



The Impact of Treated Coal Waste Sludge on Paddy Soil Chemistry Rice Growth

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Authors' contributions

This work was carried out in collaboration between both authors. Author SD did data validation, funding acquisition, performed methodology, edited, investigated and designed the study. Author AA did the project administration, recording and tracking data, preparing draft reports, analyzing operations, conducting reviews and supervised the study. Both authors read and approved the final manuscript.

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ABSTRACT

Mud from the coal washing pond, treated with lime, has spilled multiple times, resulting in pollution of the rice fields and sparking conflicts between local farmers and coal miners. The focus of this study was to determine the chemical properties of paddy field soil mixed with mud, chicken manure compost, and its effect on rice plants. The research was conducted in a greenhouse using a complete random design with a 3x4 factorial and three replications. Rice was planted in a bucket containing 10 kg of soil treated with water. This study using three levels of chicken manure compost (P), designated as P₀ (0 g), P₁ (50 g) and P₂ (100 g). The soil mixture was comprised of four levels of mud (L) and paddy field soil (S), designated as M₀ (0 kg L + 10 kg S), M₁ (2 kg L + 8 kg S), M₂ (4 kg L + 6 kg S), and M₃ (6 kg L + 4 kg S). Through a series of tests, it was found that this treatment had a positive impact on the chemical properties of paddy soil, with a notable decrease in soil

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acidity (pH of 5.2 to 6.2), an increase in total nitrogen (0.17% to 0.37%), and an enhancement in total phosphorus (P_2O_5) and potassium (K_2O) levels (24 to 55 ppm and 43.3 to 72.87 ppm, respectively). The control treatment (P_0M_0) exhibited a pH of 4.5, a total N of 0.16%, P_2O_5 , and K_2O of 18.0 ppm and 41.50 ppm, respectively. During the generative phase, the application of sludge and compost separately resulted in a significant effect on plant height at 60 days after treatment (DAT). However, the interaction between the two treatments was not significant. The generative phase of P_1M_3 interaction exhibited the fastest flowering, with a duration of 53 days, which was 6 days faster than the control. The separate compost treatment exhibited a duration of 3 days, which was 3 days faster than the control. Also, the mud treatment did not yield significant results. Additionally, for panicle length, all treatments exhibited no significant differences. The weight of dry seed contents of panicles exhibited a significant difference between the interaction and the control. The highest yield of P_1M_3 was 5.33 g, while the control exhibited a yield of only 2.12 g. These results confirm that the treated coal waste sludge spill had no negative effect on paddy rice, on the contrary, it reduced the acidity of paddy soil at the optimum level of macro and micro nutrient availability. The addition of a 50 g compost dose and 1.5 times the weight of sludge to paddy soil significantly accelerated flowering in the best rice plants, P_1M_3 , and increased yield by 2.5 times compared to the control group. These findings have changed farmers' perceptions regarding sludge spillage, which they previously viewed as a pollutant in their paddy fields.

Keywords: Coal waste; compost; nutrients; paddy rice; chemical properties; treatment.

1. INTRODUCTION

The Teluk Dalam Village (L4) which located in Tenggara Seberang sub-district, Kutai Kartanegara Regency is an agricultural area (Jiuhardi et al., 2023). Since the 1980s, the majority of the population has been engaged in the cultivation of paddy rice (Sapar & Syafruddin, 2021). The total area of paddy fields is approximately 3,500 hectares (Darma et al., 2023). Since 2004, the majority of L4 has been subject to open-system coal mining (Harjanto et al., 2019). The process of coal mining has had a detrimental impact on the surrounding area, with several instances of mud spills from the coal waste neutralisation pond entering the nearest rice field area owned by residents (Fitryarini, 2018). This resulted in disputes between various parties. The relevant parties involved in the resolution of the issue include the police, the local community, environmental agencies, research organisations and universities.

The deposition of sludge on the surface of paddy soil is a challenging phenomenon to address, particularly when the soil is ploughed. The incorporation of the contaminated material into the paddy soil can extend to a depth equivalent to the ploughing layer. Such contamination can lead to the introduction of pollutants (Hong et al., 2022; Rusdianasari et al., 2013; Shin et al., 2017).

