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Original Paper

Influences of Major Nutrients in Surface Water, Soil and Growth Responses to Application of Supplemental Activated Biochar Pellet Fertilizers in Rice (*Oryza sativa* L.) Cultivation

SangBeom Lee[a], DoGyun Park[b], ChangYoon Jeong[c], JooHee Nam[d], MinJeong Kim[e], HongShik Nam[e], ChangKi Shim[f], SeungGil Hong[g], JoungDu Shin[h†]

벼 재배 시 활성 바이오차 팰렛 비료 시용에 따른 논 표면수와 토양의 주요 양분 함량 및 벼 생육에 미치는 영향

이상범[a], 박도균[b], 정창윤[c], 남주희[d], 김민정[e], 남홍식[e], 심창기[f], 홍승길[g], 신중두[h†]

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초 록: 본 실험은 벼 재배 기간 동안 활성바이오차팰렛 비료(ABPFs) 시용에 따른 벼 생육 반응, 논 표면수 및 토양의 화학적 특성 변화를 평가하였다. 시험구 처리는 대조구, 활성왕겨바이오차 팰렛 비료(ARHBP-40%), 활성 야자수 바이오차 팰렛 비료(APBP-40%)로 구성되어 있다. ARHBP-40% 처리구에서 논 표면수의 NH_4^+-N 및 PO_4^--P의 농도가 가장 낮게 관측되었으며, 대조구에서 토양 중의 $NH4^+$-N농도가 이양 후 30일 까지 급격하게 감소되었다. 또한, 바이오차 혼합처리구에서 NH_4^+-N 농도는 이양 후 1일에 9.18 mg L^{-1}로서 가장 낮았으며, 이양 후 56일에 ABPFs 처리구에서 NH_4^+-N 농도가 1 mg L^{-1} 이하로 관측되었다. 이앙 후 30일 까지 ARHBP-40% 처리구에서 PO_4^--P농도는 0.06 mg L^{-1}에서 0.08 mg L^{-1} 범주로 처리구 사이로 가장 낮았다. 대조구에 있어 논 토양 중의 NH_4^+-N 농도는 이양 후 14일에 177.7 mg kg^{-1} 에서 49.4 mg kg^{-1}로 급격히 감소한 반면, NO_3^--N 농도는 13.2 mg kg^{-1}로 가장 높았다. 토양 중의 P_2O_5 농도는 처리에 관계없이 이양 후부터 수확기 까지 증가하는 경향 이었다. APBP-40% 처리구에서 K_2O 농도는 이앙 후 84일에 252.8 mg kg^{-1}로 가장 높았다. 대조구에서 초장은 다른 처리구에 비해 높았으며, 수량은 대조구와 ARHBP-40% 처리구 사이에 차이가 인정되지 않았다. 따라서 농업 생태계에서 ARHBP-40% 처리를 함에 따라 질소와 인산 시용량을 줄일 수 있다.

주제어: 논물과 토양 질, 활성바이오차팰렛 비료, 벼 재배, 벼 생육 반응

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[a] 국립식량과학원 작물기초기반과 연구원(Researcher, Crop Foundation Research Division, National Institute of Crop Science)
[b] 국립농업과학원 기후변화평가과 연구원(Researcher, Dept. of Assessment of Climate Change, National Institute of Agricultural Sciences)
[c] 루이지애나주립대학 교수(Professor, Red River Research Station, Louisiana State University)
[d] 경기도농업기술원 친환경미생물연구소 연구원(Researcher, Eco-friendly Environment & Microorganism Research Institute, Gyenggi-Do Agricultural Research & Extension Services)
[e] 국립농업과학원 유기농업과 연구사(Researcher, Organic Agriculture Division, National Institute of Agricultural Science)
[f] 국립농업과학원 유기농업과 연구관(Senior Researcher, Organic Agriculture Division, National Institute of Agricultural Science)
[g] 농촌진흥청 국외농업기술과 연구사(Researcher, Division for KOPIA, Rural Development Administration)
[h] ㈜다학바이오텍 대표이사(CEO, Bio-technology of Multidisplinary Sciences, Co.)

