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Improving Soil Properties and Rice Yield on Saline-affected Acid Sulfate Soil by Controlled-release Fertilizer

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ABSTRACT

Background: To determine the effectiveness of controlled slow-dissolving NPK fertilizers with NPK 19-16-18 to improve soil nutrients on rice (*Oryza sativa L.*).

Methods: The field experiment was on saline-affected acid sulfate soil in Hau Giang province, Viet Nam, in the Winter-Spring rice crop 2018-2019. The experiment consisted of 2 treatments, corresponding to 2 formulas and 2 types of fertilizers, including new generation fertilizer application with the formula 50N-40P_20_5 -30K_20 kg/ha; and conventional fertilizers of 126N-88 P_20_5-23K_20. Each formula with 3 replications and each repetition is 1,000 m^2.

Result: The NPK-CFR fertilizers and urea humate help improve proper soil nutrients and total micro-organisms. In which; (i) when compared to the farmer's control field, the rice growth and yield were comparable and did not differ significantly (5.68 tons/ha in the farmer's control field and 5.85 tons/ha in the experimental field). (ii) However, when compared to the farmer's field, the amount of fertilizer in the experimental field is reduced by more than 50%. Besides, the economic efficiency of NPK-CFR and Urea humate is higher than in farmers' fields, from 1 to 8.6%. The total profit is higher than farmers' fields. The NPK-CFR fertilizers and urea humate can be used to replace traditional fertilizers.

Key words: Acid soil, New fertilizer, Rice, Saline.

INTRODUCTION

Fertilizers play an essential role in increasing rice production. It is estimated that 55% of food production is due to the effect of fertilizers, which means that yields always rise with increasing amounts of N, P and K chemical fertilizers (Abdelhafez *et al*., 2012, Bagayoko, 2012). Nutrient use efficiency (NUE) of rice is very low for nitrogen (N) and ranges from 30-50%, 15-20% of phosphorus (P) and 60-70% of potassium (K) (Sarkar *et al.,* 2021).

Research by Selladurai and Purakayastha (2016) and T Karthik *et. al.* (2021) recommended that using slow or controlled fertilizer is a solution to increase nutrient use efficiency, minimize the risks like leaf burning, water contamination and eutrophication use for plants. It helps plants to achieve higher agronomic efficiency than using fertilizers common, helps reducing adverse effects of fertilizers on soil fertility and the environment (Naznin *et al.,* 2014). The recommended reduction of fertilizer is from 20% to 30% (Trenkel, 2010).

Accorrding to Karthik, and Maheswari, (2021), when applied to a field, humic acid is transformed into easily available humic compounds that have direct or indirect effects on plant growth. The results of Bulgari *et al.* (2015) and (Retno *et al.,* 2015) show that the application of humic can reduce N, P and K fertilizers, increase the use fertilizer efficiency of plant and help to increase the plant's tolerance to adverse environmental conditions (Yakhin *et al.,* 2017). Especially It can be used in areas with a high risk of beneficial nutrients (N, P, K), lack of irrigation water, human resources, or little environmental pollution conditions. Therefore, the potential for using fertilizers produced by new technologies will be great However, farmers have not widely applied the use of new generation fertilizers. The demonstration is needed to evaluate the feasibility of using the controlled and slow release to improve soil fertility and rice yield compared with conventional fertilizers. It serves as a basis for recommending new generation fertilizers.

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MATERIALS AND METHODS

Materials

Rice variety

The rice variety used in the study is OM5451 (confirmed variety), has a short growing time (90-95 days).

Fertilizers

The experiment used two types of fertilizers: (1) Traditional fertilizers (common fertilizers) such as NPK (20-20-15), DAP

(18-46-0), Urea (46% N) and KCl (60% K_2O) are fertilizers commonly used by farmers (2) and fertilizers produced by new technology such as controlled-release slow -release compound NPK 18-14-18 (NPK-CRF), Urea-Humate (containing 46%N, 200ppm MgO, 250ppm CaO, 3,000ppm SiO_2 and 1.2% humic acid, pH 7- 9).

Study location

The experiments was carried out on the farmers fields during the Winter-Spring rice crop 2018-2019 in Xa Phien village, Long My district, Hau Giang province. The experimental field has coordinates 9°5981443; 105°5163207.

The experiment was carried out on saline soils with two rice crops per year (Minh *et al*., 2022).

