RESEARCH ARTICLE

The effect of controlled-release urea and urea mixture on ammonia volatilization and nitrogen utilization efficiency of dryland wheat

Zhen Liu*, Pingping Cao, Yuanyuan Liu, Wanyan Zhou, Jiaxuan Wu, Xuerui Guo, Xiaolong Zhao, Yupeng Xu

Cangzhou Academy of Agriculture and Forestry Sciences, Cangzhou, Hebei, China.

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Fertilizer can effectively increase wheat yield, but excessive fertilizers can cause environmental damage and are not conducive to agricultural production activities. To improve the nitrogen utilization efficiency (NUE) of wheat in arid areas and reduce the amount of nitrogen fertilizer used during crop planting, this study investigated the effects of controlled-release urea and urea mixture on the NUE of wheat and soil ammonia volatilization. When the mixed fertilization scheme was adopted, the nitrogen element in the soil mainly existed in the form of nitrate nitrogen, and the distribution was relatively uniform. The mixed fertilization scheme increased the nitrogen agronomic efficiency in wheat by 12.23%, the partial productivity of nitrogen fertilizer by 1.77%, the contribution rate of nitrogen fertilizer by 7.21%, and the nitrogen recovery efficiency by 13.87%. The mixed fertilization scheme could effectively improve the NUE. Under the mixed fertilization scheme, the maximum cumulative emission of ammonia volatilization was only about 6.3 kg/ha, which effectively reduced the nitrogen fertilizer loss caused by soil ammonia volatilization. The study explored the effect of controlled-release urea mixed with urea fertilization on the NUE of wheat, which could help reduce the amount of fertilizer used in wheat cultivation.

Keywords: controlled-release urea; wheat; ammonia volatilization; nitrogen fertilizer; utilization rate.

***Corresponding author:** Zhen Liu, Cangzhou Academy of Agriculture and Forestry Sciences, Cangzhou 061001, Hebei, China. Email: liuzhen84575151@163.com.

Introduction

Wheat is one of the main cereal crops, and a certain correlation exists between its yield and fertilizer application. Most farmers rely entirely on fertilizers to increase wheat yield [1]. Nitrogen is a key nutrient for plant growth and development, playing an irreplaceable role in promoting crop growth and increasing crop yield. Nitrogen fertilizer is currently the most widely used fertilizer [2]. Among multiple nitrogen fertilizers, urea has become the preferred choice in agricultural production due to its high nitrogen content and cost-effectiveness [3, 4]. Urea can be quickly converted into ammonia after use. If not managed properly, ammonia will evaporate into the atmosphere, causing nitrogen loss [5, 6]. Ammonia volatilization not only reduces the available nitrogen for crops, but also pollutes the surrounding environment, affects air quality, and even has negative impacts on human health and ecosystems. In addition, the rapid release characteristic of urea means that nitrogen is released in a concentrated manner in a short period of time, which may result in crops being unable to fully absorb, reducing the overall nitrogen utilization efficiency (NUE) by crops [7, 8].

Controlled-release urea (CRU) can control the release rate of nitrogen through special coatings or formulas, making it more compatible with the growth needs of crops, reducing ammonia volatilization, and improving the NUE. Although the CRU has improved NUE to a certain extent and reduced fertilizer abuse, the CRU in arid land is relatively poor [9]. In agricultural production, nitrogen fertilizer is significant for improving crop yield. By adjusting the appropriate nitrogen fertilizer ratio and using CRU reasonably, nitrogen loss can be effectively reduced and NUE can be improved. Shi *et al*. mixed six components including urea, sodium carboxymethyl cellulose, and corn stover biochar to improve the NUE in wheat cultivation and weaken the environmental pollution. The results indicated that the mixed fertilizer could effectively improve the NUE and crop yield, while significantly inhibiting the emission of active nitrogen [10]. Yu *et al*. investigated the effects of six different ratios of slow-release urea (SRU) and conventional urea on wheat and rice yields and NUE. The results showed that the optimal rice yield was achieved when 70% SRU + 30% urea was added. The highest wheat yield was achieved when 30% SRU + 70% urea was added. The NUE increased from 27.4% to 96.5% and 22.8% to 57.1%, respectively, compared to pure urea [11]. Qiang *et al*. investigated the effects of optimal mixed nitrogen fertilizer ratio and fertilization depth on crop yield and fertilizer utilization efficiency by mixing CRU with conventional urea in four different ratios and two different fertilization depths simultaneously. When the fertilization depth was 16 cm and the CRU and urea ratio was 2:1, the fertilization effect was the best, significantly improving crop yield and NUE [12]. Zhao *et al*. investigated the effects of CRU and urea with different N ratios on rice yield and NUE. Five mixed fertilizers with different N ratios were used for fertilization during the rice growth period. The results showed that the one-time fertilization mode could significantly improve rice yield and NUE, while effectively reducing fertilizer and labor costs [13]. Han *et al.* analyzed the effect of mixed application of CRU and urea on winter wheat yield. Resin coated urea was used as CRU, and five different N ratios were set. The results showed that 70% CRU + 30% urea could significantly reduce the nitrate nitrogen (NO_3^--N) content in deep soil, while increasing the distribution ratio and yield of nitrogen to grains [14].

