# EFFECTS OF IRRIGATION AND NITROGEN FERTILIZATION ON SOIL NA$^{+}$ IN ROOT ZONE AND SALT-TOLERANT RICE YIELD

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## 水氮调控对根层土壤 Na$^{+}$及耐盐水稻产量的影响

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## ABSTRACT

*The cultivation of salt-tolerant rice (sea rice) along beaches has become an effective measure for the restoration and utilization of saline-sodic land, so this paper studies the effects of irrigation and nitrogen fertilization on soil Na$^{+}$ in root zone and sea rice yield, and provides a scientific basis for planting sea rice. A pot experiment (two-factor split plot) of sea rice with salt stress (10 g NaCl/kg soil) was carried out. The main plot consists of three types of irrigation methods: flooding irrigation (F), intermittent irrigation (I), and controlled irrigation (C). The subplots are three types of nitrogen fertilizers: urea (U), controlled-release urea (R), and mixed fertilizer (M) with U and R. The results showed: (1) The soil water-soluble Na$^{+}$ of MI was significantly smaller than that of other treatments with NaCl, but the Ca$^{2+}$/Na$^{+}$ and Mg$^{2+}$/Na$^{+}$ were opposite. (2) The nitrogen uptake and dry weight of rice of MI were significantly larger than those of other treatments with NaCl, and were respectively 23% and 32% higher than UI, 49% and 16% higher than MF, 56% and 38% higher than UF, 75% and 61% higher than RI, 76% and 50% higher than RF. (3) The sea rice yield of MI was increased by 105%, 154%, 262%, 338%, and 428% compared with MF, RF, UF, RI, and UI, respectively. Therefore, the MI can effectively reduce the Na$^{+}$ and increase the Ca$^{2+}$/Na$^{+}$ and Mg$^{2+}$/Na$^{+}$ in root layer soil, and promote the nitrogen absorption and production of sea rice. So the article recommends that M and I methods should be adapted to plant sea rice on coastal saline-sodic soil.*

## 摘要

*【目的】近年来，种植耐盐水稻（海水稻）已成为沿海滩涂及盐碱地修复与利用的有效措施，但针对海水稻的水肥管理配套技术研究还较少。本文开展了水氮调控对根层土壤 Na$^{+}$及海水稻产量影响的研究，为优化海水稻的水氮管理提供科学依据。【方法】在加氯化钠(10g/kg)高盐胁迫下，采用两因素裂区设计进行海水稻盆栽试验。主处理是施肥量相等的普通尿素（U）、控释尿素（R）、混合氮肥（M）3 种氮肥；副处理为淹水灌溉（F）、间歇灌溉（I）、控制灌溉（C）3 种灌水方式。另设未加 NaCl 的无盐对照，共 10 个处理。【结果】（1）MI 处理的土壤水溶性 Na$^{+}$在水稻生育期内基本保持不变，且显著小于其它加盐处理的，而其它加盐处理的 Na$^{+}$均呈增加趋势；MI 处理的土壤 Ca$^{2+}$/Na$^{+}$和 Mg$^{2+}$/Na$^{+}$随着水稻生长期的延长显著增大，且在水稻孕穗期和成熟期时，显著大于其它加盐处理的。（2）MI 处理的海水稻吸氮量和干重显著大于其它加盐处理的，分别比 UI 高 23%和 32%，比 MF 高 49%和 16%，比 UF 高 56%和 38%，比 RI 高 75%和 61%，比 RF 高 76%和 50%。（3）水氮调控对海水稻的产量影响显著。MI 的产量分别比 MF 提高 105%，比 RF 提高 154%，比 UF 提高 262%，比 RI 提高 338%，比 UI 提高 428%。【结论】MI 处理能有效降低耕层土壤中的水溶性 Na$^{+}$，而提高水溶性 Ca$^{2+}$/Na$^{+}$和 Mg$^{2+}$/Na$^{+}$，减轻根层土壤 Na$^{+}$对海水稻的危害，促进海水稻的氮素及生物量累积，增加海水稻产量。因此，本文建议在 NaCl 危害较重的滨海盐渍地上种植海水稻，应采用控释尿素与尿素混合施肥，并综合间歇式浇灌的水肥管理模式。*

## INTRODUCTION

Soil salinization is a serious problem facing agriculture all over the world *(Liang et al., 2018).* There are 950 million hm$^{2}$ of saline-sodic land in the world, in which 100 million hm$^{2}$ of saline-sodic land and 2.34 million hm$^{2}$ of tidal flats are in China *(Chen et al., 2018)*. There are nearly 200,000 hm$^{2}$ of saline-sodic land along the beach in Guangdong, in which a tidal flat area of 100,000 hm$^{2}$ is in Zhanjiang, and accounts for 1/2 of the coastal tidal flat area of Guangdong. In addition, there is a coastal saline land of 40,000 hm$^{2}$ in Zhanjiang.

