all soils. This major nutrient was significantly released in the highest amount from CSW amended soils. The available K surprisingly released in the greatest amount at the early period of incubation, day 3 and day 7, in CSW amended saline sodic soils (SD1 and SD2) with the amount ranging between 578.1-626.7 mg kg^{-1} (Fig. 3). All soils amended with CTS also had a reasonable high available K release with the amount varying between

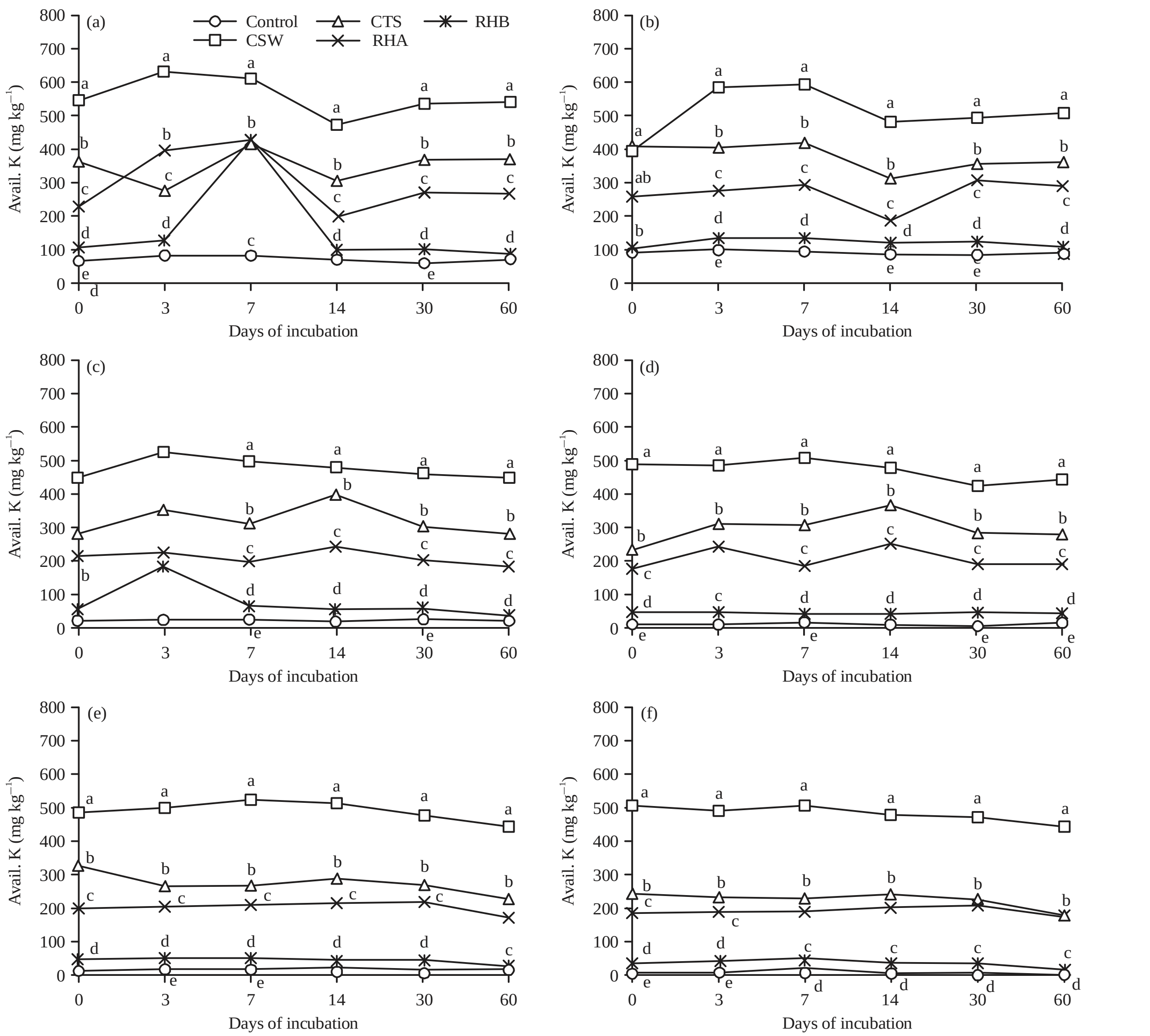

Fig. 3(a-f): Potassium release from different soil amendments in different soils under incubation condition
Different lowercase letters on lines grouped under the same measured day are significantly different ($p \leq 0.05$)

181.0-415.1 mg kg^{-1} even though the amount being lower than that with CSW (391.6-626.7 mg kg^{-1}). These amounts were followed by those released from RHA amended soils whereas all soils amended with RHB almost had no difference in available K release to the control with the amounts released of lower than 50 mg kg^{-1} throughout the incubation period in NP1, NP2 and UP soils.

