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Application of residual basalt for the cultivation of jasmine rice from northeastern Thailand; an example of the reduction of methane emissions

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Abstract: The cultivation of rice in mainland Southeast Asia countries is concerned with the emissions of greenhouse gases (GHG) today. Methane is one of the GHG gases originating from long flooding periods of rice growth. This paper aimed to experiment with the environmentally re-soil technique by adding residual basalt in the rice cultivation process with non-fertilizer usage and to shorten the flooding period as a consequence to reduce methane emissions. We apply wet-dry techniques in rice production to measure rice growth and yield. We analyzed the chemical qualities of residual basalt from the Khao Kradong, Buriram province, northeastern Thailand where extinct volcanoes and residual soils are extensively located nearby. A geological survey after processing the GIS data was carried out to specify the suitable residual basaltic sites. Then, residual basaltic soil from 7 profiles was analyzed by XRD and XRF. Then, the selected residual basalt was used for mixing with local soil in the jasmine rice experiment where the rice growth and yield, coupled with aromatic properties were observed. The results showed that the re-soil technique significantly and positively affected the height of rice, germination, number of ears, number of seeds per ear, and the total yield weight.The yield of the experiment is equal to the average yield of planting with chemical or organic fertilizers, but water is saved for 42 days. With a total cultivation period of 126 days, rice production can reduce water usage by 33.3%, with no need for fertilizers.

Keywords: Residual basalt, re-soil, methane, GHG, Khao Dawk Mali 105, Khorat Plateau

INTRODUCTION

Rice is a staple food that is consumed by more than half of the world's population. The grain of rice is not only important for food security, but cultivation is also an important source of livelihood. Rice production from Asia covers 90% of the total global production (Fukagawa & Ziska, 2019). Although rice is useful to humans, using fertilizers for rice farming today affects the environment and causes global warming. Some steps of rice production also release greenhouse gases (GHG) into the environment, and it impacts both, directly and indirectly, the biodiversity (Jeswani *et al*., 2018). For example, the excessive addition of chemical fertilizers may cause nutrient leaching, and storage of water in the paddy fields significantly emit carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) (Berkhout *et al*., 2015; Chang *et al*., 2018; He *et al*., 2018; Jeswani *et al*., 2018; Habibi *et al*., 2019; Dastan *et al*., 2019; Fukagawa & Ziska, 2019; Liu *et al*., 2022; Mahmood & Gheewala, 2023).

Over the past few decades, researchers around the world have tried to find a method to improve rice production that gives a high yield, reduces the environmental impact due to rice cultivation, and is sustainable for rice production. Some of the methods, for example, are organic rice farming (Mahmood & Gheewala, 2023), system of rice intensification (SRI) (Berkhout *et al*., 2015), wetting and drying water management and rice straw incorporation, and efficient post-harvest management, such as handling rice straw by turning it into compost (Zakarya *et al*., 2018). Sustainable and environmentally friendly rice cultivation is a challenge that cannot be a successful case with one method, but using multiple processes at each stage of cultivation can help to achieve the objectives (Lin & Fukushima, 2016). Consequently, in this paper, we focus on examining natural nutrients from residual basalt to reduce fertilizer use, and water level control to reduce methane. It is well-known that weathering basalt

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is rich in natural nutrients such as silica, iron, aluminum, potassium, and calcium which plants need and benefits plant growth (Römheld & Marschner, 1986; Marschner, 1995; Nozoye *et al*., 2011; Rout & Sahoo, 2015; Farooq & Dietz, 2015; Guerriero *et al*., 2016; Artyszak, 2018; Sukyankij *et al*., 2020; Ramírez-Olvera *et al*., 2021; Swe *et al*., 2021; Zuverza-Mena *et al*., 2023).

Adding fertilizers can ensure that plants receive the nutrients they need at planting time and during the growing period. However, some substances in fertilizer can impact the environment. Over-fertilizing can be hazardous, such as the toxicity of iron, aluminum, and manganese in rice. Overfertilization can also lead to sudden plant growth with an insufficient root system to supply adequate water and nutrients to the plant. Poor root structure causes inefficiency in nutrient absorption and can also inhibit plant growth (Dobermann *et al*., 2002).

Water management in paddy fields can reduce environmental impacts. Normally, a higher and longer flooding periods of paddy fields will increase methane (CH_4) emissions. Conventional rice production (90 - 120 days of irrigation) also promotes the highest impacts on CH_4 emission (Carrijo *et al*., 2017; Oo *et al*., 2018; Liao *et al*., 2020; Zhang *et al*., 2021; Liao *et al*., 2023). Although the short flooding water into the rice farm reduces methane emissions, some studies have also found that water level in paddy fields has the potential to release N_2O if the source of nitrogen is from both chemical or organic fertilizers (Kiese *et al*., 2008; IPCC, 2013; Xu *et al*., 2013; Yang *et al*., 2015; Zhu *et al*., 2015; Abraham *et al*., 2016; Xia *et al*., 2017; Qaswar *et al*., 2020; Liang *et al*., 2022).