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Under the dual pressure of salinization of cultivated land and scarcity of water resources, growing saline-alkali-tolerant crops on saline-sodic land and beaches to ensure the food security and quantity of cultivated land has become an urgent agricultural problem *(Wang et al., 2018)*. In recent years, saline-alkali-tolerant rice (sea rice) as a pioneer crop is planted for the development and utilization of beaches and saline-sodic land, which has become an effective measure for the restoration and utilization of saline-sodic land and provides a new way to solve the problem of food security *(Chen et al., 2018).*

At present, sea rice is suitable for growing in coastal soil with salinity below 0.6%, and it needs to be diluted with fresh water to below 1% for irrigation. Therefore, reducing the total concentration of $Na^+$ in the rice root layer soil is still the key to the normal growth and yield of seawater rice *(Chen et al., 2018).* Irrigation and fertilization is the most important agronomic measure in agricultural activities. And both compressed salt by water and fertilizer supply should be taken into consideration in the irrigation and fertilization of saline-sodic land. Unreasonable fertilization and irrigation will lead to accumulation of soil salt, which cannot reduce salt and increase yield. Therefore, the reasonable regulation of water and fertilizer is an important measure to reduce the $Na^+$ and other salt content in coastal saline soil and increase crop yields quality *(Lima et al., 2020).* Numerous studies have shown that the use of comprehensive water and fertilizer control technology for saline-sodic soils can achieve good salt control and yield increase effects *(Lima et al., 2019).* However, researches on sea rice in coastal areas are currently mostly focused on the selection and breeding of high-yield salt-tolerant sea rice varieties, but lack of supporting sea rice water and fertilizer management technology. Therefore, the production of sea rice on the coastal saline-sodic land is limited. At the same time, there is low water and nitrogen utilization rate, which causes water resources and environmental problems *(Bao et al., 2019).*

Rice is the crop with the largest amount of nitrogen fertilizer in China *(Huang et al., 2019)*. The application of nitrogen fertilizer plays a decisive role in the yield of rice. Among them, controlled-release nitrogen fertilizer reduced salinity in soil because of the slow release of nutrients, so it can effectively regulate the soil salinity of saline-sodic soils *(Qi et al., 2019).* Therefore, this paper studies the water and nitrogen regulation modes of different irrigation methods (continuous flooding irrigation, intermittent irrigation, controlled irrigation) and fertilizers (urea and controlled-release urea, etc.) under high salt stress of NaCl (10 g/kg), and study its influence on the $Na^+$ and other salts in root zone soil and the yield of sea rice. In anticipation of optimizing the water and nitrogen management mode of sea rice, it provides a scientific basis for the efficient restoration and utilization of coastal saline-sodic land.

## MATERIALS AND METHODS

Test soil: soil taken from the cultivated layer (0-20 cm) of the rice breeding base of Guangdong Ocean University (N21°8′54″, E110°18′14″). Its pH is 6.52, bulk density is 1.25 g/cm$^3$, organic matter is 29.08 g/kg, alkali hydrolyzed nitrogen is 77.67 mg/kg, available phosphorus is 29.01 mg/kg, and available potassium is 52.33 mg/kg. After the soil sample is air-dried and crushed, it is passed through a 10-mesh sieve (2.00 mm), fully mixed, and 400 g of NaCl is added and mixed evenly, and then packed into a barrel (inner diameter 28 cm, height 60 cm), 40 kg per barrel.

Test crops: The "sea rice 86" series variety HR86401 provided by Prof. Risheng Chen's group from Guangdong Ocean University was used as the test rice. The rice is salt-tolerant rice, which can grow normally on coastal saline soil with a total salt content of 0.6%, and its root is mainly distributed within 25 cm of the soil surface. The rice seedlings are cultivated in a sterile incubator to 3 true leaves stage, and seedlings with the same growth are selected and transplanted into the test barrel.

Test fertilizer: Nitrogen fertilizer was provided by Environmental Friendly Fertilizer Engineering Technology Research Center in Guangdong. Including vegetable oil-coated controlled release urea (N≥43.0%, 3-4 months fertilizer validity period), ordinary urea (N≥46.0%), and mixed nitrogen fertilizer made by mixing 30% N urea and 70% N controlled release urea. Phosphate fertilizer is single superphosphate ($P_2O_5$≥16%). Potash fertilizer is potassium chloride ($K_2O$≥60%).

The experiment was carried out in the glass greenhouse of the Institute of Agricultural Biotechnology of Guangdong Ocean University from November 26, 2020, to March 26, 2021. A two-factor split zone design is adopted. The main treatments are different irrigation methods, namely continuous flooded irrigation (F), intermittent irrigation (I), and controlled irrigation (C). Side treatments are 3 kinds of nitrogen fertilizers, which are ordinary urea (U), controlled release urea (R), and mixed nitrogen fertilizer (M). The nitrogen, phosphorus and potassium fertilizers of each treatment are mixed with the soil as a base fertilizer and applied at one time. The fertilization rates of the treatments were all 0.72 g N, 0.48 g $P_2O_5$, and 0.64 g $K_2O$, that is, 1.57 g of urea, 1.71 g of controlled release urea, 1.64 g of mixed nitrogen fertilizer, 3.00 g of single superphosphate, and 1.07 g of potassium chloride were applied according to the treatment design per barrel. In addition, the flooded irrigation treatment without adding NaCl and applying urea was used as a control treatment (CK). There were 10 treatments in total; each treatment was repeated in 5 barrels, and 6 seedlings were planted in each barrel.