Table 1 provides information on the soil's physical and chemical characteristics prior to the experiment.

Research methods

Experimental design

The experiment was arranged directly in farmers' fields, in a completely randomized block, with 3 replicates, each with an area of 1,000 m^2. The experiment consisted of two fertilizer formulas as follows:

Formula 1 (Farmer field/control field): Use conventional fertilizers. The sowing density is about 100 kg/ha, row seeding. The fertilizer formula is 126N-88P_20_5- 23K_20.

Formula 2 (Experimental field): Using a new generation fertilizer, sowing density 100kg/ha, row seeding. The fertilizer formula is 50N-40P_2O_5-30K_2O.

Fertilizers use

The amount of fertilizer and the time of fertilizing farmers' fields

Fertilizers were applied four times. 1st time: 1/5 amount of urea at 7 days after sowing (DAS); 2nd time: 1/3 of urea +1/3 of DAP on 18 DAS; 3rd time: 1/3 Urea+1/3 DAP+1/2 NPK to 35 DAS; 4th time: 1/3 Urea+1/3 DAP+1/2 NPK+ 100% KCl in 45 DAS. The total fertilizer used for 1 hectare was 190 kg Urea, 174 kg DAP, 50 kg NPK (16-16-8) and 32 kg KCl.

Fertilizer amount and time of fertilizing experimental fields

Fertilizers were applied 3 times. The entire NPK-CRF slow-release fertilizer before final tillage, then plow and bury the manure in the soil; 1st application: 1/2 Urea-Humate+ 1/2 DAP+2/3 KCl on 18 DAS; 2nd application: 1/2 Urea Humate+1/2 DAP+1/3 KCl on 45 DAS. The total amount of fertilizer used for 01 ha is 150kg of controlled-release NPK 19-16-18, Urea humate (33 kg), 35 kg/ha DAP and 5 kg KCl.

Water management and care of experimental fields are carried out in the same way as farmers' fields.

Experimental data collection

Monitoring and evaluating the indicators related to the change of some chemical and biological properties of the soil:

Soil samples were collected two times: (1) Before conducting field experiments, representative soil samples for the study point, which were taken by hand drill at a depth of 0-20 cm with 05 different positions, then mixed well and then averaged samples according to the principle of division by 4, taking a representative sample of the experimental point; (2) At the end of the experimental season at the rice harvest, soil samples for analysis of soil chemical and biological parameters were collected individually for each treatment and replicate.

After collection, soil samples were dried in natural conditions, then finely ground through 2 mm and 0.5 mm sieves. These soil samples were analyzed for pH, EC, Organic matter (OM), available N, available P, Al^{3+}, H^+, soil density, soil porosity, soil texture (for early crop samples only) and total microorganisms (for total bacteria, total fungi and total actinomycetes only).

Monitor and evaluate the indicators related to yield

(1) Indicators related to yield components such as number of panicles/m^2, number of seeds/cotton, percentage of filled grain and 1000 seeds weight will be randomly collected in a frame of 0.25 m^2 on each rice field. Four frames will be placed (1 field 4 frames × 3 repetitions= 12 frames); (2) Yield (ton/ha) was collected in a frame with an area of 5 m^2 (2 m × 2.5 m frame), 3 frames were placed in each rice field. After harvest, actual rice yield (ton/ha) was recorded by converting to 14% grain moisture.

Financial efficiency

Profit (vnd/ha) =

Total revenue (vnd/ha) - Total expenditure (vnd/ha).

The following indicators are calculated according to the respective formula to measure the financial performance of each production crop.

Profit (vnd/ha) =

Total revenue (vnd/ha) - Total expenditure (vnd/ha)

It is the remainder of the total product value minus the total cost. In which,

Total revenue=

Total output × Selling price of products by the time of harvest (as of 2019). The entire amount has been obtained from the consumption of the product.

Total cost (vnd/ha) =

Inputs (seeds+fertilizers) that farmers spend in the production process. They should be ignored because labor and pesticides are the same in experimental and farmer fields.

The efficiency of capital (B/C)=

Profit/total cost -Soil sample and analysis

Soil sample analysis parameters: Soil pH and soil EC (mS/cm) were extracted with water according to the soil: water ratio of 1:2.5, then measured by pH meter and EC meter. Soil organic matter (%C) was determined by Walkley and Black (1934).