In Southeast Asia, one source of greenhouse gases (GHG) is released from growing rice. Fertilizers and traditional irrigation or conventional rice production emit CO_2, CH_4, and N_2O throughout the cultivation process. We believe that the use of fertilizers in soil is a matter of concern for GHG release in rice fields. Therefore, in this paper, we selected and analyzed the residual soil from basaltic terrain in the southern part of the Khorat Plateau, northeastern Thailand. We focused on the experiment to propose environmentally-friendly ways of cultivation by omitting fertilizer and replacing the residual basalt in the soil instead. We set up the re-soil experiment for growing jasmine rice (Khao Dawk Mali 105 (KDML 105)).

MATERIALS AND METHODS

Data acquisition

Remote sensing and geographic information system (GIS) data

In this study, we made a geological field survey around Khao Kradong and the surrounding areas where an extinct volcano is located (Figure 1). We accessed various types of remote sensing data including Landsat-8OLI satellite images (Path 128 and Row 050) taken on June 22, 2021, Zone 48N with the geodetic reference system WGS 84. The resolution is 30 m for bands OLI-1 to OLI-7, respectively.

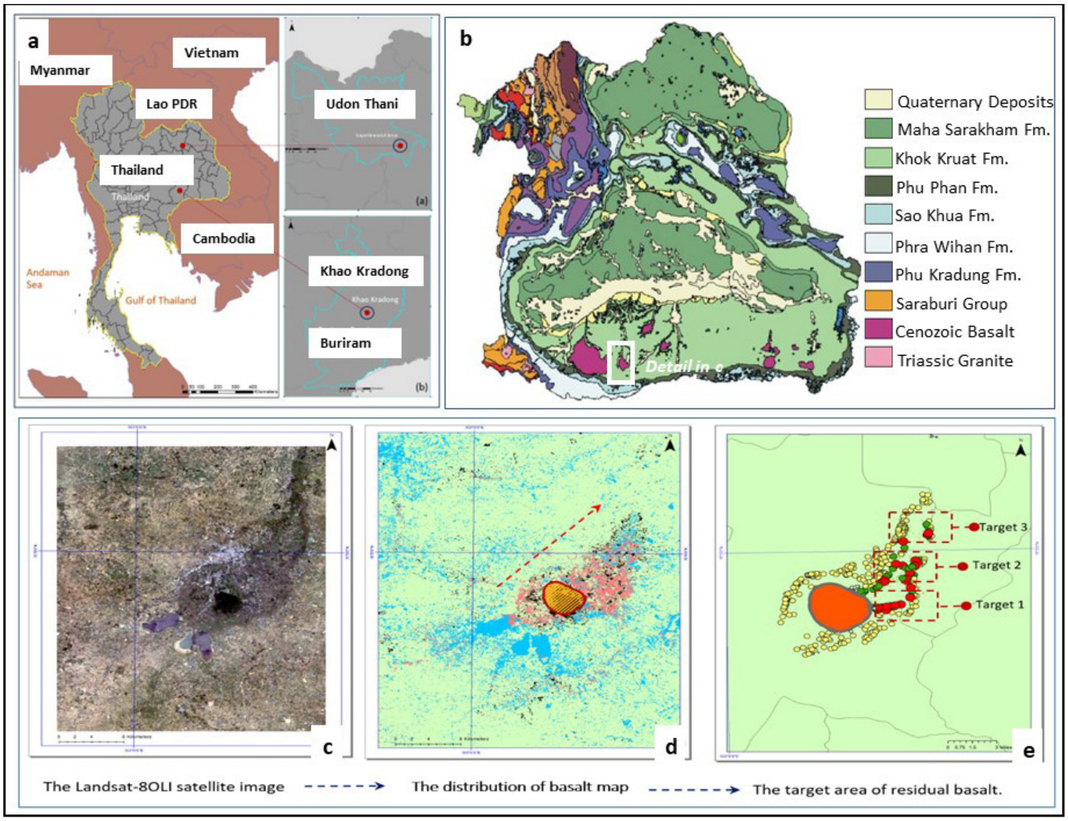


Figure 1: (a) Index map of Thailand and provincial names mentioned in this paper. (b) Geological map with basalt exposure in the south. (c) Landsat 8 satellite image. (d) Basalt exposure and distribution of residual basalt, Khao Kradong, Buriram Province. (e) Three target areas of residual basalt for this study.