† Corresponding author(e-mail: jdshin61@gmail.com)

ABSTRACT: The application of supplemental activated biochar pellet fertilizers (ABPFs) was evaluated by investigating key factors such as changes of surface paddy water and soil chemical properties and rice growth responses during the growing season. The treatments consisted of control, activated rice hull biochar pellet (ARHBP-40%), and activated palm biochar pellet (APBP-40%) applications. It was shown that the lowest NH_4^+-N and PO_4^--P concentrations were observed in surface paddy water to the ARHBP-40%, while the NH_4^+-N concentration in the control was abruptly decreased until 30 days after transplant in the soil. However, the lowest NH_4^+-N concentration in the blended biochar application was 9.18 mg L^{-1} at 1 day of transplant, but its ABPFs application was observed to be less than 1 mg L^{-1} at 56 days after transplant. The lowest PO_4^--P concentration in paddy water treated ARHBP-40% ranged from 0.06 mg L^{-1} to 0.08 mg L^{-1} until 30 days after transplant among the treatments. For the paddy soil, the NH_4^+-N concentration in the control was abruptly decreased from 177.7 mg kg^{-1} to 49.4 mg kg^{-1}, while NO_3^--N concentration was highest, 13.2 mg kg^{-1} in 14 days after transplant. The P_2O_5 concentrations in the soils increased from rice transplants until the harvesting period regardless of the treatments. The highest K_2O concentration was 252.8 mg kg^{-1} in the APBP-40% at 84 days after transplant. For the rice growth responses, plant height in the control was relatively high compared to others, but grain yield was not significantly different between the control and ARHBP-40%. The application of ARHBP-40% can minimize nitrogen and phosphorous application rates into the agro-ecosystem.

Keywords: Ppaddy water and soil qualities, Activated biochar pellet fertilizer (ABPF), Rice cultivation, Rice growth responses

1. Introduction

Biomass, which is normally used for biochar production, is rice husks, manure, wood remains, and crop residues. Biochar is a carbon product obtained when biomass is transformed to biochar via pyrolysis under high temperature (300~700℃) and limited oxygen content (preferably zero). Biochar has attracted attention in agro-environmental studies for its beneficial effects as a soil amendment[1] for enhancing soil quality[2], increasing crop yield[3], mitigating nitrous oxide emissions[4], and carbon sequestration capacity[2,5]. Specifically, rice husk biochar has potentially valuable for soil amendment because of its phosphorus, silicon, and potassium content[6]. However, biochar application may cause environmental issues with dust, and 25% of biochar is lost via scattering during application on fields[7].

Animal manure composts are recognized as valuable sources of major crop nutrients that reduce the application of chemical fertilizers[8]. However, environmental problems such as nutrient loss due to runoff may arise if excess manure is applied to the crop land in catchment areas. One of the critical issues plaguing animal manure compost application is the lack of an environmentally safe application method to croplands for mitigating non-point source pollution[9,10]. Most of the nutrient losses from croplands are caused by soil erosion or runoff and leaching after rainfall events[11]. Hence, the top priority was to develop methods that would minimize rapid nutrient loss from animal manure compost application. Major pathways of N losses are NH_4^+-N and NO_3^--N leaching, NH_3 volatilization, and runoff losses. New strategies such as biochar-manure pelletizing methods are available to minimize N loss from animal manure compost application. New approaches that would improve the efficiency of animal manure compost application are significant to agricultural production in Korea. Several scientists reported that the synergistic effects of biochar blended with inorganic fertilizer or biochar mixed with nutrient -rich compost were observed to improve crop production[12-14].

Pelletization can reduce the loss of biochar on fields[15]. Pelletized biochar combined with manure and fertilizer has been shown to function as a slow-release fertilizer in rice fields[5]. Information is only available on added-value biochar pellets with fertilizer for field applications. Nutrients in slow-release fertilizer are gradually discharged to the soil during the cropping season and then provide sufficient nutrients to crops by minimizing nutrient losses[16]. The application of biochar manure pellet fertilizer showed that NH_4^+-N use efficiency under biochar manure pellet fertilizer was significantly enhanced, compared with the control treatment in rice paddies[17]. Additionally, NH_4^+-N and PO_4^--P releasing accumulated amounts in the pig manure compost pellet while pelletilization decreased compared to the pig manure compost in nutrient leaching experiment[18]. Also, it was indicated that the accumulated amounts of water soluble NH_4^+-N and PO_4^--P were generally lower in the blended biochar pellet than the pig manure compost. The maximum capacities of absorption and removal rate for biochar blended with 10% pig manure compost were 2.94 mg g^{-1} and 92.2%, respectively. Nutrient use efficiency is an essential parameter to improve crop yields and reduce non-point source pollution in sustainable agriculture[19].