Total nitrogen in the soil was unorganized with a mixture of K_2SO_4:$CuSO_4$:Se in the ratio (100:10:1) and determined by the Kjeldahl distillation control method.

Total phosphorus was digested with concentrated H_2SO_4 and $HClO_4$ (5:1). It formed a phosphomolybdate-colored complex and measured the sample on a spectrophotometer.

Available phosphorus (according to Bray II method), soil extraction with 0.1N HCl + 0.03 NH_4F, water ratio 1:7, then measured on a spectrophotometer at 880 nm.

The available nitrogen in the soil was extracted with KCl 2M at a ratio of 1:10. The concentration of N-NO_3^- was determined by a spectrophotometer at 650nm. A spectrophotometer determined the concentration of N-NH_4^+ at 540 nm.

The soil texture was estimated by the Robinson pipet method.

The total population of bacteria, fungi and actinomycetes in the soil was determined by the dilution method and counted the number of colonies grown on TSA, PDA and Gause 1 medium (in order).

Data analysis

The collected were analyzed and calculated by Microsoft Excel 2013 program. The Minitab 16.0 software was used to test for the T-Test to compare the difference in some soil properties and grain yield between the two experiments in the study.

RESULTS AND DISCUSSION

The efficiency of NPK-CRF and urea-humate fertilizers on the change of soil properties

Soil physicochemical properties

The T-test results showed that (Table 2) there was no statistical difference in density, porosity, pH_{H2O}, EC, organic matter, Al^{3+} and H^+ between the experimental and farmer fields. However, there was a difference in the soil's available N and P content at the 5% significance level.

The experimental fields had higher available nutrients (N and P) than the farmers' fields. However, the total amount of fertilizer used was lower than in the farmer's field, about 50%. It shows that using fertilizers produced by new technology helps to reduce fertilizer loss and helps nutrients last longer than conventional fertilizers. In addition, the humic component in urea humate fertilizer, containing high carbon content, can act as a direct energy source for microorganisms. Which is stimulating the activity of microorganisms to grow, leading to increase mineralization provides available nutrients to the soil. According to Retno *et al*. (2015), urea-humate not only helps to improve the content of available soil nutrients such as N, P, K, Ca, Fe, Zn and Mn but also increases the plant nutrient uptake. Otherwise, Selladurai and Purakayastha (2016) found that applying urea humate can help limit N loss.

Soil biological properties

The breakdown of organic matter and the mineralization of N, P and S are two soil biochemical processes that are influenced by soil microbes (Thiele-Bruhn *et al*., 2012). Fig 1 shows that the density of total fungi, bacteria and actinomycetes in the soil in the experimental field is significantly different from that in the farmer's field through the T-test. It has been demonstrated that using urea humate has impacted the soil microbial community. The humic component in urea humate contains nutrients C, H, O, N and S that are essential in increasing soil microbial density (Nardi *et al.,* 2021).

Table 1: Chemical composition of the experimental soil samples.

pH_{H20} (1:2,5)	$EC_{(1:2,5)}$ mS/cm	avaiN (mgN/kg)	$avaiP_{Bray2}$ (mgP_2O_5/kg)	Al^{3+} (meq/100 g)	Total acid (meqH^+/100 g)	O.M (%)	Clay (%)	Silt (%)	Sand (%)
4.98	0.96	26.7	38.3	2.18	5.04	4.76	51.5	46.3	2.20

Table 2: Differences in soil physicochemical properties in Xa Phien commune, Long My district, Hau Giang province at the end of rice cultivation (Winter-spring 2018-2019).

Soil properties	Unit	Experiment[(a)]	Farmer's field	T value
pH_{H20} (1:2.5)		5.54±0.04	5.47±0.08	2.96 ns
EC	mS/cm	0.73±0.15	0.94±0.02	-4.27 ns
Organic matter	% OM	5.41±0.09	4.88±0.03	3.43 ns
Total acid	meqH^+ /100 g	2.67±0.06	3.07±0.06	-3.10 ns
Al^{3+} exchange	meq/100 g	1.08±0.08	1.15±0.03	-3.14 ns
6Avai N	mg/kg	7.80±0.17	6.19±0.14	8.40*
Avai P_{Bray2}	mgP_2O_5/kg	39.3±0.20	35.1±0.71	5.71*
Bulk Density	g/cm^3	1.00±0.08	1.01±0.04	-1.01ns
Porosity	%	40.8±1.63	41.9±1.71	-0.12ns

Note: (ns) is not significantly different; a statistically significant difference at 5% (*); ± represents the variation from the mean.

