Effects of Controlled-release Bulk Blending Fertilizer on Wheat Yield of Different Varieties under Various Soil Basic Fertility

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ABSTRACT
In order to explore a fertilization scheme that can adapt to different soil fertility conditions and wheat varieties, two kinds of controlled-release ureas with different release periods (60 days (CRU-60 d) and 90 days (CRU-90 d)) blending with ordinary urea were applied in different proportions at three different sites to evaluate the impacts of controlled-release bulk blending fertilizer (CRBBF) on soil NO$_3$N, NH$_4$N contents and dynamic change of tillers, SPAD value, grain yield and yield components. The results indicated that applying CRBBF could increase soil NO$_3$N, NH$_4$N contents, tiller numbers, leaf areas, leaf SPAD values and grain yield. Compared with local farmers’ habitual fertilization treatment, CRBBF application presented a higher soil inorganic N content, yield with more spikes and grains per spike. This study has important guiding significance for one-time fertilization of wheat and provides an effective way to alleviate the non-point source pollution caused by excessive fertilization.

Wheat (*Triticum aestivum* L.) is an important subsistence crop in China. Its yield and quality are directly related to China’s food security [1]. Since the 1950s, agricultural production has become heavily dependent on the application of chemical fertilizers [2]. Although fertilization can effectively improve grain yield and quality, excessive fertilization has also caused a series of environmental problems, such as soil acidification, greenhouse gas emissions and water eutrophication [3–5]. On the other hand, with the aging of China’s population and the increasing outflow of rural labor force [6,7], the traditional farming and planting mode have now been difficult to meet the demand for labor force in agricultural production.

Controlled-release fertilizer (CRF) can release the nutrients in the fertilizer slowly, so that the nutrient release is basically synchronized with the nutrient absorption law of the crop, thereby reducing the loss of N and improving the utilization rate of fertilizers [8,9]. The application of CRF is an effective means to solve labor shortages and non-point source pollution of nitrogen (N) and phosphorus [10,11]. However, the CRF cannot release nutrients into the soil in the early stage after being applied to the soil, and the production cost of the CRF is still very high at present. Therefore, the CRFs are usually blended with ordinary fertilizers to make up for the problems of slow nutrient release in the early stage and high cost [12]. One-time application of this controlled-release bulk blending fertilizer (CRBBF) can greatly reduce farmers’ labor and fertilizer input, N loss and environmental pollution while ensuring crop yield. It has been listed as one of the main popularized technologies by the Ministry of Agriculture and Rural Affairs of the People’s Republic of China.

However, there are still many problems in the promotion of CRBBFs. The nutrient release of controlled-release fertilizer will be affected by many external factors, such as temperature, humidity, crop species and soil microbial activity [13–15]. On the other hand, the soil texture and soil fertility are different in different regions [16]. Hence, the types and amounts of fertilizers applied in different regions also need to be adjusted in a targeted manner. Recent research studies also showed that the effect of controlled-release fertilizer on crops was closely related to the soil basic fertility and directly affected crop yield in the current season [17]. It can be seen that clarifying the effects of CRBBF on wheat yield under different soil basic fertilities has important guiding significance for the rational application of fertilizer. Besides, the nutrient use efficiency and nutrient accumulation laws of different crop varieties are also very different.

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Screening a fertilization scheme suitable for multiple wheat varieties is also an effective means to promote the popularization of controlled-release fertilizers.

Therefore, according to the differences in wheat varieties and soil fertility in different regions, it is of great significance to formulate different fertilization schemes, especially the one-time basic application scheme of controlled-release fertilizer. However, so far, the fertilizer efficiency research of controlled-release fertilizer is mostly based on the fixed-point research of a certain place and a certain variety, and there is still a lack of a broad-spectrum fertilization scheme for multiple regions and varieties. To sum up, this study carried out the fertilizer efficiency test of controlled-release fertilizer on two wheat varieties in multiple locations, in order to provide a theoretical basis for the development of a broad-spectrum fertilization strategy.

