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Application Rates of Cricket Feces Influencing Soil Properties and Rice Yield in Soils of Different Moisture Contents

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ABSTRACT

Background: Cricket feces is a potential high-quality soil amendment, but there is currently no established optimum rate for its application in paddy soils with varying moisture contents. This study therefore aimed to evaluate the effects of varied rates of cricket feces on soil properties, rice growth and yield in paddy soils with differing moisture contents.

Methods: Two study factors were evaluated: (i) the maximum water-holding capacity (WHCmax) and flooded soils and (ii) cricket feces applied at rates of 0 (unamended), 3.13 (low), 6.25 (medium) and 12.50 (high) t/ha.

Result: The total grain weight of rice in soil with WHCmax was 2.60, 4.33, 6.91 and 7.49 g/hill under the cricket feces from unamended to high rates, respectively, with no significant difference between the medium and high rates. Meanwhile, the total grain weight in flooded soil was 1.85, 4.02, 4.70 and 5.72 g/hill, respectively. Cricket feces increased the content of essential elements and decreased the acidity and toxicity of Al, Ca and Na in the soil, thereby promoting rice growth and yield. The optimal application rates of cricket feces for rice in the WHCmax soil were determined to be the medium rate, while that in flooded soil was the high rate.

Key words: Cricket frass, Element toxicity, Optimum rate, Paddy soil, Soil acidity.

INTRODUCTION

The economic exports of numerous nations, including Thailand, India, Vietnam, Pakistan and the United States, heavily rely on rice (FAO, 2021). Nevertheless, the progress in rice production has been impeded by soil degradation, resulting in low yields on arable lands. Thailand, specifically the northeastern part, has faced significant challenges with poor rice yield performance, with an average yield of only 2.20 t/ha, falling below the national average of 2.78 t/ha (Office of Agricultural Economics, 2021).

The topography of Northeast Thailand necessitates rice cultivation in lands of varying elevations, resulting in the classification of upper and lower paddy fields (Vityakon *et al.,* 2004). The water management differs between these fields, with lower paddy fields retaining water until rice is harvested, while upper paddy fields maintain maximum moisture content at water-holding capacity (Sawatraksa *et al.,* 2018).

Enhancing soil fertility in paddy fields requires increasing organic matter and essential nutrient contents. A common method is the use of manure-type soil conditioners, including cricket feces, which are rich in nitrogen (N) (2.27-2.58%), phosphorus (P) (1.55-2.02%) and potassium (K) (1.78-2.26%) (Halloran *et al.,* 2017). With cricket farms capable of producing up to 44 tons of feces annually, cricket feces can be used as a valuable resource for crop production (Halloran *et al.,* 2017).

Limited research is however available on using cricket feces as a soil amendment, yet existing studies highlight its significant potential. Treelokes (2013) demonstrated that applying 15.6 t/ha of cricket feces increased the yield of morning glory, Chinese kale and coriander compared to other organic fertilizers. However, the optimal application rates of cricket feces have not been determined for paddy fields with varying soil moisture levels. It was hypothesized that by increasing the application rate of cricket feces, soil fertility would be enhanced, leading to an increase in the growth and yield of rice. The objective of the current study was, therefore, to evaluate the effects of varying rates of cricket waste on soil properties and their consequence on tissue nutrient concentrations, growth and yield of rice under different soil moisture contents.

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MATERIALS AND METHODS

Soil and cricket feces

The study utilized a coarsely textured soil commonly observed in paddy fields located in Northeast Thailand. The representative soil was gathered from a 0-15 cm depth at the research field facilitated by the Faculty of Agricultural Technology, Sakon Nakhon Rajabhat University

(17°11′09.9″N 104°05′17.2″E). The soil was then air-dried and sifted through a 2-mm sieve. Meanwhile, cricket (*Acheta domesticus*) feces was randomly sampled from a cricket-keeping farm in Mueang district, Sakon Nakhon province, Thailand. To eliminate any impurities, including food remnants and dead cricket organs, the cricket feces underwent a painstaking manual cleaning procedure. After this thorough cleaning, the purified feces was sifted through a 2-mm sieve and thoroughly mixed to guarantee a homogeneous blend. Characteristics of soil and cricket feces before starting the experiment are shown in Table 1.