[(a)] Experimental field: sparse sowing, combined with NPK-CRF and urea-humate fertilizers. Farmer's field: sowing sparsely, fertilizing normally.

Efficiency of NPK-CRF and urea-humate fertilizers on rice yield and yield components

Rice yield components

Table 3 shows that the number of panicles/m^2, the weight of 1,000 grains and the biomass of straw were not statistically different between the experimental and the farmer's fields. However, there was a statistically significant difference in the percentage of firm seeds. The experimental field had a higher rate of firm seeds at 94% than the farmer's field (85%). It proved that using a new generation of fertilizer not only helped to reduce the number of chemical fertilizers but also helped the plants to absorb more nutrients than conventional fertilizers, helping rice plants' remarkable growth and development. Al-Uthery and Al-Shami (2019) concluded that when applying new technology, fertilizer increased the plant utilization efficiency to 86% (N), 178% (P) and 120% (K), as compared to conventional fertilizers.

Rice yield

Fig 2 shows the yields of the experimental field (use urea humate, controlled slow-release NPK, sowing 100 kg/ha seeds) and the farmer field (use conventional fertilizers and 100 kg/ha seeds) did not show a statistically significant difference. The yield of experimental rice was 5.85 tons/ha and farmers' fields were 5.68 tons/ha. However, the experimental fields used N and P fertilizers more than 50% lower than farmers' fields. The reason is that the new generation of fertilizers releases nutrients slowly, limiting the loss of fertilizers through many ways such as spillage, direct migration, evaporation and precipitation, leading to reduced fertilizer loss. Besides, the humic compound that coats the outside of the urea tablet is high in cation exchange capacity. Therefore, it could control the release of nutrients to plants, stimulated root growth, helped plants absorb nutrients better and improved nutrients in the soil.

The economic efficiency

The aim of the producer is to obtain high economic efficiency per unit area in a unit of time. However, additional capital investment may be possible. The two experimental fields' profit margin analysis showed that the price of urea humate and controlled NPK fertilizers was much higher than that of conventional Urea and NPK fertilizers (Table 4). However, the total amount of fertilizer used for the whole crop is lower, leading to a lower investment cost of fertilizer than in farmers' fields, 1,210,000 vnd /ha/crop. As a result, the experimental field earned a higher profit than the farmer's field of

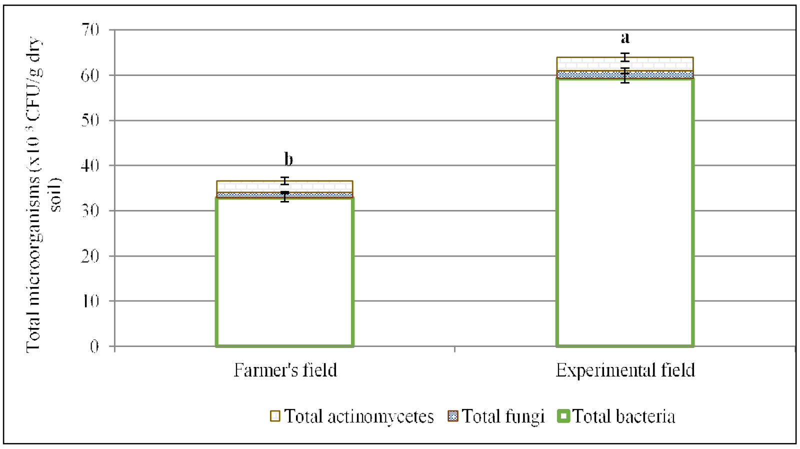

Fig 1: Change of total microbial density in saline acid sulfate soil in two rice fields in winter-spring crop 2018-2019.