Irrigation method: The F treatment is to maintain a 2 cm water layer in the barrel. The I treatment is to stop the irrigation after watering to the 2 cm water layer, and the water surface is naturally dried before watering, cyclically. The C treatment is continuous precision irrigation, and maintains 80%-100% of the soil field water holding capacity by weighing and adding water.

Collection of soil and plant samples: The sea rice seedlings were transplanted on November 26, 2020, and the first soil sample was collected in the middle of the rice green-returning stage (December 26, 2020). A soil drill was used to collect the 0-25 cm root layer soil in the barrel, and the collection was repeated 5 times (5 barrels/treatment). After removing stones and plant roots from the soil samples, they were passed through a 2 mm sieve and were air-dried for testing. On January 5, 2021, the second sampling was conducted during the mid-tillering stage of rice, and soil and plant samples were collected. Separate the above-ground parts and roots of rice for sampling, and gently wipe the leaves with wet gauze. The roots were washed with deionized water and then blotted dry with absorbent paper. Measure the fresh weight first, and then dry it at 75°C to a constant weight after curing (105°C, 30 min), then measure its dry weight, and store it after crushing for testing. On January 30, 2021, the third soil and plant samples were collected at the middle of the rice booting stage. On March 26, 2021, soil samples were collected and the rice was harvested, and the yield was measured when the rice was mature.

Determination of plants and soil samples: After the plant samples were digested with $H_2SO_4$–$H_2O_2$, the nitrogen content was determined with Full Automatic Azotometer (Shanghai Yihong NKY6120) *(Lu, 2000).* Use the German STEP soil salinity detector (PNT300 type) to regularly monitor the soil electrical conductivity (EC) of the 0-25 cm deep root layer in the barrel. The alkaline hydrolysis diffusion method was used to determine the soil alkaline hydrolysis nitrogen content *(Lu, 2000)*. Use atomic absorption spectrophotometer (Japan Shimadzu AA-7000) to determine water-soluble sodium ($Na^+$), calcium ($Ga^{2+}$), magnesium ($Mg^{2+}$) ion content in soil (Lu, 2000). Count the number of effective panicles per pot, the number of grains per panicles, the grain ripening percentage, and the weight of thousands of grains per pot to calculate the yield per pot.

$$Yield\ (g/pot) = \frac{E(piece/pot) \times G\ (piece/pot) \times P\ (\%) \times W\ (g)}{1000 \times 100} \quad (1)$$

*E* means effective panicles number (piece/pot), *G* means grain number per panicles (piece/pot), *P* means grain ripening percentage (%), *W* means thousand-grain weight (g) *(Liu et al., 2017)*.

Use Excel 2007 and SPSS 22.0 software for data processing.

## RESULTS

### *Dynamics of soil electrical conductivity under different water and nitrogen regulation modes*

As shown in Figure 1, different water and nitrogen control treatments have significant effects on root zone soil electrical conductivity (EC).

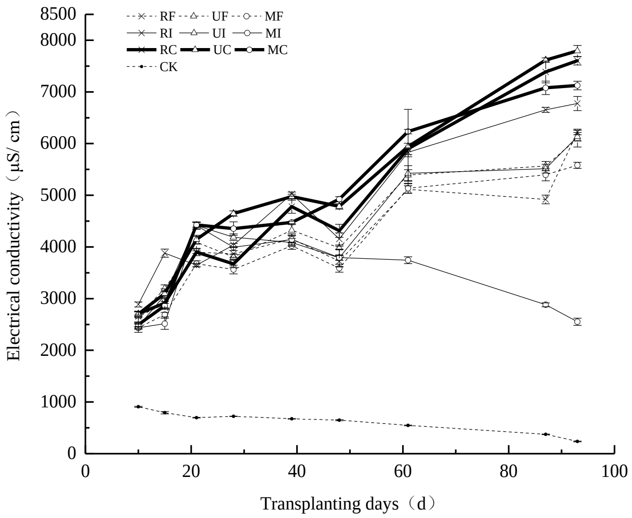


**Fig. 1 - Soil EC under different irrigation and N fertilization modes**

Among them, the CK treatment showed a slow decline with the increase of the number of rice transplanting days, and it was significantly lower than the treatments with NaCl. The MI treatment first increased and then decreased, and other treatments showed an upward trend. There was basically no difference in soil EC of treatments with NaCl during 0-40 days, and the difference began to be obvious after 40 days, and the C treatments (RC, UC, MC) were significantly larger than the other treatments. RI was significantly greater than UI, MI, and F treatments (RF, UF, MF), while MI was the smallest and significantly smaller than other treatments with NaCl.