1. Materials and Methods

1.1 Experimental sites

The experiment was conducted in the rice and wheat industry-integrated innovation center (119° 55’ E, 32 ° 31’ N), Guangling District, Yangzhou City, Jiangsu Province; the Modern Agricultural Industrial Park (120 ° 14’ E, 32 ° 60’ N), Jiangyan District, Taizhou City; and the modern agricultural comprehensive demonstration base (120 ° 31’ E, 32 ° 41’ N), Hai’an County, Nantong city from November 2020 to June 2021 (Figure 1). The soil types and the basic physical and chemical properties of the 0–20 cm soil layer are shown in Table 1.

1.2 Experimental materials and design

The tested wheat varieties were ‘Yangmai 29’ (1000 grain weight 43.7 g) and ‘Nongmai 88’ (1000 grain weight 40.9 g). A total of nine treatments were set in the test, and each treatment was set for three repetitions (Table 2). Wheat was mechanically sown in early November, with a sowing depth of 2–3 cm and a sowing rate of 375 kg hm⁻². Chemical weeding was strictly carried out after sowing. The controlled-release urea used in CRU1-CRU6 treatments was polyurethane-coated urea produced by Moith New Fertilizers Co., Ltd., and the controlled-release periods are 60 days and 90 days, respectively. The ratio of two different controlled-release fertilizers in CRU3 and CRU6 treatment was 1:1. The controlled-release characteristics of the two CRFs in 25°C still water are shown in Figure 2.

Table 1. Types and basic physical and chemical properties of soil.

| Area   | Soil Type | pH | NO₃⁻N (mg kg⁻¹) | NH₄⁺-N (mg kg⁻¹) | Total N (g kg⁻¹) | Available P (mg kg⁻¹) | Available K (mg kg⁻¹) |
|--------|-----------|----|-----------------|------------------|------------------|-----------------------|-----------------------|
| Guangling | Clay     | 6.45 | 17.9            | 10.3             | 1.56             | 43.61                 | 78.74                 |
| Jiangyan | Clay     | 6.70 | 30.4            | 15.1             | 1.96             | 48.65                 | 99.03                 |
| Hai’an  | Sandy loam soil | 6.83 | 33.2            | 18.2             | 2.12             | 55.43                 | 93.87                 |
Fertilizers used in CK2 treatment was ‘Maijianqiang’, a special controlled-release bulk blending fertilizer (CRBBF) for wheat produced by Moith New Fertilizers Co., Ltd. CK1 treatment was the local farmers’ habitual fertilization methods, and the ratio of base fertilizer, regreening fertilizer, jointing fertilizer and ear fertilizer is 5:1:2:2. The control treatment was a blank treatment without N application. The common fertilizers used in the experiment were urea (N 46%), potassium chloride (K₂O 60%), calcium superphosphate (P₂O₅ 12%) and common compound fertilizer (15–15–15). Phosphorus and potassium fertilizers were applied as base fertilizers one time, and all fertilizers were evenly applied in the 0–15 cm topsoil before sowing.

### 1.3 Sample Collection and Determination

#### 1.3.1 Sampling

At the seedling stage, single 1 m row⁻¹ wheat seedlings with uniform growth were signed to monitor their growth status. The tillering numbers and effective panicles were recorded at the overwintering stage, rejuvenation stage, jointing stage, flowering stage and mature stage of wheat. At the same time, 0–20 cm soil samples were collected, then air-dried, ground, passed through a 2 mm and 0.25 mm sieve successively and finally stored in paper bags for the determination of soil NO₃⁻N and NH₄⁺-N concentrations. For the plants at the jointing stage, all the leaves were removed and used for the determination of the leaf area. Plant and grain samples were collected at maturity, dried in a 75°C oven after green removing at 105°C for 30 mins, weighed followed by grinding to pass through a 2 mm sieve and bagged for the determination of the N content in plants and grains.