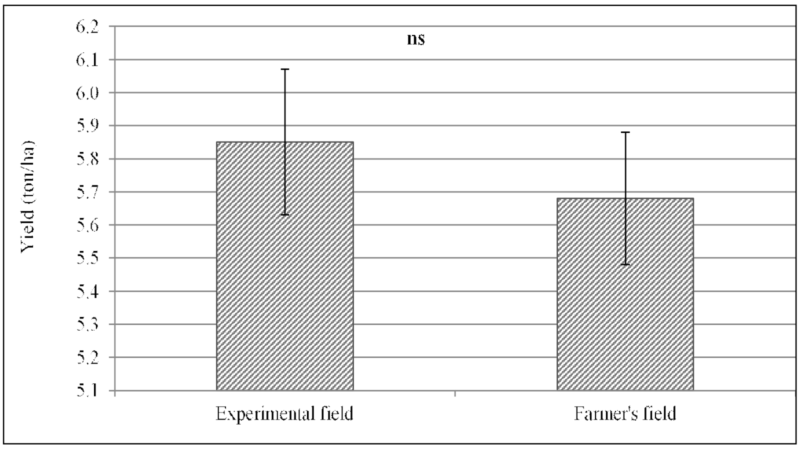

Fig 2: The yield of cultivated rice in winter-spring crop 2018-2019 in experimental and farmer fields.

Table 3: Composition of rice yield between experimental and farmers' fields in winter-spring rice crop 2018 - 2019. The experiment was carried out at Xa Phien commune, long my district, Hau Giang province.

Stt	Evaluation criteria	Experimental field[a] $50N-40P_20_5-30K_20$	Farmer's field $126N-88P_20_5-23K_20$	T value
First	Panicle number/m^2	379±13.5	414±33.0	-2.77 ns
2	% of filled grain	93.9±0.23	85.0±0.51	5,10*
3	1,000 seeds weight	27.4±0.29	26.8±0.26	3.15ns
4	Straw biomass	5.79±0.02	5.66±0.03	0.73ns

Note: (ns) is not significantly different; A statistically significant difference at 5% (*); ± represents the variation from the mean.
[a] Experimental field: sparse sowing, combined with NPK-CRF and urea-humate fertilizers. Farmer's fields: sowing sparsely, fertilizing usually.

Table 4: Comparison of financial efficiency between rice farming using fertilizers produced according to new technologies and traditional fertilizers in the winter-spring rice crop 2018-2019. (Unit: vnd/ha/crop)

No	Comparative criteria	Experimental Field-EF (vnd)	Farmer's Field=EF (vnd)	Deviant EF/FF
I	Total expenditure/ha (vnd)	6,170,000	7,380,000	- 1,210,000
I.1	Rice seeds*	1,800,000 (100 kg ×18,000 vnd)	1,800,000 (100 kg × 18,000 vnd)	0
I.2	Fertilizer	4,370,000	5,580,000	-1,210,000
	- Urea*/urea	495,000 (33 kg × 15,000 vnd)	1,900,000 (190 kg × 10,000 vnd)	-1,405,000
	- DAP	525,000 (35 kg × 15,000 vnd)	2,610,000 (174 kg × 15,000 vnd)	-2,085,000
	- KCl	50,000 (5 kg × 10,000 vnd)	320,000 (32 kg × 10,000 vnd)	-270,000
	- NPK*/ NPK	3,300,000 (150 kg × 22,000 vnd)	750,000 (50 kg × 15,000 vnd)	+2,550,000
II	Total revenue /ha	33,930,000 vnd	32,944,000	+986,000
II.1	Yield (kg/ha)	5,850	5,680	
II.2	Selling price (vnd/kg)	5,800	5,800	
III	Profit/ha (= II-I)	27,760,000vnd (108.6%)	25,564,000d vnd (100%)	+2,196,000 (+ 8.6%)
	Efficiency of capital (=III/I)	4.5	3.5	+1.0

Note: Urea* represents 46N urea humate; NPK* represents controlled release NPK 19-16-8, normal NPK (16-16-8) and standard Urea 46N.

2,196,000 vnd/ha/crop. Thus, the controlled use of urea humate and NPK fertilizers helped farmers save significantly on fertilizer compared to rice cultivation using conventional fertilizers. Experimental results have shown enormous potential for using fertilizers produced by new technology.

CONCLUSION

The application of urea humate, controlled slow-release NPK, combined with the addition of balanced conventional fertilizers, helped increase the valuable nutrient content and total density of soil microorganisms. As a result, rice yields were equivalent to farmer rice cultivation fields (using conventional fertilizers). However, the reduction of the amount of fertilizer in the experimental field was lower than 50% compared to the farmer's field. The use of urea humate controlled slow-release NPK combined with the addition of a balanced conventional fertilizer resulted in a total profit of 8.7% higher than using conventional fertilizers.

Conflict of interest: None.

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