The production cost of biochar may be the critical factor to make biochar technologies viable avenues to reduce the amount of input biochar in the production of ABPFs and thus overall cost, it is necessary to enhance the NH_4^+-N adsorption capacity of biochar. Activated carbon is the most promising approach for the adsorption of organic compounds due to its high removal capacity[20]. Activated carbon materials utilizing renewable, low-cost agricultural by-products such as crop residues have the potential of playing in an important role in mitigating environmental pollution[21]. Several researchers have focused on activated carbon generated with biomass to reduce landfill leachate[22,23]. In another application, activated biochar can be applied in wastewater treatment (WWT) to eliminate organic micro-pollutants instead of using traditional fossil-based activated carbon, which releases significant amounts of GHGs(Greenhouse gases) during production[24]. The environmental benefits of new fertilizers based on activated biochar have also been evaluated[25].

Most biochar studies have reported on modification of biochar properties to improve the absorption capacity, or use activated biochar pellet fertilizers[26-29]. Wu *et al.*[30] reported a field experiment to determine the adsorption capacity of ammonium and nitrous oxide ions using biochar. However, few studies have been conducted on the agricultural effects of activated biochar pellet fertilizers, especially for surface paddy water quality in agricultural practices. *Da et al.*[31] reported that no significant impact on surface water N runoff potential in biochar study on rice growth and nitrogen retention, but biochar amendment significantly increased NO_3^--N content of rhizosphere soil at the tillering stage in the first year ($p < 0.05$).

Therefore, the objective of this experiment was to investigate the impact of activated biochar pellet fertilizers (ABPFs) application for rice cultivation, specifically by exploring the changes of chemical properties in surface paddy water and plant growth characteristics. It is hypothesized that the use of activated biochar instead of biochar for ABPFs can enhance NH_4^+-N adsorption capacity and control the nutrient release.

2. Materials and Methods

2.1. Processing activated biochar production

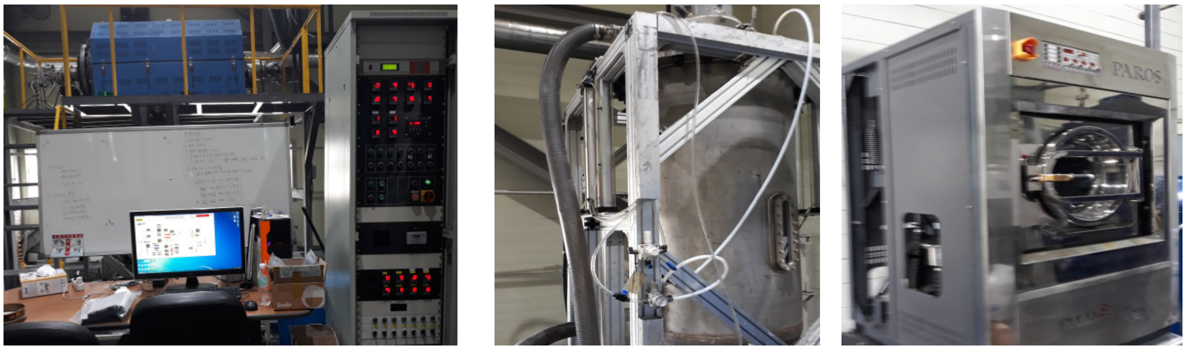
Rice hull biochars purchased from U-Gi industry Co. (Gochang, Jeonbuk, South Korea), and activated palm biochar was bought from Green Biochar Co. (Hwasung, Gyeonggi, South Korea). Then 6M KOH solution (1: 2 ratios, 6M KOH: biochar) based on the previous NH_4^+-N adsorption experimental results[32] was sprayed into rice hull biochar and left overnight to complete suction. The 30 kg of 6M KOH treated rice hull biochars were then placed in a reactor heated from room temperature to 850℃ at a rate of 10℃ min^{-1} under N_2 flow at a flow rate of 5ml min^{-1}. After pyrolysis, the activated rice hull biochar was removed from the reactor after cooling and then transferred to the washing system. These activated rice hull biochars were washed with deionized water three times to remove residual KOH.

Then the activated rice hull biochar was placed in the dryer to evaporate any remaining moisture. These processes were conducted via an automatic pyrolysis system (Fig. 1).

The chemical properties of ABPFs are shown in Table 1. The activated rice hull biochar was generally alkaline with pH 8.8 and low total nitrogen (TN) at 2.0 g kg^{-1}, while pH and TN in the activated palm biochar were slightly high at 9.1 and 0.6 g kg^{-1}, respectively. Furthermore, the TN contents in the pig manure compost were 14.6 times higher than that of activated rice hull biochar.