#### 1.3.2 Sample detection

Soil NO₃⁻N and NH₄⁺-N concentrations were determined using a flow injection analyzer (AA3, Bran-Luebbe, Germany). SPAD values of wheat leaves were measured at the jointing stage and flowering stage using a chlorophyll meter (SPAD-502, Minolta, Japan). The number of grains per year, 1000 grain weight, was measured by conventional counting and balance weighing methods; wheat yield was converted according to the actual yield of 1 m² in the field. The leaf area was tested using a leaf area meter (Li-3100C, Li-COR, America). The plant N concentration was determined by H₂SO₄-H₂O₂ digestion and the micro-Kjeldahl procedure [20].

#### 1.3.3 Calculation of N use efficiency

The N use efficiency was calculated based on the following formula: N use efficiency = (total plant N uptake from N treated plants – total N uptake from plants receiving no N fertilizer)/(total applied fertilizer N in the N treatment × 100).

### 1.4 Data Analysis and mapping

Microsoft Excel 2016 was used for data processing, SigmaPlot 14.0 was used for mapping, and SAS 9.4 software was used for statistical analysis, including
analysis of variance (ANOVA) and Duncan difference significance test, to compare the significance level of $P < 0.05$ between different treatments.

2. Results

2.1 Effects of different fertilization treatments on tillering dynamics of wheat

Different fertilization schemes have a significant impact on the tillering dynamics of wheat (Figure 3). The tillering of wheat at each growth stage is closely related to the intensity of N supply. The tillering dynamics of the two wheat varieties are roughly the same affected by fertilization. In the Control treatment, the tillering numbers reached the highest value at the seedling stage because no N fertilizer was applied during the growth period, and the number of effective tillers decreased gradually with time going on. Compared with Control treatment, the application of N fertilizer can significantly increase the tillering numbers of wheat. The tillering numbers of CK1 treatment were high at the seedling stage and increased slightly at the jointing stage, but decreased gradually after the jointing stage. In contrast, the treatment with controlled-release fertilizer could maintain a high tillering number at the

Figure 3. Tillering dynamics of different fertilization treatments at different test sites. Figure A1, B1 and C1 represent the ‘Yangmai 29’ variety at Guangling, Jiangyan and Hai’an test sites, respectively; and Figure A2, B2 and C2 represent the ‘NongMai 88’ variety at Guangling, Jiangyan and Hai’an test sites, respectively.
jointing stage and flowering stage, and this phenomenon is also reflected in the number of effective panicles in the later stage (Table 2).

### 2.2 Effects of different fertilization treatments on the leaf area

The leaf area (LA) of wheat was greatly affected by fertilization (Table 3). The LAs of CRU3 and CRU5 treatment at the three test sites were significantly higher than those of other treatments. Compared with CK1 treatment, the LA of CRU3 and CRU5 treatment at Guangling, Jiangyan and Hai'an increased by 20.93–35.67%, 26.57–36.25% and 24.11–30.56%, respectively. However, the LAs of CRU4, CRU5 and CRU6 treatment were smaller than that of CK1 treatment, which may be caused by the small application proportion of controlled-release fertilizer and the insufficient nutrient supply at the jointing stage.

### 2.3 Effects of different fertilization treatments on the SPAD value of wheat leaves

The application of N fertilizer had a significant effect on the SPAD value of wheat leaves (Figure 4). On the whole, the SPAD values of wheat leaves at the three test sites showed a similar trend. First, the SPAD value of Control treatment remained at a low level at the jointing stage and flowering stage, compared with the fertilized treatments. Besides, there was no significant difference between the CRBBF treatments and CK1 treatment, except for the CRU3 treatment, whose SPAD value had an increase of 9.5–31.7% in comparison to CK1 treatment.

### 2.4 Effects of different fertilization treatments on soil NO$_3^-$N and NH$_4^+$-N contents

Different fertilization treatments have significant effects on the soil NO$_3^-$ N content (Figure 5). Compared with Control treatment, each fertilization treatment can significantly improve the soil NO$_3^-$ N content at each growth stage. The application of controlled-release fertilizer can significantly improve the soil NO$_3^-$ N content at the jointing stage and flowering stage. Compared with Control treatment, the increase ranges of the jointing stage at Guangling, Jiangyan and Hai’an were 5.75–92.80%, 12.97–66.33% and 27.58–90.06%, respectively. During wheat flowering, the soil NO$_3^-$ N content of CRBBF treatments at Guangling, Jiangyan and Hai’an test sites increased by 11.06–81.88%, 24.61–69.28% and 22.42–98.60%, respectively, compared with Control treatment.