***Dynamics of soil water-soluble $Na^+$ content under different water and nitrogen regulation modes***

It can be seen from Figure 2 that different water and nitrogen control treatments have significant effects on the water-soluble $Na^+$ content of root layer soil. Among them, CK remained basically unchanged in each growth period of rice and was significantly lower than that treated with NaCl. MI was basically unchanged and significantly smaller than other treatments with NaCl. Except for CK and MI treatments, other treatments showed an increasing trend throughout the rice growth period. And C treatments were significantly larger than I (RI, UI, MI) and F treatments. UF, RI and UI were significantly larger than MF and RF in booting stage and maturity stage.

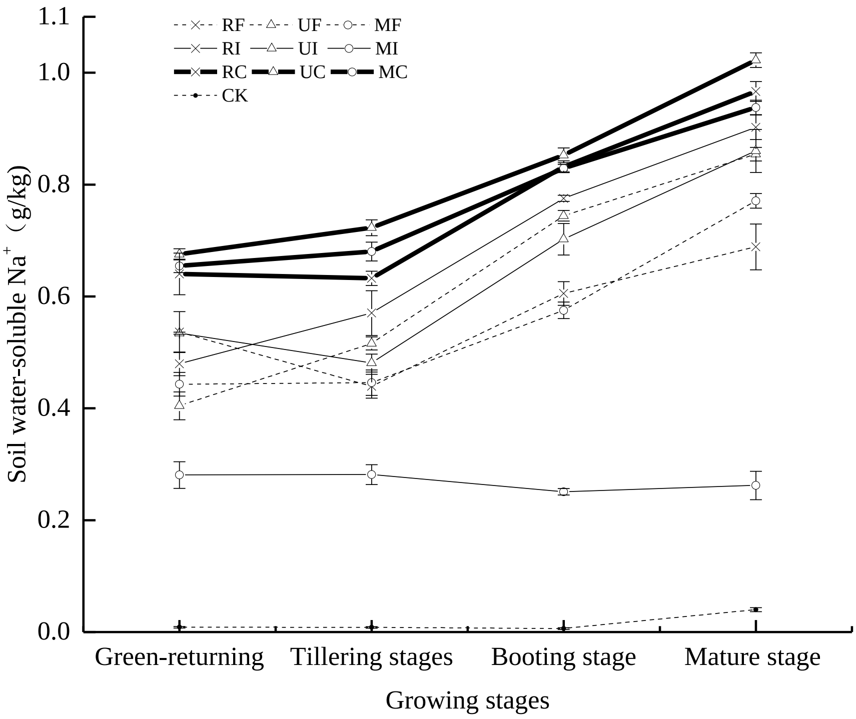


**Fig. 2 - Soil water-soluble $Na^+$ under different irrigation and N fertilization modes**

***Effects of water and nitrogen regulation modes on the ratio of water-soluble salt ions in soil***

It can be seen from Table 1 and Table 2 that there was basically no difference in water-soluble $Ca^{2+}/Na^+$ and $Mg^{2+}/Na^+$ in the root soil of the NaCl-added treatments except MI in each growth period of the rice. The MI increased significantly with the extension of the growth period, and it was significantly larger than other treatments with NaCl at the booting and maturity stages of rice. During the whole growing period of rice, the $Ca^{2+}/Na^+$ and $Mg^{2+}/Na^+$ of CK were significantly higher than those treated with NaCl.

**Table 1**

**Soil water-soluble $Ca^{2+}/Na^+$ under different irrigation and N fertilization modes**

| Treatment | $Ca^{2+}/Na^+$ | | | |
|---|---|---|---|---|
| | Green-returning | Tillering stage | Booting stage | Mature stage |
| RF | 0.034bB | 0.094bAB | 0.124cA | 0.080cAB |
| UF | 0.033bA | 0.044bA | 0.074cA | 0.070cA |
| MF | 0.033bA | 0.051bA | 0.083cA | 0.071cA |
| RI | 0.048bA | 0.064bA | 0.086cA | 0.087cA |
| UI | 0.038bA | 0.061bA | 0.076cA | 0.079cA |

| Treatment | $Ca^{2+}/Na^{+}$ | | | |
|---|---|---|---|---|
| | Green-returning | Tillering stage | Booting stage | Mature stage |
| MI | 0.055bC | 0.125bBC | 0.206bAB | 0.219bA |
| RC | 0.022bA | 0.099bA | 0.102cA | 0.077cA |
| UC | 0.017bA | 0.071bA | 0.098cA | 0.074cA |
| MC | 0.021bA | 0.078bA | 0.098cA | 0.072cA |
| CK | 0.542aC | 1.589aB | 3.372aA | 0.854aBC |

*Note: Different lower case letters in a column indicate significant difference among treatments at the 5% level. Different capital letters in a row indicate significant difference among the same treatment for different growth stages at the 5% level.*