Experimental design and setup

The experiment was conducted under the greenhouse condition during December 2022 to March 2023 using the randomized complete block design with three blocks. The experiment involved two factors: the soil moisture levels, which included the maximum water-holding capacity (WHCmax) and flooded soils and the cricket feces rates, which included 0 (unamended), 3.13 (low), 6.25 (medium) and 12.50 t/ha (high).

A mixture of 3 kg of soil with the dry weight basis of the appropriate amount of cricket feces to meet the requirements of each treatment was placed into pots with dimensions of 20.4 cm in upper width, 13.3 cm in bottom width and 17 cm in height. The rice (*Oryza sativa*) utilized in this study was the glutinous rice variety RD 22. Before transplanting, the soil was incubated for 30 days by adding water to reach the required moisture level for each treatment. Rice seedlings were grown, nursed in nursery trays and transplanted after 30 days of sowing. Healthy and similar-sized seedlings were selected and transplanted with one hill per pot and two seedlings per hill. To achieve a reliable consistency in soil moisture levels, WHCmax diligently conducted daily weight measurements for each pot throughout the experiment. Meanwhile, in the event of flooded soil, water was added to a height of 3 cm from the soil surface, ensuring optimal moisture until seven days prior to harvesting. The rice was harvested 121 days after sowing and rice's shoot and root biomass and soil samples were collected for laboratory analyses along with measurements of rice yield components. Additionally, the harvest index was also determined using the following equation:

$$\text{Harvest index} = \frac{\text{Filled grain weight per hill}}{\text{Shoot dry weight per hill} + \text{Filled grain weight per hill}} \times 100$$

Laboratory analysis

Soil properties were determined according to the methods provided by Pansu and Gautheyrou (2006), while elemental contents in rice tissue was measured following Miller (1998).

Statistical analysis

An analysis of variance was performed based on the randomized complete block design to assess the influence of soil moisture levels and cricket feces rates on soil and plant responses. The multiple comparisons among the treatments were performed using Tukey's honestly significant difference (HSD) test. Relations among soil properties, rice yield and yield components and tissue nutrient contents were analyzed by the principal component analysis using the PROC PRINCOMP model. Statistical significance was considered at P≤0.05.

RESULTS AND DISCUSSION

High-quality cricket feces: A vital source of essential elements for rice

The cricket feces used in this study exhibited superior quality in various indicators compared to the organic fertilizer standard set by the Department of Agriculture (National Bureau of Agricultural Commodity and Food Standards, 2005). In this study, the cricket feces' pH was 7.19 and C/N ratio was 10, with 29.5 g N/kg, 18.3 g P/kg and 28.1 g K/kg (Table 1), while the Department of Agriculture's standards were pH 5.5-8.5, C/N ratio of 20, with 10 g N/kg, 2.2 g P/kg and 4.1 g K/kg (National Bureau of Agricultural Commodity and Food Standards, 2005). Although the EC of the cricket feces used in this study exceeded the standard of 3.5 mS/cm, with a value of 9.18 mS/cm (Table 1), it did not result in soil salinity. This is seen in the EC ranging from 0.32 to 0.49 mS/cm observed in the soils treated with cricket feces (Table 2).

The application of cricket feces increased the concentrations of macronutrients in the soil, as demonstrated by increases in total N, NH_4^+-N, NO_3^--N, P, K, Ca and Mg

Table 1: Initial characteristics of the soil and cricket feces.