The effect of different fertilization treatments on the soil NH$_4^+$-N content is basically the same as that of NO$_3^-$ N (Figure 6).

Compared with Control treatment, the content of NH$_4^+$-N in each fertilizer treatment increased significantly. At the jointing stage, the increase ranges of Guangling, Jiangyan and Hai’an were 25.09–93.83%, 27.75–73.41% and 1.36–48.37%, respectively. During wheat flowering, the soil NH$_4^+$-N content of CRBBF treatments at Guangling, Jiangyan and Hai’an test sites increased by 15.56–90.05%, 9.57–84.84% and 6.06–72.87%, respectively, compared with Control treatment.

### 2.5 Effects of different fertilization treatments on wheat yield and yield components

The treatments with the highest yield of the ‘Yangmai 29’ variety at the Guangling test site were CK2, CRU3, CRU5 and CRU6 (Table 4), whose yield increased by 22.09%, 23.27%, 28.42% and 25.91%, respectively, compared with CK1 treatment; the treatment with the highest yield of the ‘NongMai 88’ variety was CRU3, whose yield increased by 30.55% compared with CK1 treatment. The treatments with the highest yield of ‘Yangmai 29’ at the Jiangyan experimental site were CK2, CRU2 and CRU3, whose yield increased by 6.43%, −2.07% and 2.59%, respectively, compared with CK1 treatment; the treatment with the highest yield of the ‘NongMai 88’ variety was CRU3, whose yield increased by 17.65% compared with CK1 treatment. The treatments with the highest yield of the

| Treatment | Yangmai 29 (Guangling) | Nongmai 88 (Guangling) | Yangmai 29 (Jiangyan) | Nongmai 88 (Jiangyan) | Yangmai 29 (Hai'an) | Nongmai 88 (Hai'an) |
|-----------|------------------------|------------------------|-----------------------|-----------------------|---------------------|---------------------|
| CK1       | 1110.3 c               | 919.9 c                | 1125.3 b              | 935.6 b               | 1123.4 b            | 935.8 b             |
| CK2       | 895.1 d                | 897.0 c                | 966.0 b               | 964.6 b               | 967.1 cd            | 968.8 b             |
| CRU1      | 968.8 d                | 1188.0 ab              | 989.7 b               | 1217.6 a              | 915.2 d             | 1119.9 a            |
| CRU2      | 1506.3 a               | 1214.1 a               | 1533.3 a              | 1233.1 a              | 1442.0 a            | 1161.4 a            |
| CRU3      | 1377.9 b               | 1112.4 b               | 1472.1 a              | 1184.2 a              | 1417.7 a            | 1221.8 a            |
| CRU4      | 925.1 de               | 836.0 c                | 875.7 c               | 898.3 cd              | 878.7 d             | 900.6 b             |
| CRU5      | 816.1 e                | 731.2 d                | 994.3 bc              | 788.4 d               | 929.6 d             | 734.5 c             |
| CRU6      | 1193.9 c               | 1139.7 ab              | 1149.7 b              | 1096.9 ab             | 1188.3 b            | 1139.3 a            |
| Control   | 452.0 f                | 384.5 e                | 615.3 d               | 551.9 e               | 815.3 d             | 751.8 c             |

Notes: Means followed by the similar lowercase letters within the same column of each item were not significant in difference at the 5% level.
The application of controlled-release fertilizers significantly affected the N use efficiency in the current season (Table 5). Overall, the N use efficiency of CRBBF treatments was not significantly different or significantly higher than that of CK1 treatment. Among all CRBBF treatments, CRU3 treatment had relatively high N use efficiency in the three test sites. Compared with CK1 treatment, the N use efficiency of CRU3 treatment had a significant increase of 18.8–
39.8%, 27.6–35.9% and 17.4–21.4% at Guangling, Jiangyan and Hai’an test sites, respectively. This shows that CRU3 treatment can provide sufficient nutrients for crop growth under different soil fertility conditions.