**Table 2**

**Soil water-soluble $Mg^{2+}/Na^{+}$ under different irrigation and N fertilization modes**

| Treatment | $Mg^{2+}/Na^{+}$ | | | |
|---|---|---|---|---|
| | Green-returning | Tillering stage | Booting stage | Mature stage |
| RF | 0.069bcB | 0.233bcA | 0.293bcA | 0.201cA |
| UF | 0.081bcB | 0.108dAB | 0.197cA | 0.162cAB |
| MF | 0.082bcB | 0.126cdAB | 0.238cA | 0.178cAB |
| RI | 0.120bA | 0.163bcdA | 0.217cA | 0.219cA |
| UI | 0.104bB | 0.152bcdAB | 0.216cA | 0.198cAB |
| MI | 0.137bC | 0.314bB | 0.516bAB | 0.564bA |
| RC | 0.044cB | 0.208bcdA | 0.252cA | 0.196cA |
| UC | 0.050bcB | 0.218bcA | 0.251cA | 0.184cA |
| MC | 0.052bcB | 0.196bcdA | 0.243cA | 0.200cA |
| CK | 1.287aC | 3.940aB | 8.435aA | 2.125aBC |

*Note: Different lower-case letters in a column indicate significant difference among treatments at the 5% level. Different capital letters in a row indicate significant difference among the same treatment for different growth stages at the 5% level.*

### *Effects of water and nitrogen regulation modes on soil alkali-hydrolyzable nitrogen*

As shown in Table 3, the soil alkali-hydrolyzable nitrogen contents of all treatments in the rice green-returning stage were significantly greater than those in the tillering stage, booting stage and maturity stage. From the tillering stage to the maturity stage of rice, the soil alkali-hydrolyzable nitrogen of R (RF, RI, RC) treatments showed an increasing trend, and that of U (UF, UI, UC), CK, MF and MC remain basically unchanged, while that of MI showed a significant downward trend. During the whole rice growth period, the soil alkali-hydrolyzable nitrogen of CK was significantly smaller than the treatments with NaCl or there was no significant difference from them.

**Table 3**

**Soil alkali-hydrolyzable nitrogen content under different irrigation and N fertilization modes**

| Treatment | Soil alkali-hydrolyzable nitrogen (mg/kg) | | | |
|---|---|---|---|---|
| | Green-returning | Tillering stage | Booting stage | Mature stage |
| RF | 154.13 bcA | 57.59 dD | 77.19 bcC | 108.52 aB |
| UF | 143.73 cA | 64.12 cdB | 56.62 dB | 66.54 deB |
| MF | 159.70 bcA | 52.63 dB | 66.54 cdB | 67.99 dB |
| RI | 144.70 cA | 60.01 dC | 109.61 aB | 108.64 aB |
| UI | 158.97 bcA | 89.53 abB | 85.41 bB | 86.87 bcB |
| MI | 168.89 abA | 79.85 bcB | 70.17 bcdBC | 55.17 eC |
| RC | 155.34 bcA | 80.57 bcC | 105.01 aB | 109.13 aB |
| UC | 177.36 aA | 102.35 aB | 107.68 aB | 81.30 cC |
| MC | 173.49 aA | 86.62 abC | 106.47 aB | 98.96 abBC |
| CK | 143.97 cA | 60.25 dB | 55.89 dB | 54.20 eB |

*Note: Different lower case letters in a column indicate significant difference among treatments at the 5% level. Different capital letters in a row indicate significant difference among the same treatment for different growth stages at the 5% level.*

***Effects of water and nitrogen regulation modes on nitrogen uptake of sea rice***

As shown in Figure 3, the nitrogen uptake of F, I, and CK-treated rice all increased significantly with the growth of rice. However, C treated rice have no significant changes in nitrogen uptake, and all die at the maturity stage without nitrogen accumulation. In the tillering stage, the nitrogen uptake of UF, MI, CK treated rice was significantly greater than that of other treatments. At the booting stage, CK was significantly higher than that of the treatments with NaCl. The nitrogen uptake of UF, MF, I treatments were greater than other treatments with NaCl. At maturity stage, MI and CK were significantly larger than that of other treatments. MI was 23% higher than UI, 49% higher than MF, 56% higher than UF, 75% higher than RI, and 76% higher than RF.