Ammonia (NH_3) volatilization is one of the main pathways of nitrogen loss after nitrogen fertilizer application. In addition to reducing NUE, it can also cause environmental pollution. To reduce NH_3 volatilization, Bing *et al*. investigated the effects of different ratios of CRU and urea on NH_3 volatilization loss and annual crop yield in the winter wheat summer maize rotation system. When the ratio of CRU to urea was 5:5 and 3:7, the crop yield and NUE were significantly improved, while NH_3 volatilization loss was significantly reduced [15]. Ge *et al*. artificially increased wheat yield and NUE by preparing six types of CRUs. The results showed that phosphate rock and epoxy resin-coated urea (RPHDU) could significantly reduce NH_3 volatilization, while improving soil nitrogen supply capacity and wheat yield and NUE [16]. Zhou *et al*. proposed two rotation modes, garlic-rice and wheat-rice, to reduce soil NH_3 volatilization. The results showed that the garlic-rice rotation mode significantly improved NUE, while significantly reducing NH_3 volatilization, effectively reducing environmental risks in agricultural production [17]. Vangeli *et al*. evaluated the gaseous nitrogen loss of three different fertilizers to improve the NUE and reduce NH_3 volatilization. Compared with urea ammonium nitrate, the calcium ammonium nitrate or ammonium nitrate fertilizers containing 3,4-dimethylpyrazole phosphate (DMPP) nitrification inhibitors could significantly reduce the NH_3 volatilization in corn and wheat [18]. Ashraf *et al*. improved wheat yield and reduced NH_3 loss in semi-arid areas by preparing zinc-coated urea (ZnU) mixed with inhibitors. The results showed that the ZnU combined with inhibitors could effectively reduce nitrogen loss and improve NUE, while ensuring high wheat yield [19]. The mixed application of CRU and urea may have a significant impact on NH_3

volatilization and NUE in dryland wheat. Analyzing the mechanism and influencing factors of the mixed application of CRU and urea is crucial for improving NUE and crop yield, further optimizing fertilization schemes and field management measures, and promoting green agriculture and sustainable development.

It is expected to improve the NUE in dryland wheat and reduce fertilizer abuse in dryland wheat planting areas. This study proposed a mixed application scheme of conventional urea and CRU and optimized the fertilization structure of existing dryland wheat. The effects of co-application of CRU and conventional urea on ammonia volatilization and NUE in dryland wheat areas were also analyzed.

Materials and methods

Experimental design

The experimental site was in Huanghua, Hebei, China (38°24'N, 117°00'E) with an average annual temperature of 13℃, a cumulative temperature of 4,349℃·d for temperatures ≥ 10℃, and an average annual precipitation of approximately 600 mm. The soil was alluvial soil with an organic matter content of 12.5 g/kg, an alkali nitrogen content of 37%, an effective phosphorus content of 9.5 mg/kg, and an effective potassium content of 268.1 mg/kg in the 0 -20 cm soil layer. Cangmai 6005, a drought alkali wheat variety cultivated by the Cangzhou Academy of Agricultural and Forestry Sciences (Cangzhou, Hebei, China), was employed in this study. The experimental fertilizers were purchased from Hebei Dongguang Chemical Co., Ltd. (Cangzhou, Hebei, China). The planting area of each experimental plot was about 30 m^2 with a sowing density of 225 kg/hectare and a sowing row spacing of 16 cm. The planting time was October 15th, while the harvest time was June 11th of the following year. The urea nitrogen content of conventional urea was 46%, while the nitrogen content of CRU was 34.0%. The CRU was sulfur coated urea with a release period of 180 days. In addition to nitrogen fertilizer, the fertilizers of potassium sulfate with a potassium content of 50% and calcium superphosphate with a phosphorus content of 18% were also applied. During the experimental process, both conventional urea (U) and the mixture of CRU and conventional urea (CU) at 1:1 ratio were applied with the nitrogen application rates of 140 kg/ha, 185 kg/ha, and 230 kg/ha as U_{140}, U_{185}, U_{230}, and CU_{140}, CU_{185}, CU_{230}, respectively. The individual group without fertilization was defined as the control group (CK). All the environmental and growth conditions of the experiment were completely consistent.