3. Discussion

Premature and excessive fertilization will rapidly expand the soil N pool and then lead to the loss of soil N through leaching and volatilization [21]. The lost nutrients will not only cause the waste of fertilizer resources but also cause a series of problems such as the decline of soil quality and non-point source pollution [22,23]. We reduced the contact area and time between fertilizer and soil by coating to make the N in fertilizers release slowly, so that more N can be used by plants and less part would be lost. Besides, the demand for N of the crop in each growth period is different [24]. In our experiment, the normal urea in the combining treatments was aimed to supply N required earlier in the growing season, while the CRU would delay N release until later in the growing season, so as to meet the N demand of wheat in each period.

Soil inorganic N (mainly including NO$_3^-$-N and NH$_4^+$-N) is the N that plants can absorb directly from soil, which is an important index to reflect the soil N supply capacity. During the crop growing season, the soil inorganic N of most treatments decreased in different degrees (Figures 4 and 5).

**Figure 5.** Soil NO$_3^-$-N content of different fertilization treatments at different test sites. Figures A1, B1 and C1 represent the ‘Yangmai 29’ variety at Guangling, Jiangyan and Hai’an test sites, respectively; and Figures A2, B2 and C2 represent the ‘NongMai 88’ variety at Guangling, Jiangyan and Hai’an test sites, respectively.
However, the treatments with CRBBF decreased more slowly and even showed an increasing trend. This illustrated that the treatments with CRBBF can ensure the soil N supply and promote the growth of wheat at all growth stages. Recent research studies also showed that combining slow release fertilizers and normal fertilizers can better match the crop uptake curve [25,26]. N supply intensity is the key factor for rice to maintain effective tillering [27]. In our experiment, the treatment with CRBBF could ensure higher effective tillers in the early stage and maintain higher effective panicles at the panicle stage. The SPAD value of leaves is an effective parameter reflecting the chlorophyll content and photosynthetic intensity of wheat leaves, which is significantly correlated with the nitrogen supply level [28]. In this experiment, the treatment with CRBBF maintained a high SPAD value at the jointing stage and flowering stage, which also showed that the application of CRBBF could improve the N supply intensity of soil.

Besides, through analyzing the yield components, we found that the TGW was not significantly different among treatments, while the spikes and grains per spike were quite different. This indicated that maintaining a high effective tiller number and nutrient supply had a key influence on the formation of panicle and yield in the later stage [29].

The climate and soil fertility conditions in different regions, especially in different cultivation areas, are not exactly the same. A single fertilization type or method is difficult to meet the nutrient demands of crops in multiple areas. Therefore, this experiment designed
Table 4. Wheat yield and yield components of each treatment.

