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Potassium Nutrition in Rice (*Oryza sativa* L.) for Higher Yield with Lower Sodium Uptake under Saline Conditions of Central Vietnam

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ABSTRACT

Background: Potassium (K) is an essential macronutrient, improves rice yield and contributes to salt stress tolerance. This study determined the best potassium (K) application level on yield formation and the saline resistance capability of rice under salinity field conditions of central Vietnam.

Methods: Experiments were comprised of five K fertilizer application rates (0, 25, 50, 75 and 100 kg K_2O/ha) and two rice varieties, *viz,* OM8104 and MNR3 for two growing seasons of 2021 and 2022. All treatments were arranged in a split-plot design with 3 replicates in Duy Vinh commune, Duy Xuyen district, Quang Nam province.

Result: Potassium application affected the number of panicles per unit area, filled grain per panicle and actual grain yield of both rice varieties in both seasons under saline condition. Application of 50 kg K_2O/ha reduced the soil salinity over the monitoring periods compared to the other K rates. EC values of soil were significantly higher during the hot season than the wet season showing high temperature effects. Application of 50 kg K_2O/ha also accumulated maximum dry matter at different crop stages and produced the highest rice yield with 7.57 and 5.25 tons/ha for OM8104 and 7.35 and 5.18 tons/ha for MNR3 in both wet and hot seasons respectively. The harvest index could not affect significantly by K application irrespective of seasons and varieties. These increases in actual grain yields using 50 kg K_2O/ha were attributed to increased filled grains per panicle, accumulation of high K^+ content and K^+/Na^+ ratios in rice varieties in both seasons under saline field condition.

Key words: K^+/Na^+ ratio, rice, saline soil, salt tolerance, yield.

INTRODUCTION

Soil salinity is one of the major challenges of agriculture worldwide affecting 11% of the total arable land. Around 30% of total irrigated lands are salt-affected which may further increase to 50% by 2050 posing an alarming threat to sustainable agriculture and food security (Jiang *et al.*, 2019). The possible reasons for increasing salinity include increasing usage of saline irrigation water, rise in sea level and global warming potential (Shahid *et al.*, 2018). Under saline conditions, plants are subjected to an accumulation of high Na^+ and Cl^- causing ionic toxicity which results in nutritional imbalance (Hauser and Horie, 2010).

Both ion toxicity and nutritional imbalance are associated with reduced K^+/Na^+ ratio and disturbed ionic homeostasis which inhibits the growth of rice plants by reducing leaf growth and dry matter accumulation (Singh *et al.,* 2016).

Under salt stress, excessive accumulation and high concentrations of Na^+, Cl- become toxic and retard the absorption of other essential plant nutrients including K^+. Potassium (K^+) is the most versatile nutrient in plants involved in numerous physiological and biochemical mechanisms including N metabolism, sugar transport, water utilization, stress resistance and osmotic adjustment. The ability of various plant tissues to retain K^+ under stress conditions has been recognized as a novel and essential mechanism of salinity stress tolerance in plants (Shabala *et al.,* 2016; Wu *et al*., 2018). While K^+ limitation in rice decreases net photosynthetic rate and stomatal conductance damaging PS-II reactions (Pamuta *et al*., 2020). Nonetheless, sodium-potassium ratio determines their synergistic or antagonistic response. The increase in yield with K fertilization was associated with panicle number per unit area, grain number per panicle and rice grain yield in the upland rice system (Zhang *et al.,* 2021). Thus, K application can efficiently raise output and agricultural productivity (Jiang *et al*., 2019). Rice production in many areas of Vietnam has been seriously affected by salinity deteriorating soil and crop quality (Department of Agriculture and Rural Development, 2022). Several studies reported on the improvement of yield and salt tolerance of

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rice under field salinity conditions through the application of nitrogenous, phosphatic, zinc and copper-based fertilizers. But rare few studies evaluate the effects of potassium fertilizers on rice in saline soils and likely studies on rice production in central Vietnam under salinity conditions are limited (Trinh Thi Sen *et al*., 2015).