Observation indicators and determination of NUE

The observation indicators of NUE included soil nitrate and ammonium nitrogen (NH_4^+-N) content after crop harvest, as well as crop nitrogen uptake. The crop nitrogen uptake was calculated based on nitrogen agronomy efficiency (NAE), nitrogen partial factor productivity (NPFP), nitrogen contribution rate (NCR), and nitrogen recovery efficiency (NRE). The NAE was calculated as below [20].

$$NAE = \frac{Yield_i - Yield_{CK}}{F_i} \tag{1}$$

where $Yield_i$ was the crop yield at the i-th fertilization site. $Yield_{CK}$ was the crop yield at the control point. F_i was the nitrogen application rate (NAR) at the i-th fertilization site. The NPFP was calculated as follows.

$$NPFP = \frac{Yield_i}{F_i} \tag{2}$$

The NCR was calculated using equation (3).

$$NCR = \frac{Yield_i - Yield_{CK}}{Yield_i} \times 100\% \tag{3}$$

The NRE was calculated in equation (4).

$$NRE = \frac{N_i - N_{CK}}{F_i} \times 100\% \tag{4}$$

where N_i was the crop nitrogen uptake at the i-th fertilization site. N_{CK} was the crop nitrogen uptake at the control site.

After crop harvest, the NO_3^--N and NH_4^+-N contents in soil were measured by flow analysis. Briefly, before and after wheat sowing, a five-point sampling method was used to collect 500 g of soil samples in each experimental area. The sampling points were arranged in a cross or star shape with the center point located at the geometric center of the graph and the other four points located at the midpoint of the graph perimeter. The distance between each sampling test point was maintained at approximately 5 m to ensure uniform spatial coverage and minimize the impact of local changes in soil properties, which was sufficient to capture the changes in the graph while preventing excessive overlap between sample regions. The soil was collected from multiple depths of 0 – 20 cm (topsoil), 20 - 40 cm (subsoil), and 40 – 60 cm (deep soil) at each sampling point to illustrate the vertical distribution of nitrogen in the soil profile, which covered the range where most nitrogen conversion and plant uptake occurred. A soil sampler or auger with a diameter of approximately 5 cm was used to collect soil samples from each. After collection, the soil samples were carefully mixed to ensure uniformity followed by passing the sample through a 2 mm sieve to remove any debris and standardize the particle size before analysis. The sample was extracted using 1 mol/L potassium chloride solution, and the contents of NO_3^--N and NH_4^+-N in soil were determined by a continuous flow analyzer (Guangzhou Gardner Instrument Co., Ltd, Guangzhou, Guangdong, China).

Observation indicators and determination of ammonia volatilization

Ammonia volatilization was detected using the static chamber method. The soil sample was placed in a sealed container to determine the volatilization of ammonia in the soil. Briefly, a unidirectional open soil ammonia volatilization collection device made by hard plastic material and consisting of a cylindrical body with an inner diameter of 10 cm and a height of 30 cm was placed in each experimental area. A sponge soaked in glycerol phosphate solution was placed in the collection device with a distance of 10 - 15 cm from the soil (Figure 1). Two sponges in layers were stacked with the upper sponge at the top of the collection device. Starting from self-fertilization, the soil ammonia volatilization collection device was placed in each experimental area and labelled. Every morning at 9 am, the sponge was soaked with glycerol phosphate, and the lower layer sponge in the collection device was replaced with a fresh one. The upper sponge was replaced every 3 - 5 days depending on the degree of sponge infiltration. The replaced sponges were stored separately according to the labels. The concentration of ammonia volatilization was determined by standard acid titration after boric acid uptake.

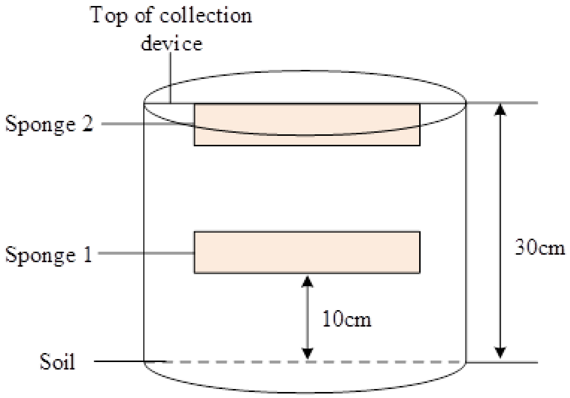


Figure 1. Soil ammonia volatilization collection unit.

The ammonia concentration at different time points, the cumulative loss, and the rate of ammonia volatilization were then determined. The cumulative loss of ammonia volatilization was calculated as follows.

$$R = V \cdot C \cdot \frac{N}{A} \cdot \frac{24}{T} \tag{5}$$

where R was the ammonia volatilization rate (kg/ha·d). V was the volume of sulfuric acid used for titration (L). C was the standard sulfuric acid concentration (mol/L). N was the relative atomic mass of nitrogen atom, taken as 0.014 kg/mol. A was the cross-sectional area of the capture device (ha). T was the time (h) for continuous collection of ammonia gas. The calculation of

Table 1. Dry material mass and nitrogen uptake amount.