2.2. Supplemental activated biochar pellet fertilizers

Before pelletizing, the activated rice hull and palm biochars (4:6, activated biochar: pig manure compost) were separately mixed with pig manure compost using an agitator, while spraying nutrient solutions into the mixture. The mixtures are fed into a commercial pellet mill (7.5 KW, 10HP, KumKang Engineering Pellet Mill Co., Daegu, South Korea) for producing ABPFs. The primary nutrient contents of ABPFs are described in Table 2. The total nitrogen contents were 89.2 g kg^{-1} and 87.2 g kg^{-1} in the ARHBP and APBP, respectively.



Black carbonization system Washing system Dryer

Fig. 1. Automatic pyrolysis system to enhancing the porosity of biochar[33].

Table 1. Chemical Properties of Activated Biochars and Pig Manure Compost used[33]

Materials used	pH(1:10)	EC	TC	TOC	TIC	TN
		(dS m^{-1})		--------------(g kg^{-1}) --------------		
Activated rice hull biochar	8.79±0.06	7.25±1.63	327.1±2.39	294.7±0.45	33.0±0.21	2.0±0.04
Activated palm biochar	9.06±0.72	5.98±1.79	329.6± 9.23	310.2±13.81	19.4±0.32	0.6±0.01
Pig manure compost	8.77 (1:5 ratio)	3.4±0.05	289.0±0.42	259±0.31	30.2±0.12	29.1±0.31

EC; Electric conductivity, TC; total carbon, TOC; total organic carbon, TIC; total inorganic carbon, and TN; total nitrogen. The values were average of triplicate samples with standard deviation (p < 0.05).

Table 2. Major Nutrient Contents of ABPFs[33]

Input materials*	TC	TN	TP	TK
		-----------------------(g kg^{-1}) -----------------------		
ARHBP	325.0±0.23	89.21±0.13	10.8±0.02	293.6±0.51
APBP	376.0±0.14	87.15±0.42	11.6±0.04	270.4±0.32

TC; total carbon, TN; total nitrogen, TP; total phosphorus, and TK; total potassium. The values were average of triplicate samples with standard deviation (p < 0.05).

These nitrogen contents were 1.2-1.4% higher than the value of the added-value biochar pellet (BMP-NPK, Biochar manure practice with nitrogen, phosphorous and potassium)[25] because ABPFs were treated with 6M KOH through black carbonization. It was shown that the total potassium contents in the ABPFs were 4.7-5.1 times higher than that of BMP-NPK.

2.3. Field experiment

The experimental cultivation field has clay loam soil and is located at 35° 49.515′N of latitude and 127° 2.532′E of longitude in the National Institute of Agricultural Sciences (NAS), Rural Development Administration (RDA), Jeonju, Republic of Korea. The average precipitation and temperature were 4.3mm and 22.2℃, respectively, during the season of rice cultivation. Additionally, the average solar radiation quantity and duration of sunshine are measured at 16.6 MJ and 6.6 hours during the cultivation period, respectively. The rice variety used in this experiment was ‘Shindongjin’, and the planting distance was 30 cm × 60 cm, and one or two rice plants were planted at each point in the paddy. The experimental design was a block design with three replications. The treatments consisted of 1) control (90-45-57 kg ha^{-1}, N-P-K and 2,500 kg ha^{-1} of pig manure compost application), 2) activated rice hull biochar pellet (ARHBP-40%, 36 kg ha^{-1} based on TN), and 3) activated palm biochar pellet (APBP-40%, 36 kg ha^{-1} based on TN). The choice to use a 40% application rate of ABPFs is based on 30-35% of nitrogen (urea) use efficiency for rice[34] with a slow-release fertilizer. The application amount of pig manure compost in the control was 2,600 kg ha^{-1}, based on NAS recommended application rates for rice cultivation[35]. The water was irrigated by pumping from groundwater well in the paddy fields through rice cultivation periods. The physicochemical properties of the soil before the experiment are presented in Table 3.

2.4. Chemical analysis of surface paddy soil and water

Surface soil and water samples were collected every 20 days after transplant in the paddy throughout the cropping season. The collected water samples were filtered through Whatman #2. The surface paddy water was analyzed for PO_4^--P, K^+, and SiO_2 contents using a UV spectrophotometer (C-Mac, Daejeon, Korea). The wet soil samples were extracted using a 2M KCl solution (1:5, soil: extractant ratio). Those samples were analyzed directly with NH_4^+-N and NO_3^--N using the Bran-Lubbe Segmented Auto Analyzer (Seal Analytical Ltd., Wisconsin, USA). The concentrations of NH_4^+-N and NO_3^--N from wet soil extractions are compensated for their moisture content. The dried ABPFs and soil samples were milled with a grinder to pass through a 2 mm sieve before chemical analysis. The milled samples were extracted using the Mehlich III method[36], and the extracted liquid was stored in a refrigerator at 4℃ until analyzing PO_4^- and K^+ using a UV spectrophotometer (C-Mac, Dae-Jeon, Korea).