The objective of this research was to model the impact of coal sludge post-treatment on paddy

soil, with the addition of chicken manure compost, on paddy rice plants. Chicken manure is the optimal organic fertiliser, exhibiting a complete nutrient profile comprising a high nitrogen content, sufficient phosphorus and potassium, and a range of micronutrients. The introduction of post-treatment sewage sludge must be balanced with the addition of organic matter to control and improve soil properties, *i.e.* physical, chemical, and biological (Mounika et al., 2021). The findings of this study aim to provide an explanation for the negative perceptions held by local rice farmers and other residents of L4 regarding the management of coal sludge waste in the area.

2. MATERIALS AND METHODS

The research was conducted from March to August 2024 at Universitas Mulawarman Greenhouse. The main materials used were coal washing sludge, chicken manure, paddy field soil and IR-64 rice seeds as test plants. The sludge, which had been neutralised with lime from coal mining activities adjacent to rice fields, was taken as the main ingredient of the planting media mixture. The 10 kg planting media mixture was placed in a bucket with water according to the needs and phase of the rice plant. The tools used are: hoes, machetes, sacks, scales, buckets, stationery, and a set of tools in the laboratory. Chemical properties of sludge samples, chicken manure compost, and treatment soil were analysed at the Soil Laboratory from Faculty of Agriculture -

low to medium. This was due to the fact that chicken manure contains the highest concentration of N, at 1.93%, accompanied by other nutrients (Murakami et al., 2011). It can be observed that the application of post-treatment coal waste sludge and chicken manure has resulted in an increase in the status of P and N nutrients. This has been observed to occur from a low to a medium status for P and from a low to a medium status for N. The K nutrient status was naturally high, but there was a significant quantitative increase following treatment. Prior to treatment, the concentration of K nutrients was 415 ppm, while following treatment, it increased to between 443 and 682 ppm. Furthermore, the application of chicken manure also added other macro nutrients, namely potassium (K), calcium (Ca) and magnesium (Mg), as well as micro nutrients manganese (Mn), copper (Cu) and zinc (Zn) (Warman & Cooper, 2000). The addition of manure serves to complement the soil nutrients of the treatment, as evidenced by Larney & Angers (2012), Rech et al. (2020), and Shaji et al. (2021). The incorporation of neutralised coal waste sludge and chicken manure compost into paddy field soil resulted in a discernible improvement in the chemical properties of the soil. A reduction in soil acidity, an increase in macro- and micro-nutrients, and their subsequent impact on the

growth of rice plants during the vegetative and generative phases have been documented.

3.2 Effect of Treatment on Vegetative Phase

The results of the analysis of variance on the growth of rice plants at the age of 10 days after planting demonstrated that there were no significant differences between the treatments. It is postulated that rice plants are still undergoing a period of adaptation to their external environment. Young rice plants must adapt to the absorption of nutrients following their transfer from diverse environments, which are influenced by a range of factors, for example: temperature, humidity, and aeration. The effect is not significantly different until the age of 30 days after planting, but there is a clear overall tendency for the treatment of higher plants. The effect of each treatment was evident at the age of 60 days after planting, but the interaction (PxM) was not significant. The treatment of chicken manure was found to be significantly different from the control (P₀), while the treatment of M₂ and M₃ mud mixture was also found to be significantly different from the control (M₀). This is due to the nature of manure, which reacts slowly to the availability of nutrients it contains. Hussain et al. (2022) states that the primary nutrient influencing plant height is nitrogen (N).

Table 3. Effect of treatment on the plant height was evaluated at 10, 30 and 60 days after planting

Sludge + Paddy Soil (M)	Chicken Manure (P)			Average
	P ₀	P ₁	P ₂	
10 days of age				
M ₀	25.66	28	29	27.55
M ₁	28.66	29.33	30.33	29.44
M ₂	27	32	30.84	29.95
M ₃	27	33	30.66	30.22
Average	27.08	30.58	30.21	29.29
30 days of age				
M ₀	63.66	61.66	63.33	62.88
M ₁	64.66	65.33	73	67.66
M ₂	64.66	72.33	65.33	67.44
M ₃	64.66	71	69.66	68.44
Average	64.41	67.58	67.83	67.7
60 days of age				
M ₀	91	85.33	89.66	86.66 a
M ₁	87	95.66	90.33	91.00 ab
M ₂	87.66	101	101.66	96.77 bc
M ₃	89.66	102	104	98.66 c
Average	88.33 a	96.08 b	96.41 b	93.61

Note: Mean numbers followed by the same letter are not significantly different in the LSD test at the 5%.