Characteristic	Soil	Cricket feces
Soil particle distribution (%)		
Sand	82.32	-
Silt	14.35	-
Clay	3.33	-
Soil texture	Loamy sand	-
Bulk density (g/cm^3)	1.51	0.33
Water holding capacity (% w/w)	29.3	-
pH (1:1)	5.70	7.19
Electrical conductivity (mS/cm)	0.102	9.18
Cation exchange capacity (cmol/kg)	2.58	109
Organic C (g/kg)	4.30	295
Total N (g/kg)	0.13	29.5
C/N ratio	33.5	10
NH_4^+-N (mg/kg)	4.55	1315
NO_3^--N (mg/kg)	4.20	9.42
P (mg/kg)	26.6	18295
K (mg/kg)	21.1	28063
Ca (mg/kg)	361	3478
Mg (mg/kg)	42.4	1804
Na (mg/kg)	5.67	5369
Exchangeable acidity (cmol/kg)	0.176	nd
Al (mg/kg)	4.20	nd

nd = Not detectable.

Table 2: Soil chemical properties as influenced by different application rates of cricket feces under soil moisture contents corresponding to the maximum water-holding capacity and flooded conditions.

Soil amendment †	Soil chemical property														
	pH	EC (mS/cm)	CEC (cmol/kg)	Organic C (g/kg)	Total N (g/kg)	C/N ratio	NH_4^+-N (mg/kg)	NO_3^--N (mg/kg)	P (mg/kg)	K (mg/kg)	Ca (mg/kg)	Mg (mg/kg)	Na (mg/kg)	Al (mg/kg)	Exc. acidity (cmol/kg)
WHCmax+CrF_{un}	6.35 d ‡	0.23 e	2.49 c	3.93 e	0.124 d	31.7 a	4.55 cd	0.83 b	36.6 f	23.4 d	288 e	57.0 e	17.5 d	4.16 b	0.101 b
WHCmax+CrF_{low}	6.33 d	0.34 d	2.60 c	4.33 d	0.159 c	27.3 b	5.18 b-d	0.71 b	65.3 c	26.1 d	300 de	69.1 c	24.7 c	3.58 cd	0.096 b
WHCmax+CrF_{medium}	6.57 b	0.37 c	3.40 ab	4.76 c	0.174 bc	27.3 b	6.21 ab	1.76 a	73.6 b	37.5 c	325 bc	81.2 b	31.3 b	3.31 de	0.064 c
WHCmax+CrF_{high}	6.79 a	0.42 b	3.75 ab	5.15 ab	0.189 ab	27.2 b	6.57 a	1.33 ab	103.4 a	64.6 a	369 a	91.5 a	45.5 a	3.15 e	0.061 c
Fld+CrF_{un}	6.33 d	0.25 e	2.48 c	4.17 de	0.133 d	31.4 ab	4.23 d	0.80 b	34.9 f	26.5 d	313 cd	60.3 de	18.1 d	4.61 a	0.136 a
Fld+CrF_{low}	6.43 cd	0.32 d	2.60 c	4.74 c	0.157 c	30.2 ab	5.19 b-d	0.79 b	43.1 e	38.4 c	317 b-d	68.3 cd	21.0 cd	4.23 ab	0.074 c
Fld+CrF_{medium}	6.56 bc	0.38 c	3.38 b	4.85 bc	0.170 bc	28.6 ab	5.81 a-c	0.89 b	53.5 d	53.2 b	335 b	82.1 b	24.3 c	3.71 c	0.059 c
Fld+CrF_{high}	6.68 ab	0.49 a	3.84 a	5.44 a	0.198 a	27.4 ab	5.49 a-d	1.77 a	74.9 b	69.7 a	362 a	92.6 a	29.9 b	3.36 c-e	0.056 c
P-value	<0.001	<0.001	<0.001	<0.001	<0.001	0.050	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
F-test	***	***	***	***	***	*	***	***	***	***	***	***	***	***	***
CV (%)	0.72	2.74	5.10	2.76	5.00	5.14	8.1	20.83	2.57	7.45	2.13	3.90	5.81	3.60	8.91

***=$P \leq 0.001$. † WHCmax and Fld denote the soil moisture contents at maximum water-holding capacity and when flooded, respectively. CrF_{un}, CrF_{low}, CrF_{medium} and CrF_{high} correspond to cricket feces rates at unamended and low (3.125 t/ha), medium (6.25 t/ha) and high (12.5 t/ha) levels.