Total nitrogen (TN) and total carbon (TC) in biochar and soils were analyzed with total organic carbon (TOC) analyzer (Elementa Vario TOC cube, Hanau, Germany). The combustion temperature was 950℃ and tungsten trioxide (WO_3) was the catalyst. For 350mg of biochar and soil samples, total TN contents were determined by dry combustion with 250mg of L-Glutamic acid, standard compound, by using Vario Max CN (Elementar, Hanau,

Table 3. Physicochemical Properties of Paddy Soil before used[33]

Soil type	pH	EC	TN	P_2O_5	K_2O
	(1 : 5)	(μs cm^{-1})	(g kg^{-1})	(mg kg^{-1})	(g kg^{-1})
clay loam	5.1±0.05	58.0±0.40	7.6±0.02	58.8±0.12	10.6±0.04

TN; total nitrogen. The values were average of triplicate samples with standard deviation ($p < 0.05$).

Germany). Total P and K in ABPFs were analyzed using inductively-coupled plasma atomic emission spectrometry (ICP-AES, IntegraXL, GBC Ltd., Braeside, Australia) after digesting the samples with nitric and hydrochloric acids.

2.5. Statistical analysis

Statistical analysis was conducted using SAS version 9.2 Software (SAS, Inc., Cary, NC, USA), with a one-way ANOVA test for comparison among treatments with responses of growth characteristics during rice cultivation. Duncan multiple range tests were used to compare the rice yield components under the influence of different treatments. The standard deviation used for comparisons of chemical properties of paddy water properties at each sampling date among the treatments.

3. Results and Discussions

3.1. Effects of major nutrients in the paddy water

The study shows that the application of biochar pellet blended with pig compost decreased NH_4^+-N and NO_3^--N concentrations in the paddy water compared to the control until 7 days after transplant[5)]. NH_4^+-N concentration in the ARHBP-40% treatment was significantly lower than those of the other treatments at 30 days after transplant. In comparison, the NO_3^--N concentration of paddy water in the APBP-40% was lower than those of the other treatments at seven days after transplant (Fig. 2). The NH_4^+-N and NO_3^--N concentrations were not significantly different ($p > 0.05$) among treatments in 56 days and 20 days after transplant, respectively. However, the lowest NH4$^+$-N concentration in the blended biochar application was 9.18 mg L^{-1} at 1 day of transplant[5)], but its ABPFs application was observed to be less than 1 mg L^{-1} at 56 days after transplant because of the influence of activated rice hull biochar. An assessment of the environmental benefit of new fertilizer revealed that the reduction of nitrogen losses achieved was 63% for applying activated biochar-based fertilizer[25)]. This effect may be due to the NH_4^+-N adsorption capacity of biochar[15)]. The NO_3^--N concentrations were very low in paddy water until 30 days after transplant regardless of the treatments.

Changes of PO_4^--P, K^+, and SiO_2 concentrations in the paddy water applied with ABPFs are described in Fig. 3. The lowest PO_4^--P concentration in paddy water of ARHBP-40% ranged from 0.06 mg L^{-1} to 0.08 mg