Table 4. Presents the effects of various treatments on generative phase

Sludge + Paddy Soil (M)	Chicken Manure (P)			Average
	P ₀	P ₁	P ₂	
Flower exit time (days)				
M ₀	59.33 abcd	60.66 abc	57.66 abcdef	59.22
M ₁	59.33 abcd	57.33 abcdefg	58 abcdef	58.22
M ₂	61 ab	56 defg	57.66 abcdef	58.22
M ₃	62 a	53.33 g	57 abcdefg	57.44
Average	60.42 a	56.83 b	57.58 b	58.27
Panicle length (cm)				
M ₀	19.66	20.66	21.33	20.55
M ₁	22	22.33	20.66	21.66
M ₂	22	21.33	21.66	21.66
M ₃	20.66	22.66	22.33	21.88
Average	21.08	21.75	21.5	21.44
Dry kernel weight per panicle (g)				
M ₀	2.12 c	2.33 bc	2.21 c	2.22
M ₁	2.66 abc	3.33 abc	3.33 abc	3.11
M ₂	3 b	3.66 abc	5.28 ab	3.98
M ₃	3.49 abc	5.33 a	5 abc	4.61
Average	2.82	3.66	3.96	3.47

Note: Mean numbers followed by the same letter are not significantly different in the LSD test at the 5%.

3.3 Effect of Treatment on Generative Phase

Significantly different from the control (P₀) and its interaction with mud treatment, the mud treatment was not found to be significantly different (see Table 4). The LSD test revealed that the application of chicken manure to the soil resulted in a faster time to flowering of rice, with an average of 57.21 days for the P₁ and P₂ treatments, in comparison to the control, which took 60.42 days. The time to flower was found to be accelerated by 3.21 days. The interaction between the two treatments exerted a significant influence on the acceleration of flower discharge. Nutrients that play a role in flower formation include P (Khan et al., 2023; Osman et al., 2014). The interaction P₁M₃ exhibited the shortest flower exit time, at 53.33 days after planting. This acceleration is five days faster than the average observed in the interaction, while the interaction control (P₀M₀) is six days faster. A shorter flower exit time will result in a shorter harvest time.

The extent of the flowering time acceleration observed in rice plants following the application of each treatment is contingent upon the quantity of chicken manure and coal waste sludge administered. The P₁M₃ treatment combination exhibits the highest level of available phosphorus (P₂O₅) nutrient content, at 55.1 ppm. The soil pH is slightly acidic, at 6.0. This condition provides greater P uptake because its availability is close

to optimal, with a pH of 6.5. Al-bound P is mostly released, and its availability is optimal (Hartemink & Barrow, 2023). P nutrients play a pivotal role in the generative phase, facilitating the acceleration of flowering. Chicken manure contains macronutrients (nitrogen, phosphorus, and potassium) and micronutrients that are complete and available to plants (Dey et al., 2019; Dikinya & Mufwanzala, 2010).

The length of rice panicles was not significantly affected by the treatments of chicken manure and mud, nor by their interactions. The longest panicle, measuring 22.66 cm, was produced by the P₁M₃ treatment, while the average length of all treatments was 21.44 cm. The lack of a significant difference between the treatments and their interactions on panicle length is thought to be due to the natural or genetic constituents of rice plants, as evidenced by the test plants in this study (Li et al., 2021).