Experimental group	Dry matter mass (kg/ha)		Nitrogen uptake (kg/ha)	
	2021	2022	2021	2022
U_{140}	13,879	13,228	108.49	99.61
CU_{140}	14,209	14,840	111.97	107.23
U_{185}	16,338	16,406	158.88	160.14
CU_{185}	16,638	18,126	164.68	173.68
U_{230}	16,225	14,707	143.92	143.92
CU_{230}	16,351	19,353	157.36	157.36
CK	10,173	8,954	80.17	71.35

ammonia volatilization rate was shown in equation (6).

$$F_N = \frac{2(F_i - F_{i-1})}{t_N - t_{N(i-1)}} \quad (6)$$

where F_i was the ammonia volatilization flux at the i-th sampling after cultivation. t_N was the cultivation time during sampling.

Statistical analysis

Microsoft Excel (Microsoft, Redmond, WA, USA) was employed for the experimental data analysis. The student t-test was applied to inspect the difference between groups with P values less than 0.05, 0.01, and 0.001 as statistically significant at 5%, 1%, and 0.1% confident levels, respectively.

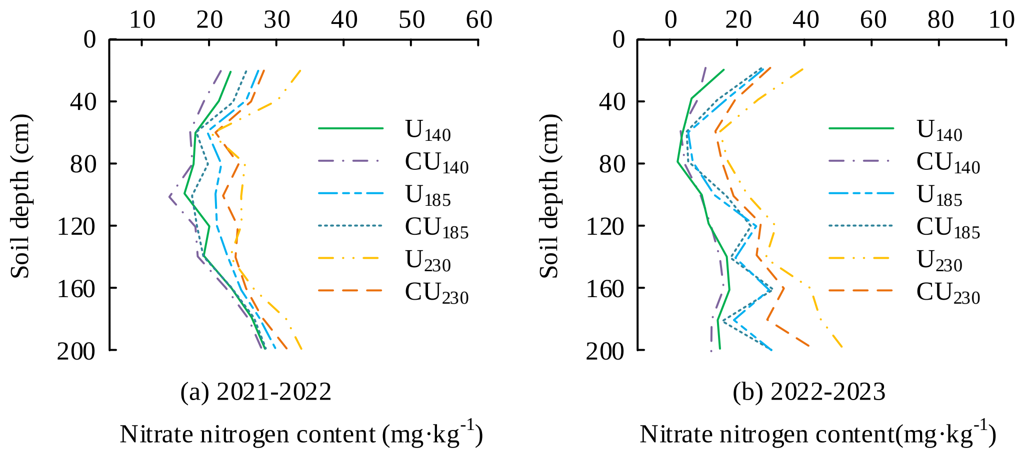
Results and discussion

Dry matter mass and nitrogen uptake of crops

The dry matter mass and nitrogen uptake of wheat from 2021 to 2022 showed that, at a nitrogen fertilizer application rate of 140 kg/ha, CU140 demonstrated slightly higher dry matter mass than that of U140 in both years, indicating that the mixed fertilization might help increase crop biomass. At a nitrogen fertilizer application rate of 185 kg/ha, the dry matter mass of CU185 treatment was significantly higher than that of U185 treatment, which indicated that the mixed CRU might be more effective at high nitrogen application levels. At a nitrogen fertilizer application rate of 230 kg/ha, the dry matter mass of CU230 treatment was significantly higher than that of U230 treatment in 2022, while the difference was not significant in 2021, which might be because the effect of mixed fertilization varied under different environmental conditions or years. The nitrogen uptake of CU140 treatment was slightly higher than that of U140 treatment over two years, which was consistent with the trend of dry matter mass, while the nitrogen uptake of CU185 treatment was significantly higher than that of U185 treatment within two years, which further confirmed the potential advantage of CRU combination in improving NUE. The nitrogen uptake of CU230 treatment was also significantly higher than that of U230 treatment in 2022, but there was no significant difference in 2021. The CK had the lowest dry matter mass and nitrogen uptake among all treatments, indicating that nitrogen fertilizer was crucial for improving wheat biomass and nitrogen uptake (Table 1).