GIS data used in this work include (i) Buriram provincial boundaries (province, district, sub-district), polygons (reserved forest, water reservoir, wetland, and national park, basin), lines (stream, river, road), points (village, groundwater well) and land use. Geological data include geological boundaries, aquifers, faults, soil groups, and slopes.

Various types of remote sensing data were classified. The aim was to locate the distribution of basaltic exposures and residual basalt. All data were processed using GIS software to define target areas 1, 2, and 3 and to determine the excavated location. The method is shown in Figure 2.

Experimental design

In this study, we explored and targeted the sources of residual basalt around the Khao Kradong, an extinct volcano, in Buriram Province, northeastern Thailand. Remote sensing and GIS analysis were applied to locate the high-potential areas for basaltic soil excavation (more than 50% of SiO_2, based on XRF and XRD analysis) (Kaew-in & Choowong, 2023). Basaltic soils were transported and used in the experimental rice growing area at Rai Kaew-In, Udon Thani Province (Figure 1a). The experiment was designed as the randomized complete block design (RCBD) consisting of 5 treatments, i.e., t1-t5 (Figure 2). The mixing ratio of each treatment is shown in Figure 3. The experimental unit is 0.5 m high and 1 m in diameter. The distance between the blocks and the units is 1 m (Figures 3a-b). The number of treatments and blocks was randomly selected, as shown in Figure 3(d). The crop processes are demonstrated in Figure 3e. Rice was harvested at 18 weeks (126 days) after planting. Plant parameters and yield were recorded, including plant heights measured from the soil surface to the tip of rice every week until the harvested period, stem size, leaf size, number of stems, number of leaves, number of ears, number of seeds per ear, total weight, and the smell from volatile gas called 2-Acetyl-1-Pyrroline (2AP) analysis by using Headspace Gas Chromatograph Mass Spectrometry (HS-GC/MS). The present study was analyzed for statistical variance using the Analysis of Variance (ANOVA) method.

RESULTS AND DISCUSSIONS

Remote sensing and GIS

The Landsat-8 satellite images were processed and limited to the distribution of residual basalt located about 20 km to the northeast of Khao Kradong, on the way to Huai Rat District from Muang Buri Ram District. The distribution map of basaltic rock and soil is shown in Figure 1(b). Based on the remote sensing and GIS analyses, the most suitable area for collecting basaltic soil is from the Khao Kradong buffer zone, 15 km of distance to the northeast where the criteria of site selection is the highest potential (Kaew-in & Choowong, 2023) (Figures 1b-c). The first target area is situated

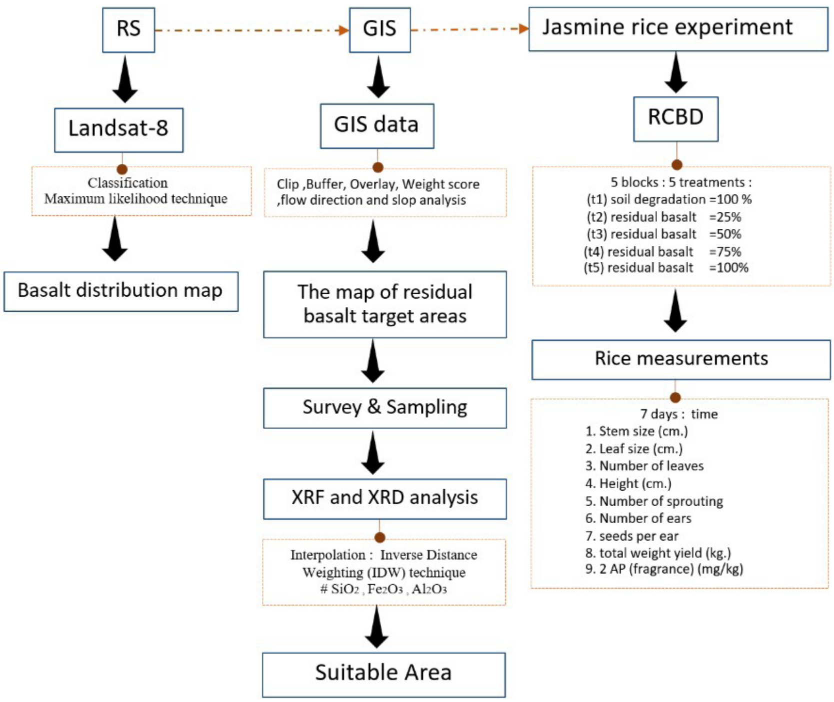


Figure 2: Flowchart shows the methodology for residual basalt site selection, mineral analysis, and parameters for rice measurement in this work.