| Test site | Treatment | Grain yields (kg·hm⁻²) | Spikes (m⁻²·row⁻¹) | Grains per spike | TGW (g) |
|-----------|-----------|------------------------|---------------------|------------------|---------|
| Guangling | CK1       | 4575.0 d               | 101.3 cd            | 33.2 bc          | 40.5 ab  |
|           | CK2       | 5585.5 ab              | 104.3 cd            | 27.8 c           | 39.3 b   |
|           | CRU1      | 5398.0 bc              | 138.8 ab            | 34.4 ab          | 38.9 b   |
|           | CRU2      | 5152.1 c               | 135.1 ab            | 39.2 cd          | 38.7 b   |
|           | CRU3      | 5639.6 ab              | -                   | 36.8 a           | 40.2 ab  |
|           | CRU4      | 4629.2 d               | 119.5 bc            | 29.6 d           | 42.3 a   |
|           | CRU5      | 5875.0 a               | 144.5 a             | 33.8 ab          | 39.2 b   |
|           | CRU6      | 5760.5 ab              | 145.3 a             | 30.2 cd          | 39.3 b   |
| Jiangyan  | CK1       | 6373.1 ab              | 94.0 d              | 31.6 d           | 40.4 bc  |
|           | CK2       | 6782.7 a               | 110.8 cd            | 35.8 b           | 39.9 bc  |
|           | CRU1      | 6048.0 bc              | 146.8 ab            | 37.2 ab          | 39.7 c   |
|           | CRU2      | 6241.3 ab              | 147.8 ab            | 38.0 a           | 41.4 a   |
|           | CRU3      | 6538.3 ab              | 135.3 abc           | 36.8 ab          | 40.5 b   |
|           | CRU4      | 5924.7 bc              | 158.3 a             | 36.6 ab          | 40.3 bc  |
|           | CRU5      | 4796.3 d               | 119.5 bcd           | 37.6 a           | 41.3 a   |
|           | CRU6      | 5558.5 c               | 121.5 bcd           | 31.2 d           | 41.3 a   |
| Hai'an    | CK1       | 5640.6 cd              | 98.5 d              | 33.8 c           | 40.3 bc  |
|           | CK2       | 5180.2 d               | 110.0 cd            | 34.0 b           | 40.7 ab  |
|           | CRU1      | 5301.3 d               | 146.8 a             | 37.2 a           | 40.2 b   |
|           | CRU2      | 5970.0 bc              | 142.5 a             | 34.8 ab          | 41.0 ab  |
|           | CRU3      | 6636.3 a               | 136.0 ab            | 32.0 c           | 40.5 ab  |
|           | CRU4      | 6320.0 ab              | 149.8 a             | 35.6 ab          | 40.3 b   |
|           | CRU5      | 5259.0 d               | 122.0 bc            | 32.0 c           | 41.3 a   |
|           | CRU6      | 5431.8 d               | 132.3 ab            | 34.8 abc         | 41.3 a   |
| Control   | -         | -                      | -                   | -                | -       |

Table 5. N use efficiency of different treatments.

| Treatment | Yangmai 29 | Nongmai 88 | Yangmai 29 | Nongmai 88 | Yangmai 29 | Nongmai 88 |
|-----------|------------|------------|------------|------------|------------|------------|
|           |            |            |            |            |            |            |
| Guangling |            |            |            |            |            |            |
|           | CK1        | 28.4 b     | 28.7 c     | 30.4 b     | 25.6 b     | 29.3 b     | 32.3 ab    |
|           | CK2        | 30.1 b     | 31.9 b     | 33.0 b     | 24.1 b     | 27.8 bc    | 29.8 b     |
|           | CRU1       | 27.6 b     | 28.4 c     | 33.5 b     | 25.5 b     | 23.8 c     | 35.7 ab    |
|           | CRU2       | 28.4 b     | 38.1 a     | 37.4 a     | 28.1 b     | 29.5 b     | 29.7 b     |
|           | CRU3       | 39.7 a     | 34.1 ab    | 38.8 a     | 34.8 a     | 34.4 a     | 39.2 a     |
|           | CRU4       | 22.4 c     | 21.1 d     | 27.1 c     | 26.4 b     | 24.0 bc    | 26.8 c     |
|           | CRU5       | 36.5 c     | 27.3 c     | 25.6 c     | 18.6 c     | 25.5 b     | 20.7 d     |
|           | CRU6       | 36.0 a     | 33.3 ab    | 30.7 bc    | 26.3 b     | 34.2 a     | 34.8 ab    |
| Control   | -          | -          | -          | -          | -          | -          |

Notes: Means followed by the similar lowercase letters within the same column of each item were not significant in difference at the 5% level.

the combined application of controlled-release fertilizer with different controlled-release periods to improve the adaptability of this fertilization scheme in different regions. The results from three test sites showed that the best effect was achieved when the controlled-release urea with controlled-release periods of 60 days and 90 days was blended with ordinary urea at a ratio of 3:3:4. Compared with the farmers’ habitual fertilization, the stable yield can be maintained under the condition of reducing three times of topdressing operations, which greatly reduces the labor input of farmers. Besides, compared with Jiangyan and Hai'an test sites, the soil basic fertility in the Guangling test site was lower, so fertilization brought a better yield increasing effect. At the same time, the N use efficiency in the current season is also higher than that in other two test sites. In general, the application of CRBBFs has a good yield-increasing effect at the three experimental sites. This shows that the fertilization scheme designed in this experiment can be applied under different soil fertility conditions.