Effect of fertilization on soil NO_3^--N content

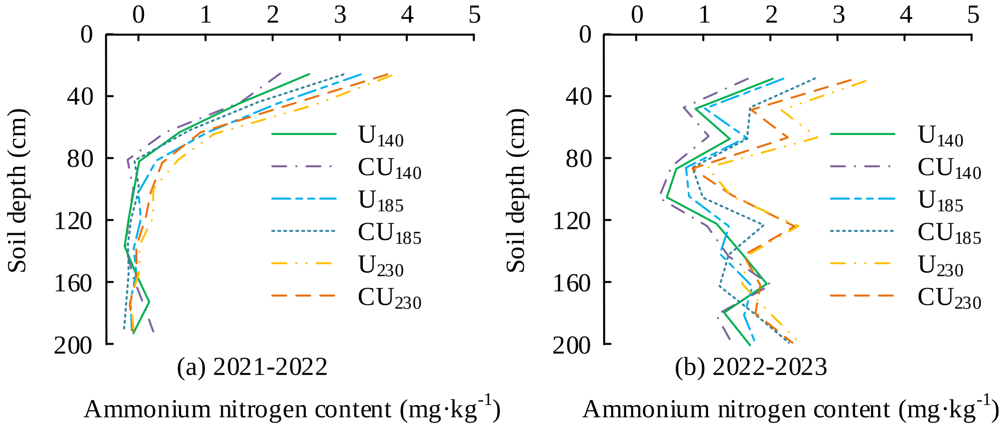
The effects of various fertilization schemes on the NO_3^--N content in soil after wheat harvest showed that the overall NO_3^--N contents in the soil remained between 10 and 40 mg/kg during 2021 - 2022 and 2022 – 2023 (Figure 2). After the wheat harvest, the nitrogen element in the soil mainly existed in the form of NO_3^-‒N and was higher in the surface and deep soils than that in the middle soil. When the soil sampling depth and the fertilization amount were consistent, the NO_3^--N content in the soil using a mixed fertilization scheme of CRU and traditional urea was lower than that of using traditional urea



(a) 2021-2022

(b) 2022-2023

Figure 2. The effects of various processing methods on soil nitrate nitrogen (NO_3^--N) concentration after wheat harvest.



(a) 2021-2022

(b) 2022-2023

Figure 3. The effects of various processing methods on soil ammonium nitrogen (NH_4^+-N) after wheat harvest.

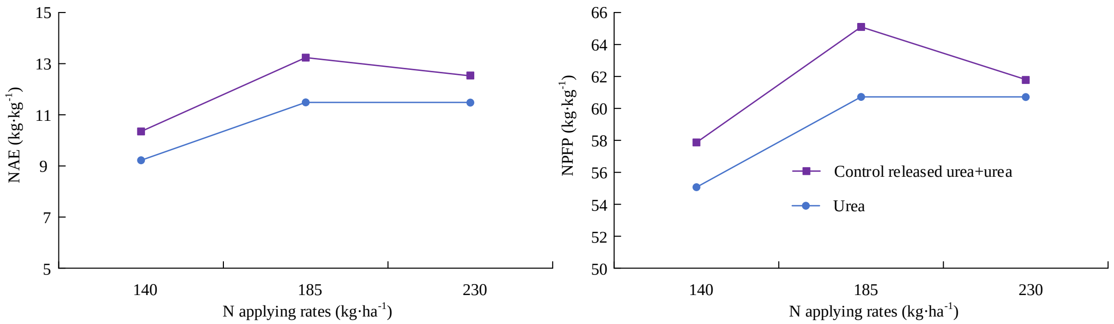
alone soil with significant difference ($P < 0.01$). When the NAR was 140 kg/ha, the mixed fertilization scheme reduced the NO_3^--N content in the soil by 13.2% to 39.1%. When the NAR was 185 kg/ha, mixed fertilization reduced the NO_3^--N content in the soil by 4.2% to 16.7%. When the NAR was 230 kg/ha, the mixed fertilization scheme reduced the NO_3^--N content in the soil by 4.2% to 16.7%.

Effect of fertilization on soil NH_4^+-N content

The effects of fertilization schemes on the NH_4^+-N content in soil after wheat harvest during 2021 – 2022 and 2022 – 2023 showed that the overall level of NH_4^+-N content in the soil after wheat harvest was relatively low with the highest amount not exceeding 4.0 mg/kg. NH_4^+-N mainly existed in the surface soil. After the soil depth exceeded 60 cm, the NH_4^+-N content in the soil was less than 1.0 mg/kg. The effects of different fertilization schemes on the NH_4^+-N content in soil were basically the same as the effects of different fertilization schemes on the NO_3^--N content in soil (Figure 3).

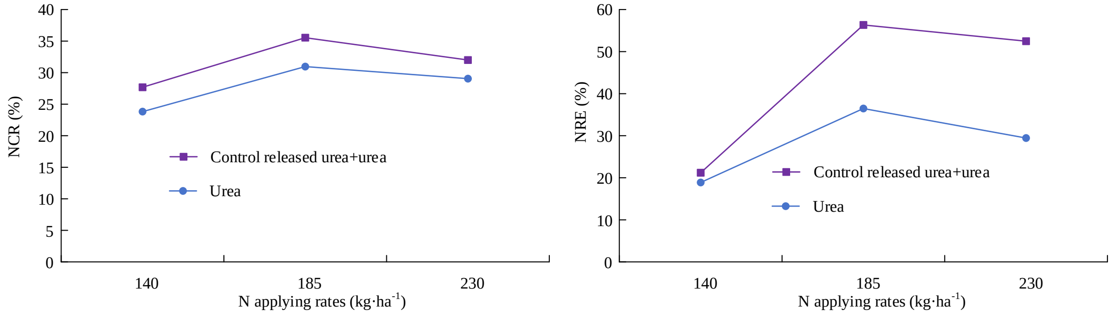
Effect of the fertilization regimen on NAE and NPFP during 2021 - 2022

The effects of fertilization schemes on NAE and NPFP values from 2021 to 2022 showed that, when the NAR was the same, the NAE value of the area fertilized with traditional urea alone was lower than that of the area fertilized with a mixture of CRU and traditional urea. A higher fertilization rate demonstrated a more significant



(a) NAE change results from 2021 to 2022 (b) NPFP change results from 2021 to 2022

Figure 4. The effects of various fertilization schemes on NAE and NPFP values from 2021 to 2022.