This study aimed to evaluate the ECe dynamics in saline soil, K^+/Na^+ ratio, yield formation and harvest index for the application of potassium fertilizer in rice under saline conditions of central Vietnam.

MATERIALS AND METHODS

The experiment was conducted at a farmer field in Duy Vinh commune (15°50′52″N and 108°20′15″E), Duy Xuyen district, Quang Nam province, Central Vietnam for two seasons. The chemical properties of soil are presented in Table 1. The weather of Quang Nam is of tropical monsoon with annual rainfall of about 2000 - 2200 mm and monthly temperature that varies between 19°C and 39°C during the year, with a distinct hot season from April to September and wet season from October to March. The typical soils of the experimental area are classified as saline. Two rice cultivars *viz,* OM 8104 and MNR 3 widely grown in Quang Nam province were used for the experiment. Rice seeds were sown on November 15, 2021 and May 20, 2022 and seedlings were transplanted on December 15, 2021 during wet season and on June 10, 2022 during hot season. Two seedlings were transplanted on each hill at a planting spacing of 20 cm × 10 cm (50 hills/m^2).

Experimental design and crop management

Two rice cultivars *viz,* OM 8104 and MNR 3 and five rates of K (0, 25, 50, 75 and 100 kg K^2O $ha^{-1)}$ were randomized in main and sub-plots in a split-plot arrangement with three replications. The main plot was of 30 m^2 (3 m × 10 m) and the sub-plot of 15 m^2 (3 m × 5 m). The soils were applied with 100 kg N; 50 kg P; 8 tons of farmyard manure (FYM) and 500 kg lime/ha. Nitrogen (N), phosphorus (P) and potassium (K) were applied as urea (46% N), thiophosphate (7% P) and potassium chloride (50% K), respectively. Lime ($CaCO_3$, 56% CaO) was broadcast and incorporated to a soil depth of 0.2 m two weeks before transplanting of rice. The FYM and P were applied together with 50% K fertilizer for respective treatment as basal at the time of transplanting. The N and K fertilizer was top-dressed at two growth stages *i.e*., two-thirds of the total amount of N fertilizer at the tillering initiation (7-10 days after transplanting in the summer season and 10-15 days after transplanting in spring season) while one-third of total amount N and a half of K fertilizer was applied at the panicle initiation.

Sampling and measurements

The salinity of soil in the field experiment was measured with an electrical conductivity (EC) meter (EC meter, SI Analytics GmbH). Soil salinity concentration was measured by the osmotic suction method of suction piles inserted into the soil at a depth of 15 cm eight times: before the experiment and at 15, 30, 45, 60, 75, 90 days after transplanting (DAT) and at the end of the experiment. For the measurement of Na^+ and K^+ ion contents, the whole plant at the panicle initiation stage was harvested and washed with ultrapure water twice. All samples were dried at 70°C for 3 - 5 days and the samples were digested with ultrapure nitric acid for 2 days (Kanto Chemical, Japan). Digested samples were boiled at 95°C for 10 minutes three times and ion contents were determined using an inductively coupled plasma optical emission spectrometer (ICP-OES; SPS3100, SII Nano Technology Inc., Japan).

At maturity, thirty plant samples were selected randomly to record yield and its components including plant height, panicle length, number of spikelets/panicle, weight of grain/plant and 1000 grains weight. After counting the number of panicles, spikelets were threshed manually and then the weight and number of grains were obtained. Percentages of filled grains were calculated by dividing the number of grains by the total number of spikelets, spikelet sterility and fertility percentage were calculated. Thereafter, 1000 grains weight of filled grains was measured using the brown grains and their moisture content was measured (Ketto Co. Ltd). Grain yield and 1000-grain weight were determined for the refined husked grains at 14.5% moisture content. Ten plants were harvested, then the seeds were removed from the plants separately. Rice seeds and whole plant biomass were dried to a moisture content of 14%. The harvest index was calculated as ratio of grain yield to biomass yield.