DISCUSSION

Major plant nutrient released: Among major plant nutrients released from the soils, available K was mineralized the most and far greater than available N and P during 2 month of incubation. Although the amounts of total K and total N in soil amendments were not too much different (1.31-10.18 and 1.14-7.79 g kg^{-1}, respectively). This was due to C:N ratio of soil amendments tested in this study being very high, especially wastes from cassava starch manufacturing plant, leading to the amount of available N released being much lower than available K. It was also the case when compared between available N and P released that the latter was also mineralized in a greater amount than available N instead of total P in soil amendments varying only between 0.76-1.28 g kg^{-1}. Similar study in an Ustoxic Quartzipsamment was reported in the case of N[14]. Although, these biochar and organic wastes had high C:N ratio of which N fertilizer is needed to enhance the use, they can have the additional benefit of improving properties of soils, such as the increase of organic C[20,21], soil aggregation and moisture retention[22,23] when added to soils.

Amount of major plant nutrients among soil amendments: RHA and RHB clearly released more available N than did CSW and CTS when incorporated into soils studied, despite the formers containing much lower total N while the RHB showing similar amount of the release as previously reported[14]. This was because CSW and CTS had very high C:N ratio of 54.2 and 56.4, respectively, whereas RHA and RHB had lower C:N ratio (7.4 and 15.7, respectively). The same trend was found in available P released. RHA and RHB generally released more P than did CSW and CTS owing to the former two wastes consisting of greater P content. In contrast to N and P released, far higher available K was released from CSW and CTS amended soils than that from RHA and RHB amended soils. It was not surprising in the case of CSW because this waste had very high total K of 10.18 g kg^{-1} as well as RHB that was composed of only 1.31 g kg^{-1} of total K but when compared between CTS and RHA that had nearly the same content of total K (5.16 and 5.41 g kg^{-1}, respectively), the former tended to release more available K indicating that CTS was likely to contain more readily available K than did RHA.

Major plant nutrient release pattern in different soils: In all soils, most of available N was released within 2 weeks to 1 month of the incubation while available P and K were constantly released since very 1st day until the end of incubation period, indicating that these two plant nutrients can still be released from amended soils after 2 months of the incorporation. There was no clear indication of soil properties such as ECe, SAR, OM, pH etc. That affected the release pattern of these three major plant nutrients.

Potential use of biochar and organic wastes as soil amendment: CSW and CTS can be used to improve soil organic matter content of all soils study due to them having high organic carbon and soil CEC in addition to supplying K, apart from other plant nutrients, to growing plant. It was used rather successfully in cassava crop practice grown in an upland soil (TypicPaleustult)[24]. However, timing of the application under field condition, especially in paddy soils that commonly have water logging for some time during rice growing season should be cautious due to their high C:N ratio as N immobilization can occur under reduced condition[25] but it might be just temporary due to microbes in paddy soils are only a temporary sink for applied N. Nitrogen immobilized in microbial biomass has a significantly lower half-life and could be re-mineralized to inorganic forms, which makes them available to plants[26,27]. RHA and RHB are likely to supply available N and P to some degree and because of their high pH nature, they are suitable for acidic paddy soils rather than sodic or saline sodic soils, nonetheless, the biochar can potentially play another role in restoring saline soils by less C mineralization and more sequestration of soil C when applied at the high rate as shown by a study using peanut shell biochar[28]. However, field experiment on these soils should be tested using different types of biochar and organic waste with varying rates.

CONCLUSION

RHA and RHB released greater available N and P than did CSW and CTS whereas the latter two organic wastes evidently released more available K. Potassium was released from biochar and organic wastes in the highest amount when compared with available N and P released. Most of available N was mineralized from these soil amendments within 1 month of the incubation and then the amount declined markedly while the amounts of available P and K detected were still high at 2 month of the incubation. Different soils having different soil properties showed no impact on release pattern of available N, P and K. The biochar and organic wastes have a potential use as soil amendment in these paddy soils due to some having high pH, high organic matter content and other plant nutrients and based on their major plant nutrients mineralization, N, P and K chemical fertilizer can potentially be reduced when used together with a specific type of these soil amendments.

SIGNIFICANCE STATEMENTS

The result obtained from this study is useful as a basic information for further study under water-logged field condition of which there are scarce information reported, particularly in the context of timing of the incorporation before planting jasmine rice because these soil organic amendments have different release pattern in different paddy soils. In addition, the use of these soil organic amendments can enhance with specific amounts of N, P and K chemical fertilizer applied in order to gain the highest quantity of rice grain yield and its best quality and a decrease in cost/benefit ratio in jasmine rice production if chemical fertilizers is minimized. In addition, these biochar and organic wastes can also be used as chemical fertilizer substitution for organic rice production.

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