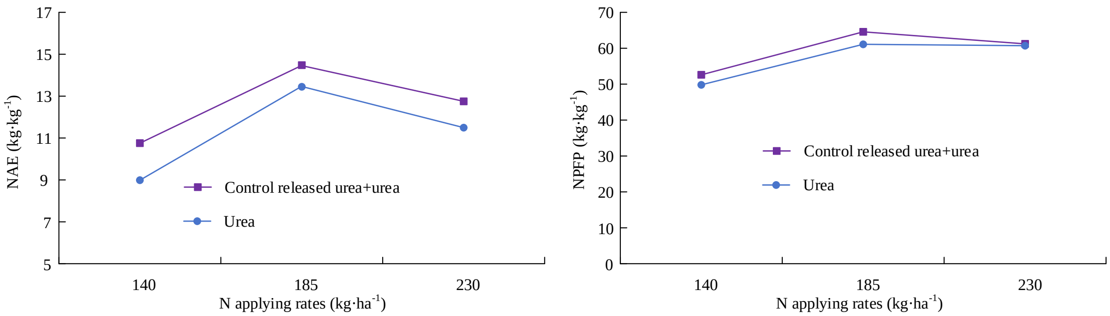
(a) NCR change results from 2021 to 2022 (b) NRE change results from 2021 to 2022

Figure 5. The effects of various fertilization schemes on NCR and NRE values from 2021 to 2022.

difference between groups ($P < 0.01$). When the NAR was 140 kg/ha, the highest NAE value in the mixed fertilization area was 10.26 kg/kg, a 17.02% increase compared to that of traditional urea fertilization scheme. When the NAR increased from 185 kg/ha to 230 kg/ha, the increase rate of NAE value significantly decreased (Figure 4a). The effects of various fertilization schemes on NPFP demonstrated that the region using the traditional urea fertilization scheme had the highest NPFP value of 60.78 kg/kg, while the region using the traditional urea and CRU mixed fertilization scheme had the highest NPFP value of 65.10 kg/kg (Figure 4b). When adopting a mixed application scheme, the changes in NPFP in the region were similar to those in NAE.

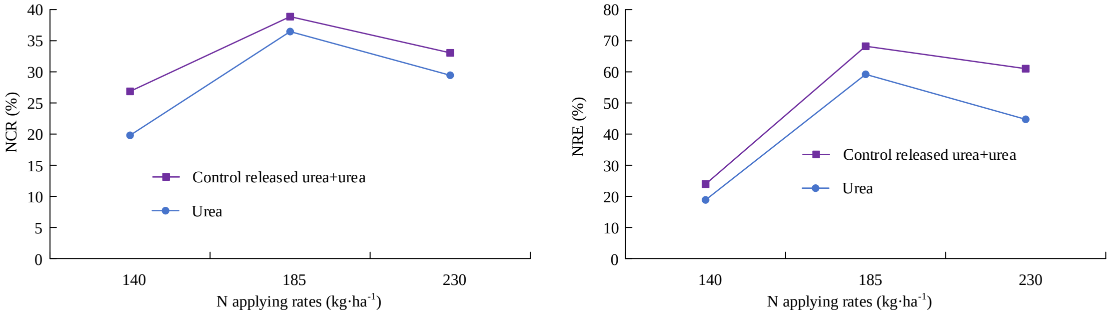
Effect of the fertilization regimen on NCR and NRE values during 2021 - 2022

The effects of fertilization schemes on NCR and NRE values from 2021 to 2022 showed that, when using the traditional urea fertilization scheme alone, the highest and lowest NCR values under different NARs were 31.05% and 23.82%, respectively. When using the mixed fertilization scheme, the highest and lowest NCR under different NARs were 35.62% and 27.26%, respectively, which showed a significant upward trend in the NCR value in the region ($P < 0.01$) (Figure 5a). When using the traditional urea fertilization scheme alone, the highest and lowest NRE values under different NARs were 36.12% and 19.52%, respectively. When using the mixed fertilization scheme, the highest and lowest NRE values were 56.85% and 20.51%, respectively, under different NARs. The changes in NRE were similar to NCR, but the impact of NAR on NRE was more pronounced. An increase in NAR further expanded the changes in NRE under different fertilization schemes with significant difference ($P < 0.01$) (Figure 5b).