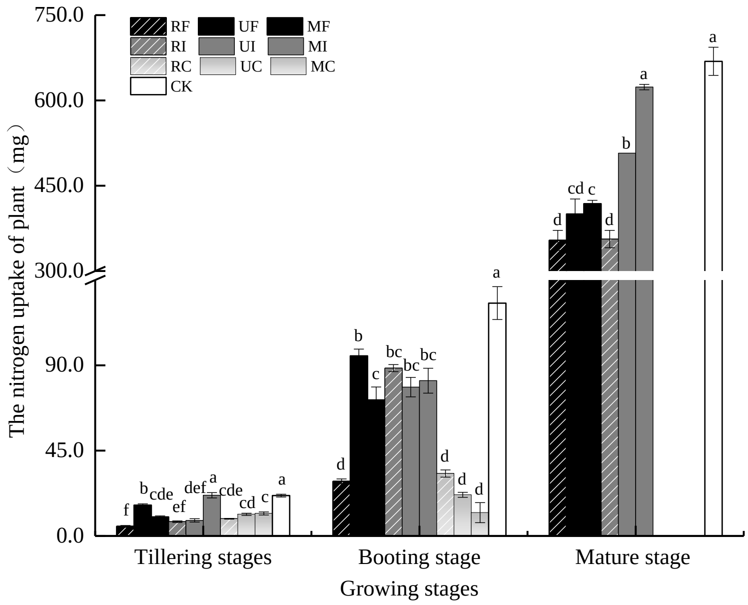


**Fig. 3 - The nitrogen uptake of single plant under different irrigation and N fertilization modes**

*Note: Different lower case letters in a column indicate significant difference among treatments for the same growth stage.*

***Effects of water and nitrogen regulation modes on the dry matter of sea rice***

As shown in Figure 4, the dry weight of rice treated with F, I, and CK increased significantly with the extension of the growth period.

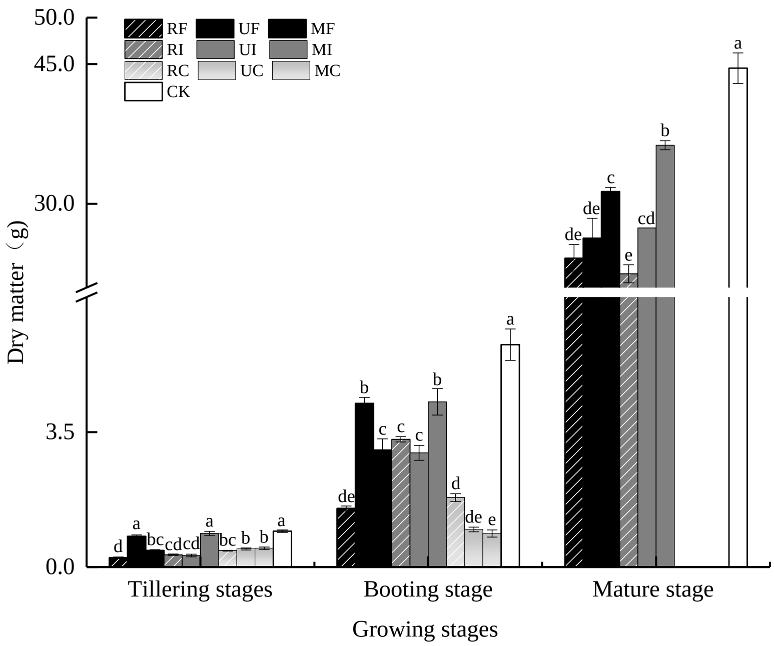


**Fig. 4 - Effects of different irrigation and N fertilization on the dry weight of rice**

*Note: Different lower case letters in a column indicate significant difference among treatments for the same growth stage.*

The C-treated rice grew slowly before the booting stage, and all died at the maturity stage. In the tillering stage, the dry weight of rice treated with UF, MI and CK were significantly greater than that of other treatments. At the booting stage, CK was significantly larger than that treated with NaCl. The UF and MI are significantly larger than other treatments with NaCl. Finally, CK was significantly larger than the NaCl-added treatments, and MI was significantly larger than other NaCl-added treatments at the maturity stage, and it was 16% higher than MF, 32% higher than UI, 38% higher than UF, 50% higher than RF, and 61% higher than RI.

***Effects of different water and nitrogen regulation modes on sea rice yield and its components***

It can be seen from Table 4 that different water and nitrogen control treatments have significant effects on rice yield and its constituent factors. Under continuous flooded irrigation condition, the sea rice yield of MF was significantly greater than that of RF and UF. Similarly, the yield of MI was significantly greater than that of RI and UI in the inter-irrigation treatments. The sea rice treated with C all died at the maturity stage, so there was no yield. The yields of MI and CK were significantly greater than that of other treatments, and the yield of MI was 10% higher than CK, 105% higher than MF, 154% higher than RF, 262% higher than UF, 338% higher than RI, and 428% higher than UI.