‡ Means in the same column followed by the same letter were not statistically different at $P \leq 0.05$ (Tukey's HSD test).

(Table 2) and raised the content of these nutrients in the rice tissue (Table 3). As a result, the growth of rice plants was improved, which is exhibited by the increases in the shoot and root biomass of the rice plant, ultimately resulting in a higher rice yield (Table 4).

Soil acidity and Al toxicity alleviated by cricket feces

The increased cricket feces rates generally resulted in decreased soil acidity, as seen in the increased pH and decreased concentrations of exchangeable acidity and Al in the soil (Table 2).

In this study, the initial soil exhibited an Al concentration of 4.20 mg/kg (Table 1). According to Slattery *et al.* (1999), Al concentrations ranging from 4 to 8 mg/kg in soil were considered highly toxic, suggesting that soil Al levels in the present study were highly toxic. However, the decreases in Al concentration in soil amended with cricket feces might not be solely attributed to the increases in pH. Instead, it might be due to the chelation of Al to organic anions, as reported by Hue (1992), who found that malate, citrate and tartrate chelated with Al in soil. Later, Hue *et al.* (2001) found that organic materials such as animal manures contained compounds that act both as a reducing agent and as a chelate with acidic elements in the soil, including Mn, Fe and Al.

Cricket feces decreased the toxicity of Ca and Na by providing K and Mg

The Ca content in rice tissue typically fell within the range of 2.42-4.46 g/kg (Table 3). This range was considered as high level (3 g/kg) according to Reuter *et al.* (1997). Nonetheless, cricket feces could decrease Ca contents in rice tissue by providing K and Mg.

Although cricket feces served as a vital source of K, Ca and Mg (Table 1), thereby increasing the concentrations of these cations in the soil (Table 2), the contents of K and Mg in rice tissue increased in proportion to the application rates of cricket feces (Table 3), mirroring the trend observed in the soil (Table 2). However, Ca contents in rice tissue (Table 3) displayed an inverse relationship with soil Ca concentration (Table 2), suggesting an antagonistic effect between K and Mg with Ca. Mengel and Kirkby (2001) demonstrated that the antagonistic relationship between K and Mg toward Ca uptake led to a decrease in the plant absorption of Ca. Additionally, plants had a higher affinity for K uptake than other cations. While the precise mechanism by which Mg counteracted Ca had not been fully understood, plants might be better able to uptake Mg than Ca due to the higher affinity of Ca for binding to organic and inorganic colloids in soil. In a study on a synthetic gel containing alginate-citrate composites, Wang *et al.* (2021) reported that the gel exhibited a Ca and Mg absorption capacity of 62.4 and 36.2 mg/g, respectively. According to Chi *et al.* (1977), the adsorption power of Ca on the exchangeable site of clay particle surfaces was stronger than that of Mg. It was further observed that the behavior of Na in soil (Table 2) and in rice tissue (Table 3) was similar to that of Ca, which was attributed to the antagonistic effects of K and Mg against Na (Mengel and Kirkby, 2001). The underlying mechanism behind this phenomenon might be similar to that of Ca.

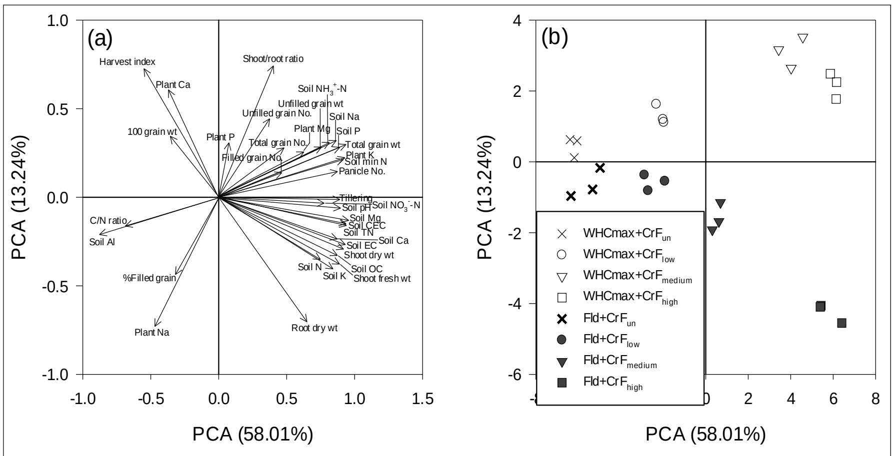
The optimum cricket feces rates and their effects on yield and yield components of rice