(a) NAE change results from 2022 to 2023 (b) NPFP change results from 2022 to 2023

Figure 6. The effects of different fertilization schemes on NAE and NPFP values from 2022 to 2023.



(a) NACR change results from 2022 to 2023 (b) NRE change results from 2022 to 2023

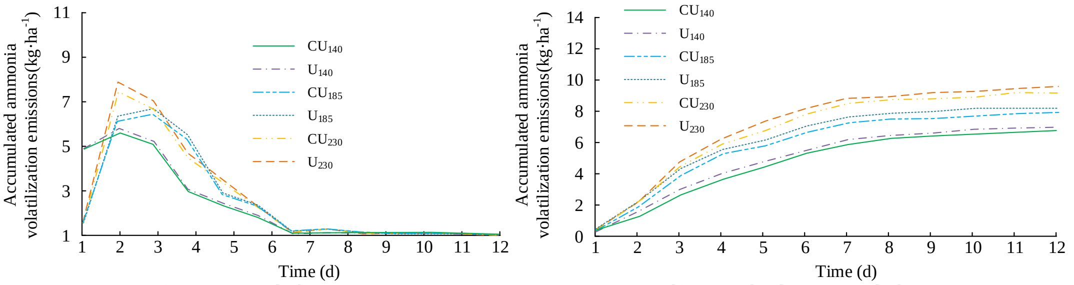
Figure 7. The effects of different fertilization schemes on NCR and NRE values from 2022 to 2023.

Effect of the fertilization regimen on NAE and NPFP values during 2022 - 2023

The effects of different schemes on NAE and NPFP values during 2022 to 2023 demonstrated that, when using the traditional urea fertilization scheme alone, the highest NAE value under different NARs was 13.15 kg/kg, while the lowest value was 9.13 kg/kg. However, when using the mixed fertilization scheme, the highest NAE value under different NARs reached 14.86 kg/kg, and the lowest reached 10.86 kg/kg. The highest regional NAE value was increased by 18.98% when using the mixed fertilization scheme (Figure 6a). The highest NPFP value under different NARs was 61.05 kg/kg, while the lowest value was 49.81 kg/kg when using the traditional urea fertilization scheme alone. When using the mixed fertilization scheme, the highest NPFP value under different NARs was 62.13 kg/kg, and the lowest was 51.06 kg/kg. There was a 2.51% increase of the highest regional NPFP value. When using the CU scheme, the NAE and NPFP in the experimental area were significantly increased compared to the traditional scheme ($P < 0.01$) (Figure 6b).

Effect of the fertilization regimen on NCR and NRE values during 2022 - 2023

The effects of different fertilization schemes on NCR and NRE values from 2022 to 2023 showed that the NCR values under different NARs reached the highest at 36.04% and the lowest at 19.80% when using the traditional urea fertilization scheme alone. When using the mixed fertilization scheme, the NCR value under different NARs reached the highest at 38.64% and the lowest at 27.12%. The regional NCR value increased by up to 36.96% (Figure 7a). The highest and lowest NRE values under different NARs were 59.82% and 18.84%, respectively, when using the traditional urea fertilization scheme alone. When using the mixed fertilization scheme, the highest NRE value was 68.12% and the lowest was 22.38% under different NARs with



(a) Ammonia volatilization rate in wheat field soil after fertilization

(b) Accumulated ammonia volatilization emissions from wheat field soil after fertilization

Figure 8. The ammonia volatilization rate and cumulative emissions in wheat field soil after using base fertilizer.

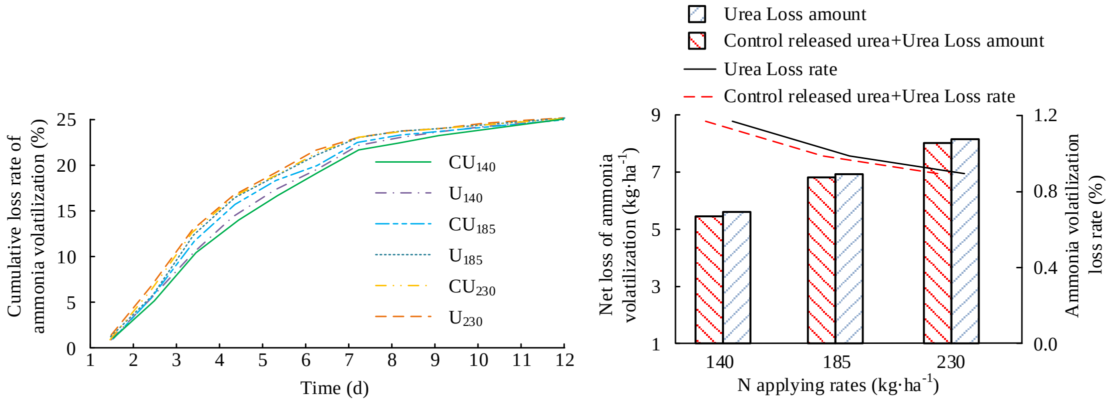
the highest regional NRE value increased by 39.72% (Figure 7b). The results showed that, when using the CU scheme, the NCR and NRE in the experimental area were significantly increased ($P < 0.01$).