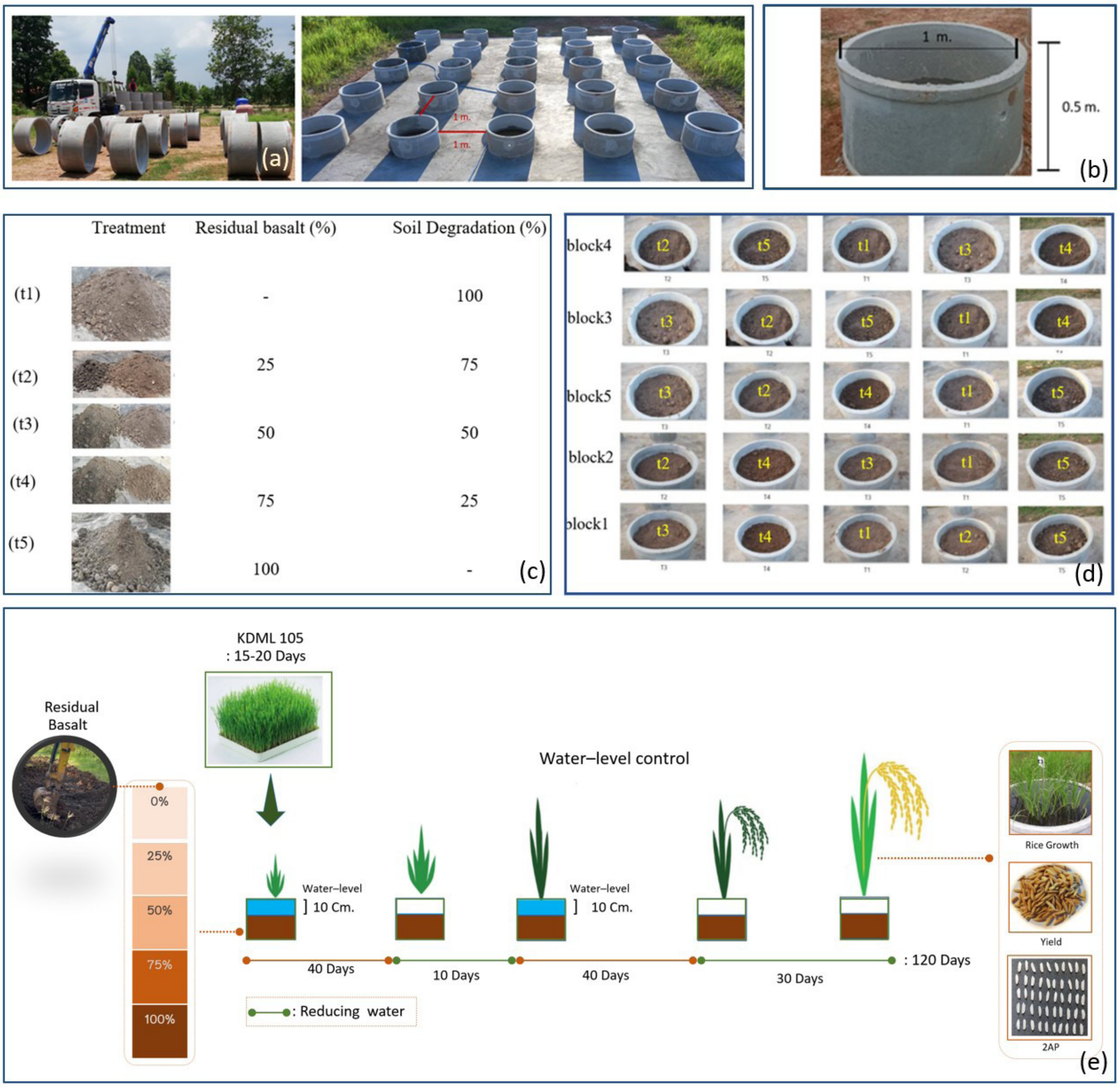


Figure 3: Experimental design, (a) the experimental unit preparation, (b) the height and diameter of the experimental unit, (c) the ratio of treatment designed for this study, (d), the number of treatments and blocks was randomly selected, (e) the cultivation process.

in Sawai Cheek Subdistrict, Mueang Buriram District, about 4 km from the buffer zone. The second target area is located at the Huai Rat and Isan Subdistrict, 7 km from the buffer zone. The third target area is located in Ban Yang Subdistrict, Mueang Buriram District, 12 km from the buffer zone. All three target areas are shown in Figure 1(e).

After the target areas were selected, we created the profile point for the survey and sampling. Target area 1 contains three profiles (profiles 1 to 3 in Table 1). Target area 2 has two profiles (profiles 4 and 5). Target area 3 includes two profiles (profiles 6 and 7). The profile point and coordinate are shown in Table 1.