4. Conclusions

The results showed that one-time application of controlled-release bulk blending urea could significantly improve the content of soil available N and effective tillering of wheat and crop yield. The increase of crop yield mainly resulted in the increase of spikes and grains per panicle. In addition, the one-time application of CRBBF also increased the SPAD value of wheat leaves and improved their photosynthetic efficiency potential. The results of three test sites showed that CRU3 treatment had a good yield increasing effect on both ‘Yangmai 29’ and ‘Nongmai 88’ varieties. Therefore, this test scheme can be applied to different
soil fertility conditions and wheat varieties. The results of this experiment have important guiding significance for the one-time application of CRBBF in wheat production and provide ideas for the development of resource-saving and environment-friendly agriculture.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

This research was funded by the Natural Science Foundation of Jiangsu Province (Grant No. SBK2022043341), Jiangsu Modern Agricultural Machinery Equipment and Technology Demonstration and Promotion Project (NJ2020-58, NJ2021-63) and Starting Fund for Postdoctoral Research of Yangzhou University (137070649).

References

[1] Zhao GQ, Mu Y, Wang YH, et al. Response of winter-wheat grain yield and water-use efficiency to irrigation with activated water on Guanzhong Plain in China. Irrig Sci. 2021;39(2):1–14.

[2] Hu YC, Su MR, Wang YF, et al. Food production in China requires intensified measures to be consistent with national and provincial environmental boundaries. Nat Food. 2020;1(9):572–582.

[3] Dubos B, Snoeck D, Flori A. Excessive use of fertilizer can increase leaching processes and modify soil reserves in two Ecuadorian oil palm plantations. Exp Agric. 2016;53(2):255–268.

[4] Xu XP, He P, Wei JL, et al. Use of controlled-release urea to improve yield, nitrogen utilization, and economic return and reduce nitrogen loss in wheat-maize crop rotations. Agronomy-Basel. 2021;11(4):723.

[5] Ahmed M, Rauf M, Mukhtar Z, et al. Excessive use of nitrogenous fertilizers: an unawareness causing serious threats to environment and human health. Environ Sci Pollut Res. 2017;24(35):26983–26987.

[6] Liu J, Zhang C, Hu RF, et al. Aging of agricultural labor force and technical efficiency in tea production: evidence from Meitan County, China. Sustainability. 2019;11(22):6246.

[7] Mok KH, Wu AM. Higher education, changing labour market and social mobility in the era of massification in China. J Educ Work. 2016;62(9):77–97.

[8] Geng JB, Ma Q, Zhang M, et al. Synchronized relationships between nitrogen release of controlled release nitrogen fertilizers and nitrogen requirements of cotton. Field Crop Res. 2015;184:9–16.

[9] Lawrenzca D, Wong SK, Low DYS, et al. Controlled release fertilizers: a review on coating materials and mechanism of release. Plants-Basel. 2021;10(2):238.

[10] Incrocci L, Maggini R, Cei T, et al. Innovative Controlled-Release Polyurethane-Coated Urea Could Reduce N Leaching in Tomato Crop in Comparison to Conventional and Stabilized Fertilizers. Agronomy-Basel. 2020;10(11):1827.

[11] Xu D, Zhu Y, Zhu HB, et al. Effects of a One-Time Application of Controlled-Release Nitrogen Fertilizer on Yield and Nitrogen Accumulation and Utilization of Late Japonica Rice in China. Agriculture-Basel. 2021;11(11):1041.