**Table 4**

**Effects of different irrigation and N fertilization on rice yield and its components**

| Treatment | Effective panicles | Grain number per panicles | Grain ripening percentage (%) | Thousand-grain weight (g) | Yield (g/pot) |
|---|---|---|---|---|---|
| RF | 54 | 113 | 85 | 18.72 | 97.45 cd |
| UF | 18 | 239 | 86 | 18.41 | 68.27 de |
| MF | 60 | 126 | 87 | 18.81 | 120.37 bc |
| RI | 45 | 79 | 85 | 18.45 | 56.50 de |
| UI | 30 | 97 | 89 | 18.32 | 47.29 e |
| MI | 60 | 234 | 91 | 18.95 | 247.22 a |
| RC | 0 | 0 | 0 | 0 | 0 |
| UC | 0 | 0 | 0 | 0 | 0 |
| MC | 0 | 0 | 0 | 0 | 0 |
| CK | 80 | 261 | 95 | 18.74 | 224.17 a |

*Note: Different lower case letters in a column indicate significant difference among treatments at the 5% level.*

## DISCUSSION

Soil electrical conductivity is closely related to soil salinity, and there is a linear relationship between the soil EC and salinity *(Nocco et al., 2019).* Therefore, soil EC can better reflect soil salinity. The EC of CK treatment showed a slow downward trend, and the water-soluble $Na^+$ remained basically unchanged, and both were significantly lower than that treated with NaCl. This is because CK did not add NaCl, and it absorbed $NH_4^+$, $PO_4^{3-}$, $K^+$, $Ca^{2+}$, $Mg^{2+}$ plasma in the soil with the continuous growth of sea rice *(Manohara et al., 2020).* Except for MI, the EC and $Na^+$ of the treatments with NaCl showed an upward trend. This is because the test soil in this experiment has a higher organic matter content (29.08 g/kg). After NaCl is added to the soil, the organic colloid adsorbs a large amount of free $Na^+$ and other salt-alkali ions. The organic matter continues to decompose with repeating irrigation, and releasing $Na^+$ plasma, which causes the content of soil EC and water-soluble $Na^+$ to increase *(El-Shazely, 2021).* The EC of MI increased first and then decreased, and the water-soluble $Na^+$ remained basically unchanged. This is because the inter-irrigation method leaches the soil soluble salt into the lower layer of the soil *(Hu and Gao, 2018).* The mixed fertilization with the controlled-release urea (CU) and urea is beneficial to the nitrogen absorption and growth of sea rice during the whole growth period. Sea rice absorbs more salt ions, and controlled-release urea controls the release of nitrogen, so slowing the soil EC of MI. The results show that the soil EC and water-soluble $Na^+$ treated with F and I are less than those treated with C. This is because a large amount of watering can dilute the soil salt concentration, and leach $Na^+$ plasma below the soil root layer *(Hu and Gao, 2018).* Control irrigation treatments are less watered, which is 80%-100% of the soil field water holding capacity. Salt ions cannot be fully leached into the underlying soil, and water evaporates quickly. Salt ions accumulate to the upper layer of the soil along with the water vapor surface, leading to the increase of soil EC and water-soluble $Na^+$ in the root layer *(Sarwar et al., 2020).*

In saline soil, high $Ca^{2+}/Na^+$ and $Mg^{2+}/Na^+$ play an important role in alleviating the toxicity of mono-salt to plants, and increasing the $Ca^{2+}/Na^+$ and $Mg^{2+}/Na^+$ in the soil can effectively reduce the toxicity of $Na^+$ to crops. The higher the $Ca^{2+}/Na^+$ and $Mg^{2+}/Na^+$, the lower the $Na^+$ toxicity in the soil *(Zhang et al., 2018).* The results showed that the $Ca^{2+}/Na^+$ and $Mg^{2+}/Na^+$ of MI showed a significant increasing trend. The reason may be that as the irrigation time increases, $Ca^{2+}$ and $Mg^{2+}$ in the soil are gradually dissolved, or replaced by $Na^+$, $NH_4^+$ plasma from the soil *(Zhang et al., 2018).* However, $Na^+$ is absorbed by sea rice or leached into the lower layer of the soil, resulting in a relative decrease in $Na^+$ in the root layer of soil, and a relative increase in $Ca^{2+}$ and $Mg^{2+}$. Therefore, $Na^+$ is less toxic to MI-treated sea rice than other NaCl-added treatments. This article only studied the soil salt content of the root layer (25 cm) where the HR86401 sea rice root is mainly distributed but did not involve the salt ion status of $Na^+$, $Ca^{2+}$, $Mg^{2+}$ in the soil profile below 25 cm. And it is a pot experiment, which is quite different from the salt leaching and migration status in the field. Therefore, it is necessary to further study the rule of water and salt transportation and salt leaching status of the soil profile by different irrigation and fertilization managements in field production. And verify the growth and yield of MI-treated sea rice in the field.

The soil alkali-hydrolyzable nitrogen content of each treatment at the rice green-turning stage was significantly greater than that at the tillering stage, booting stage and maturity stage. This is because sea rice absorbs the nitrogen in soil during the growth process, and the plant accumulates nitrogen. This was verified by the increase in the amount of nitrogen absorbed by sea rice in each treatment with the extension of the growing season (Figure 3). From the tillering stage to the maturity stage of rice, the soil alkali-hydrolyzable nitrogen of R treatments showed an increasing trend. This is because controlled-release urea slowly releases nitrogen into the soil for plant absorption and utilization in the middle and late stages of sea rice growth *(Hou et al., 2019).* The soil alkali hydrolyzable nitrogen of MI and CK showed a decreasing trend because the sea rice treated with them absorbed more nitrogen than other treatments (Figure 3).