Statistical analysis

Analysis of variance (ANOVA) was calculated using a two-way factorial design, where replications were the block variable and potassium rates and two rice varieties were

Table 1: Analysis of soil chemical characteristics.

Soil characteristics						
pH_{KCl}	OM(%)	CEC $cmol_c$/ kg	EC (dS/m)	Total N (%)	Total P (%)	Total K (%)
4.39	1.92	11.6	6.9	0.13	0.01	0.47
Available nutrient concentrations						
SO_4^{2-}(%)	Cl^-(%)	Available Pmg/100 g	K^+cmol_c/kg	Na^+cmol_c kg	$Ca^{2+}cmol_c$/kg	$Mg^{2+}cmol_c$/kg
0.09	0.26	1.29	1.88	3.10	2.11	2.18

OM: Organic matter; CEC: cation exchange capacity, EC: Electrical conductivity.

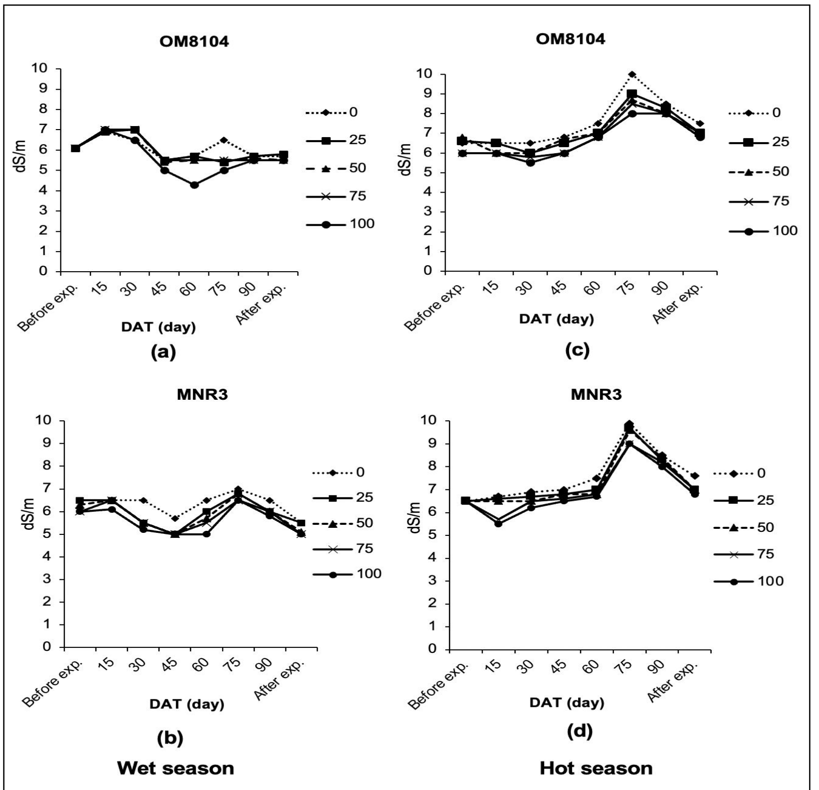
the treatment variable. Significant differences among means were determined by the LSD test at 0.05 level. Data are means±standard error (SE) was calculated using SPSS program version 20.