[12] Fan Z, Chen JX, Zhai S, et al. Optimal blends of controlled-release urea and conventional urea improved nitrogen use efficiency in wheat and maize with reduced nitrogen application. J Soil Sci Plant Nutr. 2021;21(2):1103–1111.

[13] Du CW, Zhou JM, Shaviv A. Release Characteristics of Nutrients from Polymer-coated Compound Controlled Release Fertilizers. J Polym Environ. 2006;14(3):223–230.

[14] Christianson CB. Factors affecting N release of urea from reactive layer coated urea. Ferti Res. 1988;16(3):273–284.

[15] Carson LC, Ozoresh-Hampton M. Factors Affecting Nutrient Availability, Placement, Rate, and Application Timing of Controlled-release Fertilizers for Florida Vegetable Production Using Seepage Irrigation. HortTechnology. 2013;23(5):553–562.

[16] Zheng WK, Zhang M, Liu ZG, et al. Combining controlled-release urea and normal urea to improve the nitrogen use efficiency and yield under wheat-maize double cropping system. Field Crop Res. 2016;197:52–62.

[17] Chatzistathis T, Papaioannou E, Giannakoula A, et al. Zeolite and Vermiculite as Inorganic Soil Amendments Modify Shoot-Root Allocation, Mineral Nutrition, Photosystem II Activity and Gas Exchange Parameters of Chestnut (Castanea sativa Mill) Plants. Agronomy-Basel. 2021;11(1):109.

[18] Arduini I, Masoni A, Ercoli L, et al. Grain yield, and dry matter and nitrogen accumulation and remobilization in durum wheat as affected by variety and seeding rate. Eur J Agron. 2006;25(4):309–318.

[19] Zhang Y, Chen XP, Ma W, et al. Elucidating variations in nitrogen requirement according to yield, variety and cropping system for Chinese rice production. Pedosphere. 2017;27(2):358–363.

[20] Douglas LA, Riaz A, Smith CJ. A semi-micro method for determining total nitrogen in soils and plant material containing nitrite and nitrate. Soil Sci Soc Am J. 1980;44(2):431–433.

[21] Lu H, Tian HY, Zhang M, et al. Water Polishing improved controlled-release characteristics and fertililizer efficiency of castor oil-based polyurethane coated diammonium phosphate. Sci Rep. 2020;10(1):1–10.

[22] T JX, Kou CL, Christie P, et al. Changes in the soil environment from excessive application of fertilizers and manures to two contrasting intensive cropping systems on the North China Plain. Environ Pollut. 2007;145(2):497–506.

[23] Tian YQ, Wang Q, Zhang WH, et al. Reducing environmental risk of excessively fertilized soils and improving cucumber growth by Caragana microphylla-straw compost application in long-term continuous cropping systems. Sci Total Environ. 2016;544:251–261.

[24] Muschiatti-Piana P, McBeath TM, McNeill AM, et al. Combined nitrogen input from legume residues and fertilizer improves early nitrogen supply and uptake by wheat. J Plant Nutr Soil Sci. 2020;183(3):355–366.

[25] Geng JB, Sun YB, Zhang M, et al. Long-term effects of controlled release urea application on crop yields and soil fertility under rice-oilseed rape rotation system. Field Crop Res. 2015;184:65–73.
[26] Li ZL, Zhang WT, Qiu LX, et al. Physiological-biochemical responses of wheat to blending controlled-release potassium chloride and soluble potassium chloride. Soil Tillage Res. 2021;212:105058.

[27] Zhang L, He XM, Liang ZY, et al. Tiller development affected by nitrogen fertilization in a high-yielding wheat production system. Crop Sci. 2020;60 (2):1034–1047.

[28] Debaeke P, Rouet P, Justes E. Relationship between the normalized SPAD index and the nitrogen nutrition index: application to durum wheat. J Plant Nutr. 2006;29(1):75–92.

[29] Yang DS, Peng SB, Zheng C, et al. Effects of nitrogen fertilization for bud initiation and tiller growth on yield and quality of rice ratoon crop in central China. Field Crop Res. 2021;272:108286.