The separate treatment of chicken manure and mud had no significant effect on the weight of dry kernels per panicle. However, the weight of dry kernels increased with increasing dose of treatment, although not yet to a level that could be considered significantly different. The results were found to be significantly different when the two treatments were combined, resulting in a positive interaction (P×M) that increased the results for dry kernel weight per panicle. The interaction of the two treatments resulted in a reduction in soil acidity, thereby increasing the

soil pH. The original acidic paddy soil, with a pH of 4.5, exhibited a reduction in overall soil acidity following the addition of neutralised sludge. The increase in soil pH value to 5.2–6.2 has a significant impact on the availability of all nutrients required by plants for optimal growth. According to Dey et al. (2019), Hartemink & Barrow (2023), Neina (2019), and Žurovec et al. (2021), this including macronutrients such as nitrogen (N), phosphorus (P), potassium (K), calcium (Ca) and magnesium (Mg), as well as micronutrients such as manganese (Mn), copper (Cu), zinc (Zn) and molybdenum (Mo).

Macronutrients whose availability in the soil is strongly influenced by pH is phosphorus (P). The results of soil analysis demonstrated an increase in P_2O_5 content at moderate to high levels (25–55.1 ppm), while without treatment, the content was only moderate (20 ppm). The absorption of P nutrients by plant roots occurs in the form of phosphate ions, with the largest being HPO_4^{2-} , which is more soluble, and then $H_2PO_4^{-}$, which has a smaller solubility (Johan et al., 2021). Nutrient P plays a pivotal role in adenosine triphosphate (ATP) as a store and transfer of energy in plants (Choudhury et al., 2007; Khan et al., 2023; Osman et al., 2014; Plaxton & Tran, 2011; Solangi et al., 2023). It is utilised for various processes, including photosynthesis, protein synthesis, translocation and absorption of nutrients, and respiration. the role of phosphorus (P) nutrients is related to flower formation and seed development. When fulfilled, it increases the quantity and quality of fruit. for rice plants to achieve optimal production, A P requirement of between 20 and 22 kg per ha has been identified (Basavarajappa et al., 2021; Che et al., 2016; Solangi et al., 2019; Sukristiyonubowo et al., 2012). The P content of all treatments of chicken manure and mud was found to be between 20.8 and 48.05 KG per ha, while that of the control was only 17.44 kg per ha. furthermore, several similar studies have been identified that are pertinent to the current findings. for instance, Khatana et al. (2023) found that the application of sewage sludge can enhance the availability of P nutrients. Additionally, the incorporation of coal waste, which provides complete nutrient, can improve cation exchange capacity and facilitate nutrient uptake in plant roots, thereby promoting increased plant productivity (Żukowska et al., 2023).

4. CONCLUSION

The results of the research indicate that the mixture of coal waste sludge that has been

neutralised with paddy field soil has a beneficial effect on soil chemical properties. This is evidenced by a decrease in acidity to pH of 5.2 to 6.2, which optimises the availability of nutrients that can be absorbed by rice roots. The combination with chicken manure compost adds N and P_2O_5 nutrients to the medium status from low, while K_2O is added but at a high status. In the generative phase, the height of rice plants was evident after the age of 60 days since planting, indicating a delay in nutrient availability, especially N from compost. The vegetative phase of the treatment mixture had a positive effect on each other, accelerating the flowering time and increasing the weight of panicles. The optimal combination, designated as P_1M_3 , exhibited the earliest flowering time (53 days) and the heaviest dry panicle (5.33 g). This treatment also resulted in a six-day reduction in the flowering time and a 3.21 g increase in the dry panicle weight compared to the control. These findings indicate that the coal waste sludge spill did not negatively impact paddy rice growth. Instead, it demonstrated a capacity to reduce soil acidity to an optimal level, which is contingent upon the presence of adequate macro- and micro-nutrient availability.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

The authors hereby declare that generative artificial intelligence (AI) technologies such as DeepL Translate and AI Proofreader have been used during the translating, editing, and improving of language readability.

NOVELTY STATEMENT

This research offers insights into the chemical properties of paddy soil when mixed with mud and chicken manure compost, as well as its effects on rice plants. Field findings confirm that combining neutralized coal waste sludge with paddy field soil can systematically influence soil chemical properties. Additionally, results indicate that the application of processed coal waste sludge actually has positive implications for rice cultivation, as it can reduce the acidity of paddy soil while optimizing the availability of macro and micronutrients.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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