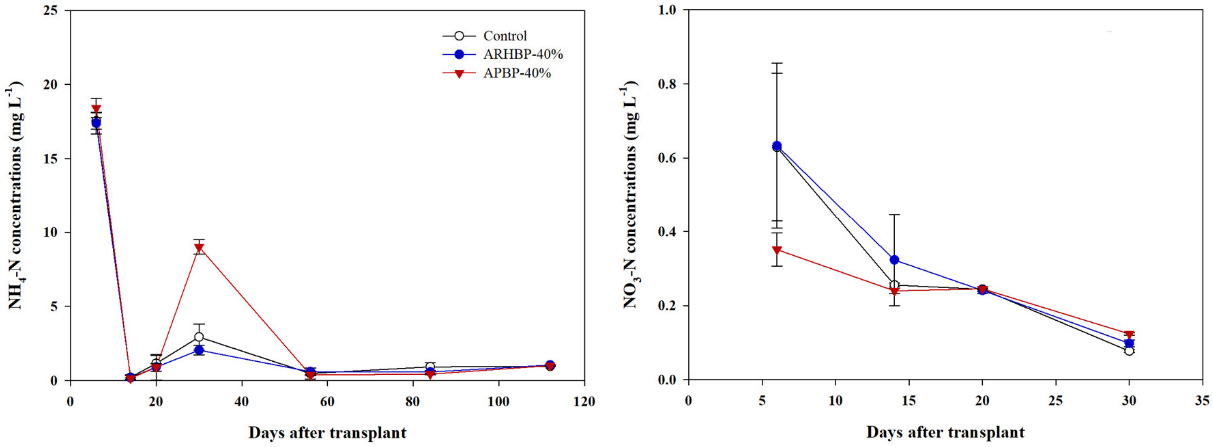


Fig. 2. Effects of NH_4^+-N and NO_3^--N concentrations on the application of ABPFs in paddy water during rice cultivation. The values were average of three replications, and error bars display standard deviation ($p < 0.05$). ARHBP; activated rice hull biochar pellets, and APBP; activated palm biochar pellets

L^{-1} until 30 days after transplant among the treatments. The PO_4^--P concentrations were not significantly ($p > 0.05$) different among the treatments from 56 days after transplant until the harvesting period. PO_4^--P can be an essential nutrient for plant growth and another microorganism despite its potential to be an environmental pollutant[37,38]. It considered to be a potential risk to the proliferation of algal growth in concentrations over 0.02 mg L^{-1} of dissolved PO_4^--P in water bodies[39]. Therefore, run-off from surface water from paddies with intensive rainfall should be controlled. The K$^+$ level in the control was higher than those in the ARHBP-40% and APBP-40% treated paddy water until 56 days after transplant. The K$^+$ concentrations in paddy water of APBP-40% ranged from 19.0 mg L^{-1} to 116.4 mg L^{-1} until 56 days after transplant. Si is necessary to strengthen the cell walls and to protect against disease as well as enhancing the uptake of other nutrients[40,41]. It was shown that the lowest SiO_2 concentration was 6.3 mg L^{-1} in paddy water of ARHBP-40%, while the highest was 14.2 mg L^{-1} in the control at 56 days after transplant. The SiO_2 concentration in the control was 2 times more than the value in paddy water of ARHBP-40% at 56 days after a rice transplant. The pig manure contained residual grain mixed with sawdust for enhancing its degradation rate during composting. Silicon (Si) in the crop residues is an available form as H_4SiO_4 relative to Si fertilizer for crop uptake[42].

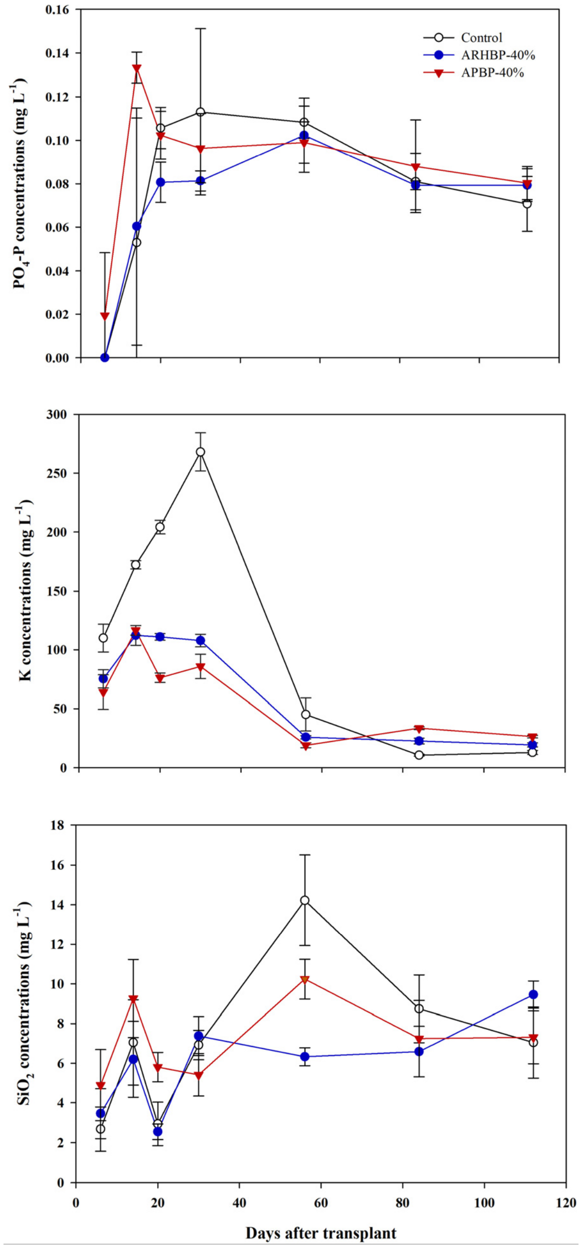


Fig. 3. Effects of PO_4^--P, K$^+$, and SiO_2 concentrations on the application of ABPFs in paddy water during rice cultivation. The values were average of three replications, and error bars display standard deviation ($p < 0.05$).