RESULTS AND DISCUSSION

ECe dynamics in saline soil at different K levels

Soil salinity at the study site fluctuated greatly over the growing seasons, from 5 - 10 dS/ m. The ECe values were lower (4.3 - 6.9 dS/m) in the wet season than in the hot season (5.5 - 10 dS/m) during monitoring periods. Highest soil salinity (10 dS/m) peaked at the flowering stage *viz,* 70 - 75 days after transplanting in the hot season. The difference in the soil salinity concentration was also found with different K application rates. Application of 50 kg K_2O/ha reduced the soil salinity over the monitoring periods compared to the other K rates. The changes of salinity in soil during the observation stages in the hot season relate to high temperature. Rice varieties that can effectively absorb K^+ are better able to block and eliminate Na^+ (Reddy *et al.*, 2017). Potential K deficiency depending on base contents of irrigation water. This is mainly on Arenosol soil group (Minh *et al.,* 2022). Controlling soil fertility, especially K under saline soil conditions is considered one of the most important method for the evaluation of tolerance of plant to salinity stress.

During wet season, the highest salinity concentration measured ranged from 6.1 to 7.0 dS/m at 15 days after transplanting during the seedling stage and from 8.0 to 10.0 dS/m at 75 days after transplanting during the heading stage in the hot season (Fig 1). Therefore, the application of K at the pre-flowering stage for rice was a measure to enhance rice plants' resistance to salinity more effectively. The rice varieties had variable responses to Na^+ accumulation to potassium nutrition. The accumulation of Na^+ in rice varieties during the hot season was higher than in the wet season. This was due to the higher temperature in the hot season and the high concentration of Na^+ toxic ions in the soil was associated with higher salinity levels (6 - 10 dS/m) compared to the wet season (4 - 7 dS/m). Rice plants absorb more Na^+ ions, increasing the antagonistic competition between Na^+ and K^+ and reducing the ability of plant roots to absorb K^+. The Na^+ competes with K^+ ions during transport across the cell membrane for uptake, making it difficult for plants to obtain the K^+ (Hashi *et al.,* 2015; Sajid *et al.,* 2017).