Growth and yield of KDML 105

The farming system in Thailand comprises two common seasons. The first is called "in-season rice" or "rain-fed rice", representing rice grown during the regular farming season. It starts from May to October and harvest is completed by February. On the other hand, the second is called "off-season rice", referring to rice grown outside the regular farming season. It starts in January and finishes in April. Our experiment began in August to November 2022 (in-season farming). The experiment was divided into 2 phases. Phase I measured the growth of stems and leaves, starting from the first week to the 12th week. Phase II was for fertility and seed formation, from

Table 1: The coordination of the profiles in the three target areas.

Target area	Coordinate			Lithology
Target 1				
Profile 1	0300259E	1652017N	Zone 48 P	Black and blown color of soil, mixed plant roots, mostly soil, and no weathered basalt at depth upper 60 cm.
Profile 2	0300573E	1651987N	Zone 48 P	
Profile 3	0300013E	1651780N	Zone 48 P	
Target 2				
Profile 4	0302967E	1655620N	Zone 48 P	Clay sediment and mixed rock in the ratio of 95:5, dark brown-black color and weathered basalt
Profile 5	0300089E	1655726N	Zone 48 P	
Target 3				
Profile 6	0302967E	1655620N	Zone 48 P	Dark brown with basalt fragments. Clay per grain is 70:30 with grain size 0.1-2 cm of weathered basalt.
Profile 7	0300089E	1655726N	Zone 48 P	

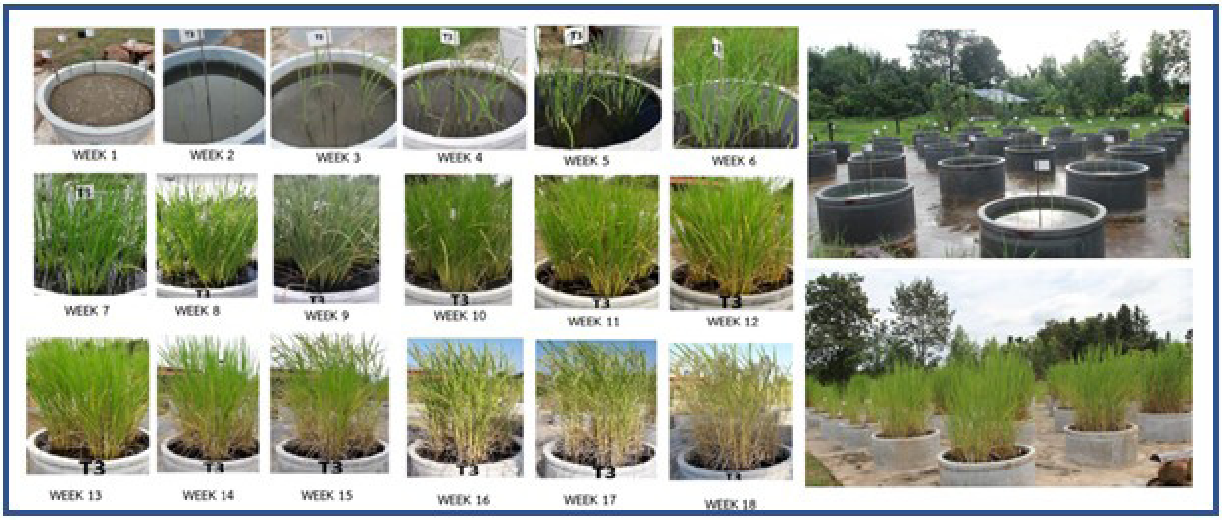


Figure 4: Series of photographs showing rice growth between week 1st – week 18th.

Table 2: Property of soils (0 - 15 cm) before conducting the experiments.

Property	Amount/Unit	Result
Organic matter (OM)	0.57%	Low
Phosphorus (P)	6 mg/kg	Low
Potassium (K)	22 mg/kg	Very low
Calcium (Ca)	561mg/kg	Low
Magnesium (Mg)	57 mg/kg	Low
pH	6.3	Slightly acidic
Electrical Conductivity (EC)	0.03 mS/m	None
Soil texture	-	Sandy loam

the 13th week to the 18th week (Figure 4). The original soil in the study area is classified as paddy soil, owing to poor nutrients. The original soil properties before the experiments are shown in Table 2.

The experiment started with seedlings for 15 days, and then transplanted into an experimental unit. Results were collected weekly by measuring stem and leaf size, height, number of leaves, and sprouting. The results are shown in Figure 5. The measurements of leaf size (b) showed that there was little difference in growth during the 1st and 2nd weeks of each treatment (t1-t5) (also see ratio of each treatment in Figure 3c). From the 3rd to the 12th week, t2 had the highest leaf width, followed by t1 (Control), t3, t4, and t5, respectively. The number of leaves (c) increased steadily and was noticeable in the 7th to 12th week, then decreased with the greatest number of leaves similar between t1 and t2, followed by t3, t4 and t5, respectively. For the size of the stem (d), the result shows in the 1st to 5th week, the growth was evident in all experimental units. From week six onwards, the stem size remained stable, starting with t2, with no change at week 5th, t1, t3, t4, and t5, and no change at week 9th until the harvesting period. The number of sprouting (e) showed that growth and sprouting increased significantly between weeks 4–12, with t2 having the highest budding followed by t1, t3, t4, and t5, respectively. From week 13 onwards, the budding number has slightly changed until the harvest time. The height of rice plants (f) continued to increase from the first week to the last week, with t2 having the highest elevation, followed by t1, t3, t4, and t5, respectively.