In soils with the maximum water-holding capacity, the application of medium and high rates of cricket feces resulted in the highest rice yield, while in flooded soils, the highest yield was obtained when a high rate of cricket feces was applied. This was supported by the filled grain weight and total grain weight per hill (Table 4). The grain weight of rice was found to increase with both medium and high rates of cricket feces in soils with the maximum water-holding capacity, as well as with the high rate of cricket feces in flooded soils. This was attributed to the increases in total grain number per hill, which in turn was due to the increases in panicle number per hill. This elucidation was supported by the significant increases in panicle number per hill in soils with the maximum water-holding capacity that received medium and high rates of cricket feces, compared to those that did not receive cricket feces or received the low rate (Table 4). The number of panicles per hill of rice in these treatments corresponded to the tillering. This finding suggested that the increased rice yield observed with the application of cricket feces was due to its ability to enhance the tillering of rice plants.

Tillering was closely associated with the number of panicles and the number of grains in each hill, ultimately contributing to the rice yield (Wang *et al.,* 2017). The tillering capacity of rice was influenced by the availability of plant nutrients (Fageria, 2014), as demonstrated in this study by the direct relationship between the contents of N, P, K and Mg in rice tissue were directly related to the tillering and yield of rice (Fig 1) and the increases in the concentrations and contents of these nutrients in the soil (Table 2) and rice's shoot tissue (Table 3), respectively. Tillering was significantly

Table 3: Rice root tissue nutrient contents as influenced by different application rates of cricket feces under soil moisture contents corresponding to the maximum water-holding capacity and flooded conditions.

Soil amendment †	Tissue nutrient content					
	N (g/kg)	P (g/kg)	K (g/kg)	Ca (g/kg)	Mg (g/kg)	Na (g/kg)
WHCmax+CrF$_{un}$	13.8 c ‡	0.90 a	12.3 de	3.96 ab	1.42 b	0.525 c
WHCmax+CrF$_{low}$	13.5 c	0.84 ab	14.3 cd	4.18 a	1.44 b	0.334 d
WHCmax+CrF$_{medium}$	16.3 ab	0.78 ab	18.2 a	4.07 a	1.69 a	0.326 d
WHCmax+CrF$_{high}$	15.2 bc	0.82 ab	19.2 a	3.39 bc	1.64 a	0.142 e
Fld+CrF$_{un}$	13.8 c	0.64 b	11.1 e	3.07 c	1.45 b	0.676 ab
Fld+CrF$_{low}$	14.0 c	0.63 b	13.4 c-e	4.46 a	1.51 b	0.733 a
Fld+CrF$_{medium}$	15.2 bc	0.78 ab	15.1 bc	3.24 c	1.70 a	0.573 bc
Fld+CrF$_{high}$	17.9 a	0.75 ab	17.3 ab	2.42 d	1.50 b	0.644 a-c
P-value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
F-test	***	***	***	***	***	***
CV (%)	4.93	9.38	5.48	9.10	2.72	8.61



Where WH Cmax and Fld denote the soil moisture contents at the maximum water-holding capacity and when flooded, respectively. CrFun, CrFlow, CrFmedium and CrFhigh correspond to cricket feces rates at unamended and low (3.13 t/ha), medium (6.25 t/ha) and high (12.50 t/ha) rates.

Fig 1: Eigenvector values based on principal component analysis of soil and plant variables related to different application rates of cricket feces under maximum water-holding capacity and flooded soils.