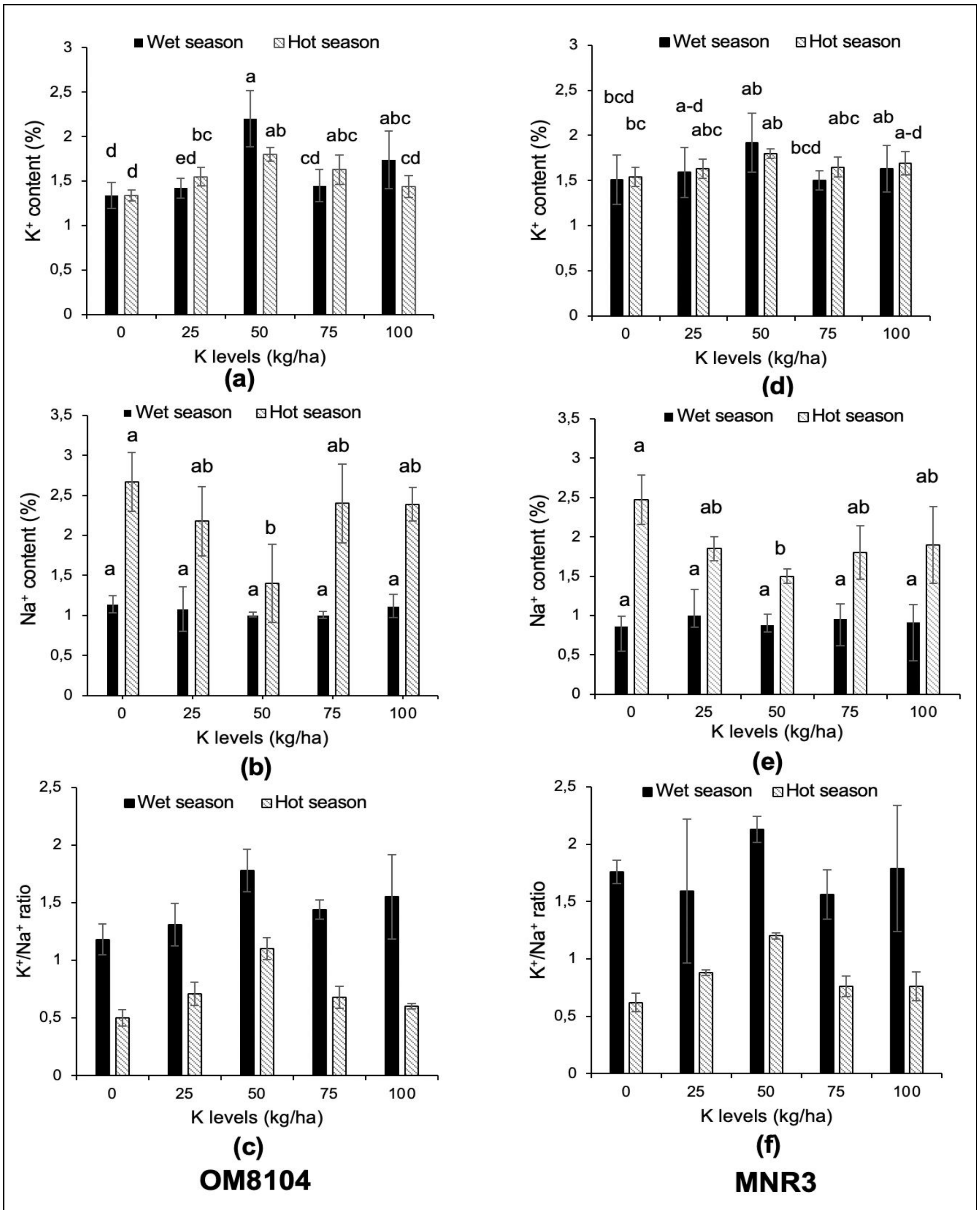


(a, b) Soil ECe (dS/m) at different potassium application rates in OM8104 and MNR3 varieties in the wet season; (c, d) Soil ECe (dS/m) at different potassium application rates in OM8104 and MNR3 varieties in the hot season.

Fig 1: Fluctuation of soil ECe (dS/m) at potassium application rates (kg K^2O/ha) at different day after transplanting (DAT).

Effect of different potassium levels on plant Na^+, K^+ contents and K^+/Na^+ ratios

Application of potassium fertilizer had a significant effect on the K^+ and Na^+ contents of two rice cultivars at the panicle initiation stage during wet and hot seasons (Fig 2). Increasing the potassium application rate increased K^+ content when compared with the control (Fig 2A,D). Nonetheless, the application of 50 kg K_2O/ha accumulated the highest K^+ and the lowest Na^+ contents for both OM 8104 and MNR 3 varieties in both seasons (Fig 2A,D). The K^+ and Na^+ contents were 1.80% and 1.40% in OM 8104 and 1.78% and 1.50% in MNR3 compared to control during hot season, respectively (Fig 2A;B and D,E). The application of different potassium rates also significantly influenced Na^+ content in both varieties (Fig 2). During the wet season, Na^+ concentration was lower than hot season in both



(a, b, c) K+; Na+ contents and K+/Na+ ratios of OM8104; (d, e, f) K+; Na+ contents and K+/Na+ ratios of MNR3 in the wet and hot seasons. Significant differences (P<0.05) are indicated by different letters using one-way ANOVA with Tukey's multiple comparisons test. Data are means±SE from 3 replications.

Fig 2: Effect of potassium levels on plant Na+ and K+ contents at the booting stage of two rice varieties.

varieties under salinity (Fig 2B, E). At the booting stage, a marked decrease in the absolute Na^+ content was observed with different potassium application rates. The lowest shoot Na^+ contents were measured at 50 kg K_2O/ha during hot season in both varieties under saline conditions compared to Na^+ content in control treatment (Fig 2B, E). In the wet season, no difference in Na^+ content was found among different potassium rates in both varieties.