3.2. Effects of major nutrients in the paddy soil

Nitrogen in the soil can be generally converted into NH_4^+-N via the mineralization process, which is subsequently nitrified to NO_3^--N. Once urea is applied in paddy soil, it is hydrolyzed to NH_4^+ and OH^- via mineralization reaction within 20 days after application in paddy soil[43]. Effects of NH_4^+-N and NO_3^--N concentrations on the application of ABPFs in paddy soil during rice cultivation are described in Fig. 4. The NH_4^+-N concentration in the control was abruptly decreased from 177.7 mg kg-1 to 49.4 mg kg^{-1}, while NO_3^--N concentration was highest, 13.2 mg kg^{-1} in 14 days after transplant. The NH_4^+-N concentration in the control was abruptly decreased and lowest in 14 days after transplant compared to the ABPFs. It appeared that the mineralization and nitrification processes in the paddy soil were almost completed within 20 days after transplant, regardless of treatments.

The effects of P_2O_5 and K_2O concentrations on the application of ABPFs in paddy soil during rice cultivation are presented in Fig. 5. The P_2O_5 concentrations in the soils increased from rice transplants until the harvesting period regardless of the treatments. The order of P_2O_5 concentrations in the soils measured in 84 days after transplant was control >ARHBP-40%>APBP-40%, which is reasonable since the amount of phosphorous in the ABPFs was lower than that of the control. This result is in agreement with another study where P and K contents in the lignite fly ash + biochar application were increased at 110% and 64% in the corn cultivation soil, respectively[44]. Biochar incorporated soil can simultaneously increase the P and Fe concentrations, which affect P availability and retention [45]. The K_2O concentrations were abruptly increased and ranged from 146.6 mg kg^{-1} to 252.8 mg kg^{-1} from 84 days after rice transplants through the harvesting period. The highest K_2O concentration was 252.8 mg kg^{-1} in the APBP-40% at 84 days after transplant. However, P_2O_5 concentrations increased until harvest, but K_2O concentrations were remained constant

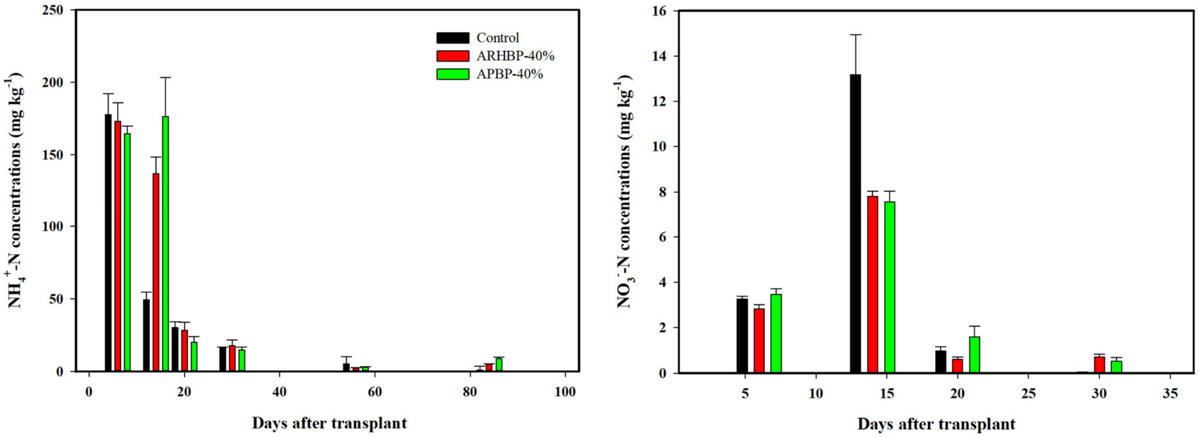


Fig. 4. Effects of NH_4^+-N and NO_3^--N concentrations on the application of ABPFs in paddy soil during rice cultivation. The values were average of three replications, and error bars display standard deviation ($p < 0.05$).