In the reproductive stage, from the 13th week onwards, the rice pinnacle initiated, then the seed turned from green to yellow. Finally, the grain color was brown and ready for harvest in the 18th week (Figure 6a). t2 gave the most significant number of ears of KDML 105 rice, followed by t1, t3, t4, and t5, respectively (Figure 6b). The number of seeds per ear showed that t2 had the highest mean number of grains per ear, and the fourth block was significantly higher, followed by t1, t3, t4, and t5, respectively. The number of maximum, minimum, and average seeds per ear in each block is shown in Figure

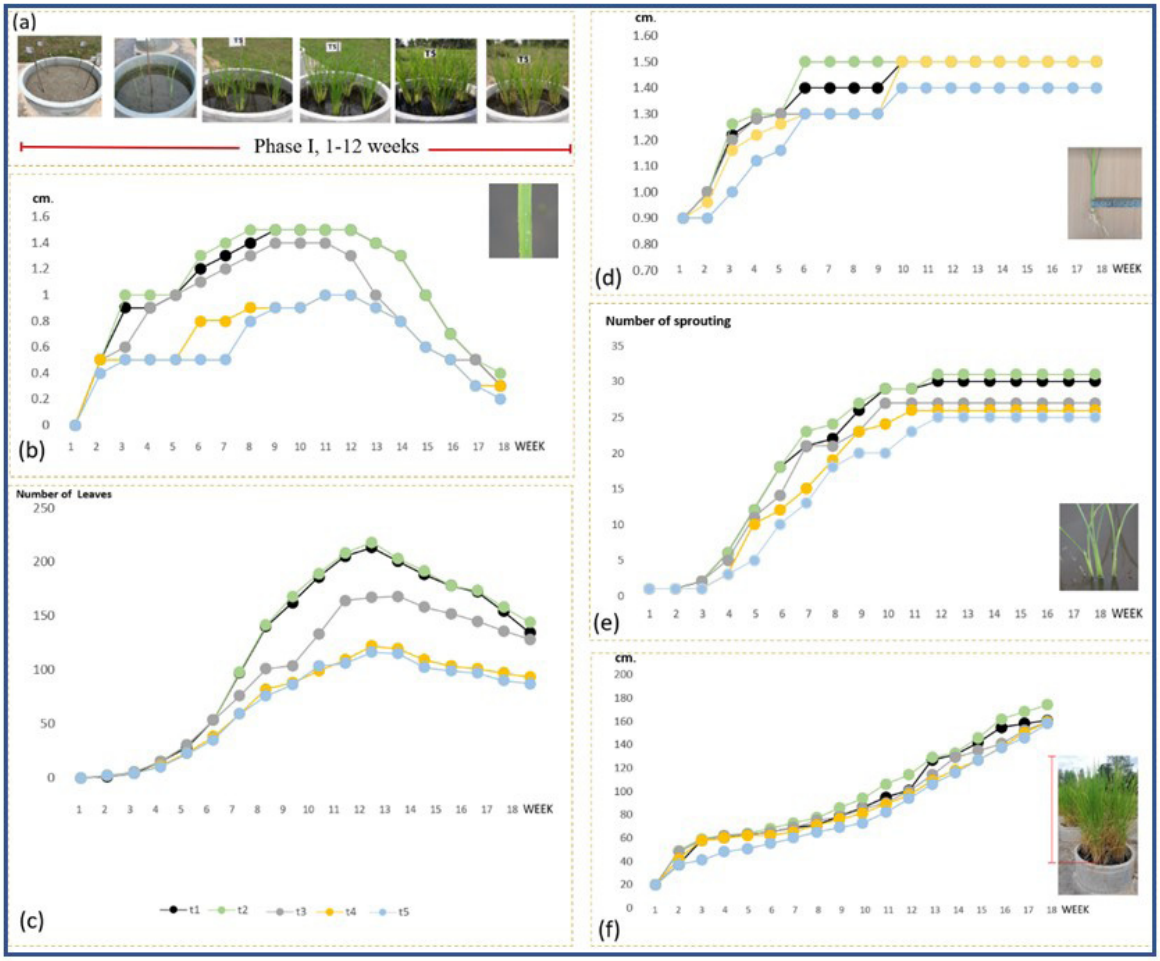
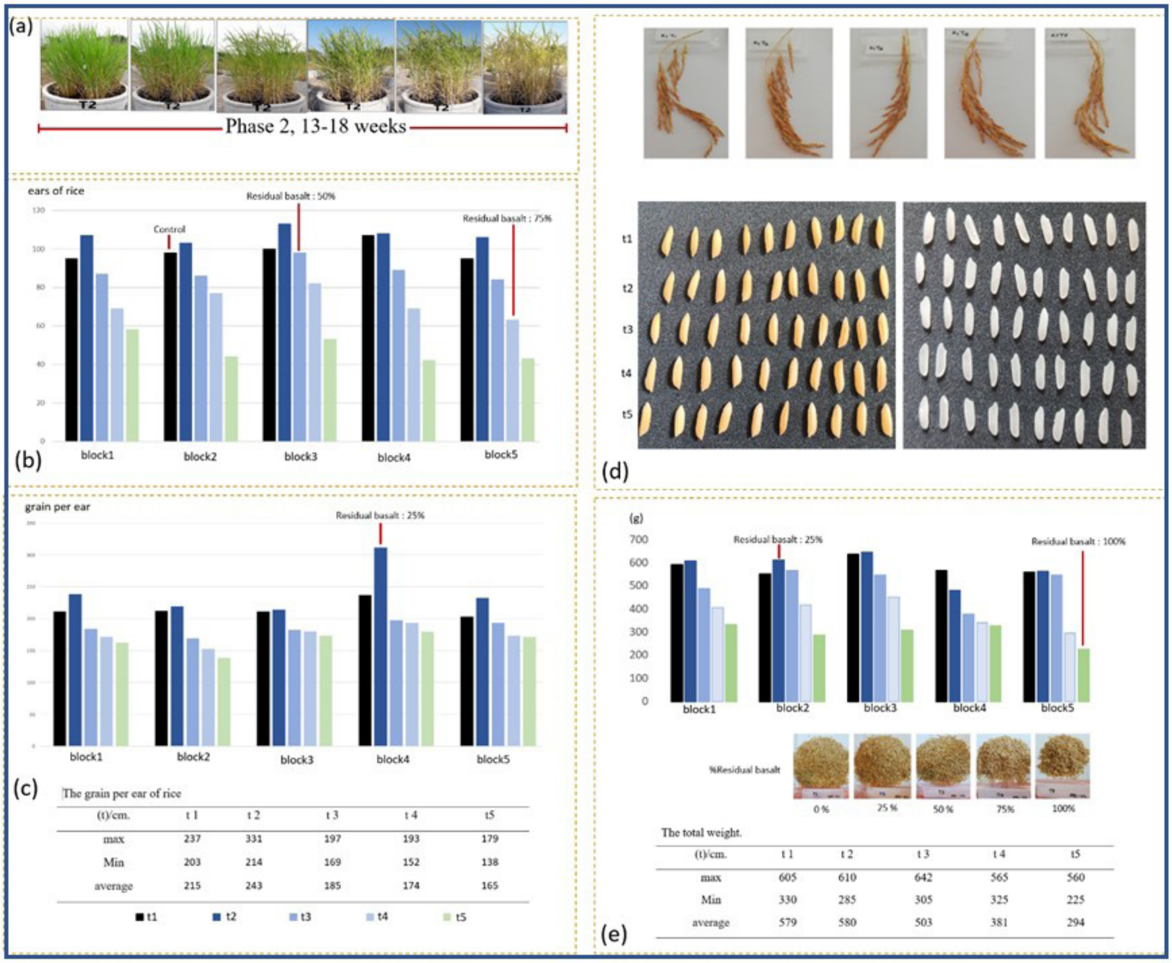