Table 4: Shoot and root biomass, yield and yield components of rice as influenced by different application rates of cricket feces under soil moisture contents corresponding to the maximum water-holding capacity and flooded conditions.

Soil amendment †	Shoot dry weight (g/hill)	Root dry weight (g/hill)	Tillering (Plant/hill)	Panicle number (Panicle/hill)	Grain number (Grain/panicle)				Grain weight (g/hill)			100-grain weight (g)	Harvest index (%)
					Filled	Unfilled	Total	Filled (%)	Filled	Unfilled	Total		
WHCmax+CrF_{un}	4.4 e	0.93 e	3.3 cd ‡	3.33 cd	60.5 c	6.5 e	67.0 c	90.3 a	2.57 d	0.03 f	2.60 d	2.74	36.8 a
WHCmax+CrF_{low}	9.4 d	1.54 c-e	4.7 bc	4.67 bc	82.4 ab	9.3 de	91.7 b	89.8 a	4.28 c	0.05 ef	4.33 c	2.68	31.3 bc
WHCmax+CrF_{medium}	13.7 c	2.14 c	7.0 a	7.00 a	85.3 ab	27.2 a	112.5 a	75.8 c	6.62 a	0.29 a	6.91 a	2.66	32.5 b
WHCmax+CrF_{high}	15.4 b	2.04 cd	7.0 a	7.00 a	94.2 a	15.4 bc	109.7 a	85.9 ab	7.33 a	0.16 b	7.49 a	2.61	32.3 b
Fld+CrF_{un}	4.3 e	1.27 de	2.0 d	1.67 d	93.0 a	19.0 b	112.0 a	83.0 b	1.78 d	0.07 de	1.85 d	2.66	32.4 b
Fld+CrF_{low}	9.2 d	1.83 cd	5.0 a-c	5.00 a-c	76.4 b	10.3 de	86.8 b	88.1 a	3.93 c	0.09 c	4.02 c	2.66	29.9 c
Fld+CrF_{medium}	10.3 d	3.65 b	5.3 a-c	5.33 a-c	72.9 bc	10.0 de	82.9 bc	88.0 a	4.63 c	0.07 cd	4.70 c	2.65	30.9 bc
Fld+CrF_{high}	22.5 a	5.57 a	6.5 ab	6.50 ab	85.7 ab	12.1 cd	97.8 ab	87.7 ab	5.55 b	0.17 b	5.72 b	2.68	19.8 d
P-value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.583	<0.001
F-test	***	***	***	***	***	***	***	***	***	***	***	ns	***
CV (%)	4.63	12.04	15.13	18.83	6.15	12.75	5.84	2.00	6.13	6.26	5.9	2.66	2.25

influenced by N and P (Murata and Matsushima, 1979), which stimulated cytokinin synthesis in tiller nodes and promoted cell division of the rice (Zha *et al.,* 2022). Moreover, N was shown to facilitate tiller development (Sakakibara *et al.,* 2006).

Although a lack of direct evidence had yet been found to establish the relationship between K and tillering, Zain and Ismail (2016) reported that K caused an increase in rice's tillering. The K generally played a key role in activating enzymes, protein synthesis, photosynthesis, stomatal opening and closing, cellular manipulation and osmotic pressure regulation (Mengel and Kirkby, 2001). Similar to K, there had been no direct evidence of how Mg influenced the tillering. However, Deng *et al.* (2023) found that Mg caused an increase in tillering in rice. The Mg was generally involved in a number of essential metabolic processes, including photosynthesis, the transport of photosynthate and the stimulation of numerous enzymes in rice plants (Mengel and Kirkby, 2001).

CONCLUSION

This study revealed that cricket feces played a dual role in rice cultivation by serving as a nutrient source for rice growth and a soil conditioner in alleviating soil acidity and mitigating the Al and Na toxicities. The results suggested that the ideal application rate of cricket feces for rice cultivated in loamy sand soils would be medium (6.25 t/ha) and high (12.5 t/ha) rates. The medium rate was appropriate for rice cultivated in a soil under the maximum water-holding capacity, while the high rate was suitable for rice in a flooded soil.

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