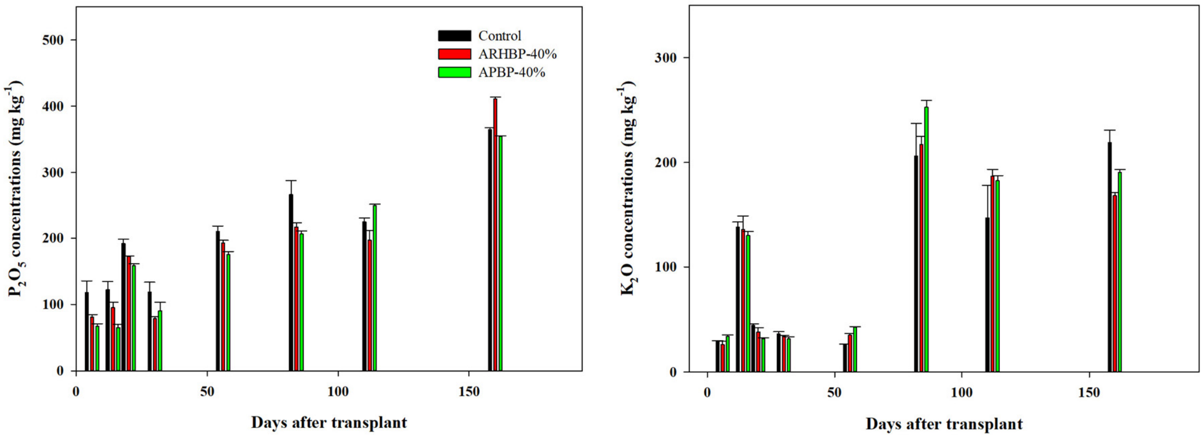


Fig. 5. Effects of P_2O_5 and K_2O concentrations on the application of ABPFs in paddy soil during rice cultivation. The values were average of three replications, and error bars display standard deviation ($p < 0.05$).

Table 4. Rice Growth Responses on the Application of ABPFs during Rice Cultivation24)

Treatments*	Plant height	Number of tillers(ea)	Grain yields	Straw yields	Harvest index
	(cm)		------(kg 10a^{-1})-----		(kg kg^{-1})
Control	84.5±3.3 ns	19.3±2.3 ns	534.8±4.2 ns	819.5± 88.1 a	0.65
ARHBP-40%	80.7±0.7 ns	19.6±1.9 ns	513.3±48.0 ns	776.0±149.1 ab	0.66
APBP-40%	80.7±2.0 ns	16.2±1.0 ns	450.9±53.4 ns	589.0± 76.8 b	0.77
F-value	2.85	3.19	3.29	3.76	-
Pr > F	0.1350	0.1141	0.1084	0.0873	-

Mean values followed by different letters, which indicate significant differences ($p < 0.05$) among treatments with a one-way ANOVA by the mean comparison for all pairs using Duncan's multiple range test for plant growth characteristics.

from the booting stage to harvest periods. This reason might be the binding abilities of activated biochars with the PO_4^--P and K^+ in paddy soil. It reported that P_2O_5 and K_2O concentrations generally decreased with increasing cultivation time43).

3.3. Rice growth responses

Responses of rice growth characteristics on the application of ABPFs are shown in Table 4. The plant height, tiller number, and grain yields were not significantly different ($p > 0.05$) among the treatments even when the application amounts of total nitrogen and pig manure compost were reduced by 60% and 2,000 kg ha^{-1} based on NAS recommended application rates, respectively, in the paddy. Although the highest harvest index was 0.77 in the APBP-40%, there was not significantly different ($p > 0.05$) between the control and the ARHBP-40%, which implies that the rice in the ARHBP-40% had higher nitrogen use efficiency than the control because nitrogen application is associated with the growth of biomass. Therefore, the reduction rate of nitrogen was by 60% in the ARHBP-40% relative to the control. This result lines up with previous studies5).

4. Conclusions

This study indicates that the application of ABPFs during rice cultivation reduced non-point pollution in the agro-ecosystem. For paddy water, the NH_4^+-N concentration in ARHBP-40% was lower than the control. The other major nutrients in paddy water of ARHBP-40% were generally lower than the control. Non-point pollutants in the rice paddy to small streams can be reduced with the application of ARHBP-40%. For paddy soil, the mineralization and nitrification in all treatments abruptly decreased 14 days after transplant. The highest K_2O contents in the treatments were maintained at high levels from 84 days after transplant until the harvest period. Grain yields were not significantly different ($p > 0.05$) among the treatments. The application of ABPFs in rice paddy allows for the reduction of nitrogen input by 60% without decreasing rice yield. Therefore, ARHBP-40% could be useful for reducing surface paddy water contamination as well as input of fertilizer. Further research is needed to investigate the binding material for enhancing nitrogen content.

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Conflicts of Interest

The author declares no conflict of interest.

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