Likely, highest K^+/Na^+ ratio was found at 50 kg K_2O/ha in both varieties and seasons. In particular, the K^+/Na^+ ratio of 1.78 and 1.10 in OM 8104 and 2.13 and 1.2 was found in MNR 3 the wet season and hot season, respectively. In summary, Na^+ accumulation was generally higher in the hot season than in the wet season, whereas K^+ accumulation was not affected by season factor. Rice plants absorb more Na^+ ions, increasing the antagonistic competition between Na^+ and K^+ and reducing the ability of plant roots to absorb K^+. The Na+ competes with K^+ ions during transport across the cell membrane for uptake, making it difficult for plants to obtain the K^+ (Hashi *et al.,* 2015; Sajid *et al*., 2017). High Na+ concentration had an antagonistic effect on potassium (K^+) ion which is an essential plant nutrient for growth and plant development (Xu *et al*., 2020). No variable response to K levels for Na^+ contents in rice plants of both varieties in wet seasons (Fig 2B, E) shows a salt-tolerant mechanism (Sen *et al.,* 2015) at the cellular level for Na^+ and K^+ ions transport channels at the cell membrane to favor the transport of K^+ ions owing to lower soil and water salt concentration in the wet season compared with the hot season. The reduced Na^+ contents were found with increasing potassium application compared with the control during hot season. It might be due to high external K^+ to inhibit Na^+ uptake into plants and could be due to the reason that Na^+ ion transport has an inhibitory effect in the presence of K^+ ions and the presence of more external K^+ ions could reduce Na^+ absorption from the rhizosphere leading to high K^+/Na^+ also evident from the present study. Lower Na+ content in rice plants of both varieties in both seasons at 50 kg K_2O/ ha (Fig: 2B, E) could be possibly due to high concentrations of K^+ in plants to reduce Na^+ absorption, while K^+ is an essential element for growth, development and rice yield (Gupta and Huang, 2014).

Table 2: Effect of potassium levels on yield components of two rice varieties.

Variety	K levels (kg/ha)	No. of panicle/m^2	Filled grain ratio (%)	Theoretical yield (tons/ha)	Actual grain yield (tons/ha)	Harvest Index (HI)
			Hot season			
OM8104	0	421.5^a	82.6^a	7.80^c	6.07^d	0.47
	25	448.0^a	80.3^a	8.70^{bc}	6.77^c	0.49
	50	444.0^a	81.7^a	9.13^{bc}	7.57^a	0.50
	75	462.0^a	77.4^a	8.68^{bc}	7.56^a	0.53
	100	441.1^a	81.1^a	9.09^{bc}	6.87^{bc}	0.45
MNR3	0	412.7^a	84.3^a	9.73^{abc}	6.01^d	0.45
	25	430.9^a	81.5^a	10.12^{ab}	7.33^{bc}	0.54
	50	437.5^a	80.0^a	11.30^a	7.35^{ab}	0.50
	75	414.6^a	77.4^a	9.23^{abc}	6.87^{bc}	0.50
	100	418.0^a	77.9^a	9.75^{abc}	6.42^{cd}	0.46
$LSD_{0.05}$	*67.8*	-	*1.02*	*2.01*	*0.21*	-
			Wet season			
OM8104	0	423.0^c	64.8^c	5.36^{cd}	4.39^{cd}	0.41
	25	438.5^{abc}	75.5^{ab}	5.72^{bc}	4.70^{bc}	0.42
	50	452.2^a	66.7^{bc}	6.08^b	5.25^a	0.45
	75	447.3^a	77.6^a	6.16^{ab}	5.15^a	0.43
	100	427.1^c	74.1^{ab}	6.07^b	5.08^{ab}	0.42
MNR3	0	403.4^d	77.3^a	5.27^{cd}	4.14^d	0.38
	25	435.2^{bc}	78.3^a	6.66^a	5.10^{ab}	0.45
	50	402.1^d	78.8^a	5.74^{bc}	5.18^a	0.46
	75	384.4^e	75.6^{ab}	5.45^{cd}	4.56^{cd}	0.41
	100	371.1^e	78.3^a	5.16^d	4.57^{cd}	0.40
$LSD_{0.05}$	15.49	8.89	0.53	0.52	0.41	-

Different letters in a column for each site and year indicate significant LSD differences between K rates at α = 5%.