Nitrogen fertilizer is one of the indispensable nutrients for the growth of rice. Nitrogen plays an important role in promoting the growth and yield of rice *(Liu et al., 2021).* The sea rice of MI and CK absorbs more nitrogen, which is conducive to its growth. Therefore, it grows fast and grows well. In the tillering stage, booting stage and maturity stage, the dry weight of MI and CK sea rice was higher than that of other treatments (Figure 4). The growth of sea rice treated with CK is better because no NaCl is added, and the sea rice is not affected by salt damage. The sea rice of MI grows well, and the biomass accumulation is more than that of other treatments with NaCl. This may be because the nitrogen supply rule of the M treatments (30% urea and 70% controlled release urea) conforms to the nitrogen demand law of sea rice. Nitrogen can be supplied by 30% urea in the early growth period, and it can be supplied by 70% controlled release urea in the middle and late growth period. It may also be because I treatments leached soil soluble $Na^+$ into the lower layer of the soil *(Hu and Gao, 2018),* the root layer (25 cm) where the rice roots are mainly distributed has low soil $Na^+$ content, and relatively high $Ca^{2+}/Na^+$ and $Mg^{2+}/Na^+$. Therefore, single $Na^+$ is less toxic to sea rice, which is beneficial to the normal growth of sea rice.

The formation of crop yield is essentially a process of dry matter accumulation and distribution, which usually depends on its yield components *(Sarker et al., 2015).* The dry weight, effective panicle number, panicle grain number, grain ripening percentage and thousand-grain weight of MI and CK were all higher than those of other treatments. Therefore, their final yield is also significantly greater than that of other treatments. There was no significant difference in yield between MI and CK (Table 4). This may be because $Na^+$ salt stress has an inhibitory effect on the carbon metabolism and yield of rice *(Zhang et al., 2018),* which affects the formation of sea rice yield components. But the sea rice of CK has no salt stress effect. At the same time, the inter-irrigation method can reduce the water-soluble $Na^+$ content of the root layer soil, and $Ca^{2+}/Na^+$ and $Mg^{2+}/Na^+$ are higher. Single sodium damage had little effect on sea rice treated with I. In addition, mixed fertilization is more suitable for the nitrogen demand of sea rice during the growth process, which is beneficial to the absorption and transformation of nitrogen, the formation of grains and increases the thousand-grain weight *(Samarajeewa et al., 2005)*. So the thousand-grain weight of sea rice grains treated with MI was the highest under the combined effect of mixed fertilization and inter-irrigation, which contributed the most to its yield. Therefore, this article recommends that the mixed fertilization with the controlled-release urea (CU) and urea as well as intermittent irrigation management should be adopted when planting sea rice on coastal saline-sodic land where NaCl is the main hazard. It is beneficial to increase the production of sea rice. However, this article does not involve field experiments and the physiological and biochemical mechanism of the mixed fertilization and inter-irrigation mode to increase the yield of sea rice. This content needs further research.

## CONCLUSIONS

(1) The soil EC of CK was significantly lower than the treatments with NaCl, and that of MI was significantly smaller than the other treatments with NaCl. The root layer soil $Na^+$ of MI was significantly smaller than that of other treatments with NaCl. The root layer soil $Ca^{2+}/Na^+$ and $Mg^{2+}/Na^+$ of MI increased significantly with the growth of sea rice, and they were significantly larger than those of other treatments with NaCl at the booting and maturity stages.

(2) The nitrogen uptake and dry weight of rice treated with F, I, CK increased significantly with the growth of rice. However, those treated with C did not change significantly, and all of them died at the maturity stage. At the maturity stage of rice, the nitrogen uptake and dry weight of MI and CK were significantly greater than those of other treatments, and those of MI were respectively 23% and 32% higher than those of UI, 49% and 16% higher than those of MF, 56% and 38% higher than those of UF, 75% and 61% higher than those of RI, 76% and 50% higher than those of RF.

(3) Irrigation and nitrogen fertilization have significant effects on the yield and its constituent factors of sea rice. The yield of sea rice treated with M was significantly higher than that treated with R or U fertilization alone under F and I irrigation. The yield of MI is significantly larger than that of other treatments with NaCl, and was 105% higher than that of MF, 154% higher than that of RF, 262% higher than that of UF, 338% higher than that of RI, and 428% higher than that of UI, respectively. Therefore, this paper recommends that controlled-release urea and urea mixed fertilization integrated intermittent irrigation should be used when planting sea rice on coastal saline-sodic soils, which can effectively reduce the water-soluble $Na^+$ in the root layer soil, thereby the $Ca^{2+}/Na^+$ and $Mg^{2+}/Na^+$ of soil can be increased, the toxicity of $Na^+$ to sea rice can be controlled, and promote nitrogen absorption and biomass accumulation of sea rice, and finally to increase the yield of sea rice grown on saline-sodic land.

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