The ammonia volatilization rate and cumulative emission in wheat field after applying nitrogen fertilizer

The NH_3 volatilization rate and cumulative emissions in wheat field soil after using base fertilizer showed that, at the same application rate, the NH_3 volatilization rate in the field soil reached the highest on the second day after the application of base fertilizer and then declined every day. After 12 days of base fertilizer application, the NH_3 volatilization rate in the soil decreased to an unfertilized state. When the number of fertilization days was the same, a higher NAR indicated higher NH_3 volatilization rate in the field soil. When the NAR was 230 kg/ha, the NH_3 volatilization rate reached 8.3 kg/ha·h after two days of fertilization, while the NH_3 volatilization rate was 5.2 kg kg/ha·h after two days of fertilization when the NAR was 140 kg/ha (Figure 8a). The cumulative emission of NH_3 volatilization from field soil gradually increased with the increase of NAR. The cumulative NH_3 volatilization emissions from wheat field soil reached 9.21 kg/ha after 12 days of fertilization when NAR was 230 kg/ha. However, the cumulative NH_3 volatilization emissions from wheat field soil reduced to 6.32 kg/ha after 12 days of fertilization when NAR was 140 kg/ha. At the same NAR, the cumulative NH_3 volatilization emissions of the mixed fertilization scheme after 12 days were lower than those of the traditional urea fertilization scheme. When NAR was fixed at 230 kg/ha, the cumulative NH_3 volatilization emission after 12 days was 8.92 kg/ha when using the traditional urea fertilization scheme. However, the cumulative NH_3 volatilization emission after 12 days reduced to 6.28 kg/ha when using the mixed fertilization scheme (Figure 8b).

The cumulative loss rate of ammonia volatilization and the change of nitrogen fertilizer level

The cumulative loss rate of NH_3 volatilization in wheat field soil and its variation with nitrogen fertilizer application level after applying base fertilizer showed that the cumulative loss rate under different NAR and fertilization schemes gradually increased as the number of fertilization days gradually increased. A larger NAR indicated a faster growth rate in the cumulative loss rate of NH_3 volatilization. When using a mixed fertilization scheme, the growth rate of the NH_3 volatilization cumulative loss rate was slower than the traditional urea fertilization scheme. The results showed that a loss rate of 22% was achieved after 8 days of fertilization when using the traditional urea fertilization scheme, while the same loss rate was achieved after 9 days of fertilization when using the mixed fertilization scheme (Figure 9a). The NH_3 volatilization loss with the nitrogen fertilizer application demonstrated that, as NAR increased, the net loss of NH_3 volatilization gradually increased,



(a) Cumulative loss rate of ammonia volatilization in wheat field soil after fertilization

(b) Net loss and loss rate of ammonia volatilization under different nitrogen fertilizer levels

Figure 9. Cumulative ammonia volatilization loss rate and net ammonia volatilization loss under different nitrogen application rates (NAR).

while the NH_3 volatilization loss rate gradually decreased. Under the traditional urea fertilization scheme, when the NARs were 140 kg/ha, 185 kg/ha, and 230 kg/ha, the net losses of NH_3 volatilization were 5.31 kg N/ha, 6.16 kg N/ha, and 8.36 kg N/ha, while the NH_3 volatilization loss rates were 1.19%, 1.03%, and 0.85%, respectively (Figure 9b).

Conclusion

To improve the NUE in wheat cultivation, reduce the abuse of chemical fertilizers, and promote the green and sustainable development of agricultural planting, this study explored the traditional urea fertilization scheme and the mixed fertilization method of CRU and traditional urea. The soil NH_3 volatilization and NUE in dryland wheat planting were analyzed. The results showed that, after fertilization, most of the nitrogen elements in the wheat field soil existed in the form of NO_3^--N. The overall NO_3^--N content in the soil remained between 10 mg/kg and 40 mg/kg. The ammonium nitrogen content in the soil was relatively low and mainly existed in the surface soil. When using the mixed fertilization scheme, the NAE value increased by 18.98%, the NPFP value increased by up to 2.51%, the NCR value increased by up to 36.96%, and the NRE value increased by up to 39.72%. After adopting the mixed fertilization scheme, the NUE of wheat in arid areas was significantly improved. In wheat cultivation in arid areas, the mixed fertilization scheme could effectively improve crop NUE and reduce NH_3 volatilization nitrogen loss. However, the study did not consider the potential impact of the ratio of traditional urea and CRU in the mixed fertilization scheme. Future research will further analyze the effects of various blending ratios on crop NUE and NH_3 volatilization.

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