Effect of potassium levels on yield components to grain yield and harvest index (HI)

Potassium application showed no significant effect on the yield components of both rice varieties in the wet season compared with the control treatment under saline conditions (Table 2). However, influence on some yield components such as the number of panicles/m^2 and theoretical yield of two rice varieties in the hot season was significant. In the hot season, the salinity effects on yield components were significant with relative reduction in the percentage of filled grain per panicle resulting in reduced grain yield (Table 2). Moreover, the traits of panicles per plant, panicle weight and dry biomass also had a positive correlation with yields of salt-tolerant rice cultivars under moderate salinity condition (Nguyen and Tran, 2020). Research on different nutrient management found not only the effectiveness of FYM fertilizer but also the effectiveness of potassium nutrients in enhancing the yield and growth attributes of rice plants (Kumar *et al*., 2023). The reduction in yield components in the hot season was larger than in the wet season in both varieties. Higher individual yield components (the panicle number/m^2, percentage of filled grain per panicle) was found for 50 kg K_2O/ha application than control in the hot season and thus contributed to the yield increase when compared to other treatment (Table 2). Changes in the potassium concentration at heading stage was significantly negatively correlated with changes in grain weight and sterility in the hot season compared to the wet season (Lawas *et al*., 2018).

The actual grain yield and harvest index of the OM 8104 variety were the highest at 50 and 75 kg K_2O/ha in both seasons. The grain rice yield of OM 8104 in the wet was 7.57 and 7.56 tons/ha with an increase of about 24.7% compared to control; 5.25 and 5.15 t/ha in the hot season with an increase of 20% compared to control. The harvest index of OM 8104 also reached 0.50 and 0.55 during wet season while 0.45 and 0.43 during hot season. For MNR 3 variety, the highest yield and harvest index were obtained at 25 and 50 kg K_2O/ha in the wet and hot seasons, with the actual grain yield of 7.33 and 7.35 tons/ha in the wet season and 5.10 and 5.18 tons/ha in the hot season with an increase of about 22% and 25% compared to control, respectively. The harvest index of MNR 3 was 0.54 and 0.50 in the wet season and 0.46 and 0.45 in the hot season at 25 and 50 kg K_2O/ha, respectively (Table 2). In general, the reduction in rice yield in the hot season was larger and the individual yield components contributed more evenly to it than in the wet season. This has been also evident that potassium application to rice under saline soil increased grain yield by 49% compared to the control (Akter *et al*., 2023). Increasing the level of potassium application from 24 to 72 kg K_2O/ha increased rice yield on saline soils (Zayed *et al*., 2007; Zaina and Ismail, 2016) validate the present study findings. Akter *et al*. (2023) reported an increase in biological and grain yield by 20 and 14 % with the application of 57 kg K_2O/ha in rice crop under salinity stress respectively over the control. The study also found that higher levels of K (114 kg K_2O/ha) caused some reduction in both parameters by about 5.5 and 4.0%, respectively.

CONCLUSION

Potassium as an essential element is involved in various physiological and biochemical processes helping plants to grow better under saline conditions. The present study showed that the application of 50 kg K_2O/ha produced high yield, increased K^+ and decreased Na^+ uptake associated with increased K^+/Na^+ ratio in rice shoots at the booting stage in both crop seasons and rice varieties under saline conditions. The increased yield was associated with increased filled grain numbers and reduced Na^+ uptake under saline condition In crux, the application of 50 kg K_2O/ha fertilizer application can increase rice performance on moderately saline soils of central Vietnam.

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Conflict of interest

All authors declare that they have no conflict of interest.

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