Figure 5: The stem and leaves measurement. (a) The picture of rice growth at 1-12 weeks, (b) the leaf size, (c) the number of leaves, (d) the stem size, (e) the number of sprouting, and (f) the height of rice plants.



The grain per ear of rice

(t)/cm.	t 1	t 2	t 3	t 4	t5
max	237	331	197	193	179
Min	203	214	169	152	138
average	215	243	185	174	165

The total weight.

(t)/cm.	t 1	t 2	t 3	t 4	t5
max	605	610	642	565	560
Min	330	285	305	325	225
average	579	580	503	381	294

Figure 6: The reproductive stage. (a) The picture of rice growth 13-18 weeks, (b) the number of ears of rice, (c) the number of seeds per ear, (e) the total weight.

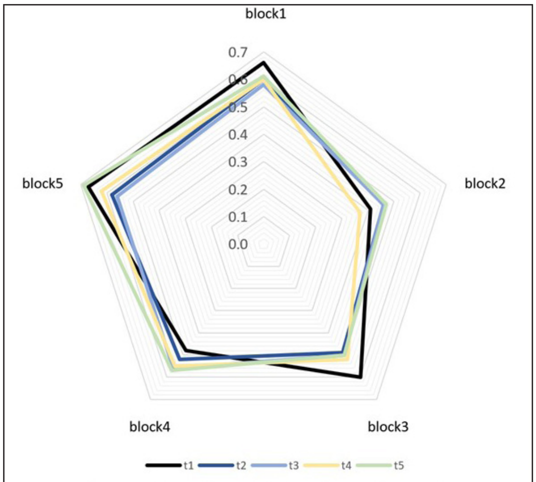
6(c). The ears and seeds' visual observations have the same physical characteristics (Figure 6d). However, t2 gives the most extensive total weight, followed by t1, t3, t4, and t5, respectively (Figure 6e).

2AP analysis

Results from analysis of rice aroma (2AP) by HS-GC/MS technique suggest that, in block one, t1 gave the highest aroma, followed by t5, t2, t4, and t3, respectively. In block two, t5 gave the highest aroma, followed by t2, t3, t1, and t4, respectively. In block three, t1 gives the highest aroma, followed by t4, t3, t5, and t2. In block four, t5 gives the highest aroma, followed by t3, t4, t2, and t1, respectively. In block five, t5 give the most aroma, followed by t1, t2, t3, and t4, respectively (Figure 7).

Statistical analysis

The results show that residual basalt significantly affected the height of rice plants, germination, number of ears, number of seeds per ear, and the total yield



t & Block	Block1	Block2	Block3	Block4	Block5
t1	0.66	0.41	0.60	0.48	0.67
t2	0.60	0.46	0.49	0.52	0.58
t3	0.58	0.46	0.50	0.56	0.56
t4	0.60	0.37	0.52	0.55	0.62
t5	0.61	0.47	0.50	0.57	0.69

*CF=7,SumSQ=8 (mg/kg)

Figure 7: The analysis of aromatic KDML 105 from an experiment.

Table 3: Analysis of variance for growth and yield of KDML105 experiment in the 2022 season.

Parameter/(t)	(t1)	(t2)	(t3)	(t4)	(t5)	Significance
Stem size (cm)	1.5	1.5	1.5	1.5	1.4	-
Leaves size (cm)	1.4	1.4	1.3	1.2	1.0	-
Number of leaves	810	871	719	550	330	* and **
Height (cm)	148	159	145	141	138	* and **
Number of sprouting	30	31	27	26	24	* and **
Number of ears	99	107	89	72	48	* and **
Seeds per ear	215	243	185	174	165	* and **
Total weight yield (g)	579	580	503	381	294	* and **
2AP (mg/kg)	0.56	0.53	0.53	0.53	0.57	-

* and ** - Significant at 0.05 and 0.01 levels, respectively.

weight. The analysis of variance for growth and yield of the KDML 105 experiment in the 2022 season is summarized in Table 3.

CONCLUSIONS AND RECOMMENDATIONS

In this study, based on geological and geochemical analyses, the high potential site of residual basalt in the southern part of the Khorat Plateau is target 2 at the coordination of 302967E, 1655620N. Residual basalt is located behind Huai Rat Sub-district Administrative Organization in the administrative area of Huai Rat Subdistrict, Huai Rat District, Buriram Province. We used residual basalt from this site for a jasmine rice (KDML 105) experiment at a depth of 10-80 cm where soil texture and mineral composition are the most appropriate for agriculture. However, the location of the potential residual basalt, in addition to physical and chemical data, should also be considered together with the other contexts, such as the ease of accessibility of an area, consent, and cooperation from the landowner.

After an experiment of adding basaltic soil to the KDML 105 farm, the growth and yield, coupled with aromatic properties were slightly increased. Adding residual basalt into the original and local soil also shows the increasing number of leaves, height, sprouting, ears, seeds per ear, and total yield weight. However, the leaves' size, the stem's length, and the aromatic of rice are among those of significance. We suggest that mixing residual basalt at 25% in local soil provides the best growth for KDML 105. The yield of the experiment is equal to the average yield for planting with chemical or organic fertilizers, but water is saved by 42 days. With a total cultivation period of 126 days, rice production can reduce water use by 33.33%, and no need for any fertilizers. Our experiment shows that the flooding period of paddy rice fields is shortened, and this leads to reduced methane (CH_4) emission.

We recommend the re-soil technique by adding the residual basalt into local soil which improves the productivity and quality of jasmine rice significantly. Overall, the application of re-soil from this study not only has a positive effect on the growth of KDML 105 but also confirms the easy and environmental friendly ways for rice cultivation to reduce GHG emissions into the environment.

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AUTHORS CONTRIBUTION

WK – conceptualization, experiment design, writing draft manuscript; MC – writing, review and editing.

CONFLICT OF INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the effort reported in this paper.

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