Effects of nitrogen application rate and topdressing times on yield and quality of Chinese cabbage and soil nitrogen dynamics
Zhao-ming Qu,*, Xing-chao Qi,†, Jing Wang, Qi Chen and Cheng-liang Li

ABSTRACT
A good understanding of the relationship between vegetable quality and soil N balance is very important for proper nitrogen (N) management for crop productions. In this study, a field experiment was carried out to investigate the N application rate and times on Chinese cabbage yield and quality, N use efficiency, soil nitrate-N concentration, and soil pH. The experiment was implemented in a two-way factorial design and the two factors comprises of number of N applications (once, twice and three times, denoted as T1, T2 and T3) and N rates (15%, 30% and 45% less than conventional rates (CF), denoted as F1, F2 and F3, respectively). The treatments were also compared with a no-fertilizer blank and a control (CF) with a conventional N management practice. The results showed that the highest yield of cabbage (164.65 t hm−2), Vitamine C content (14.80 g 100 g−2 fresh mass), soluble sugar content (2.33 mg kg−1), plant N uptake (119.2 kg hm−2) were obtained under T3F1 treatment. Compared with CF treatment, T3F1 treatment significantly increased vegetable yield, vitamin C and soluble sugar content in fruit, and nitrogen use efficiency by 10.97%, 13.76% and 17.68%, and 18.76%, respectively. Nitrate-N content in cabbage was reduced by 7.55% in T3F1 treatment. With the reduced N application rate, soil pH gradually changed from 6.25 to 7.26. T3F1 treatment is a most suitable N management practice for vegetable production, in terms of higher vegetable yield and quality, soil N content, depressed soil acidification and nutrient uptake by Chinese cabbage.

Chinese cabbage (Brassica campestris spp. pekinensis) is one of the important winter vegetables in China, even in East Asia, due to high yield and rich nutrition [1,2]. In China, vegetable production plays an important role in the supply of vegetable market and people’s daily life [3]. Excessive chemical fertilizers are applied to assure a high yield. However, too much fertilizers could cause decline of Chinese cabbage yield and quality, low nitrogen use efficiency (NUE), soil degradation [4] and increase accumulation of heavy metal in soil [5], and result in water pollution by soil nitrate leaching and runoff losses [6–8]. Therefore, the suitable fertilization management of Chinese cabbage is urgent in the production.

Many studies showed that residual levels of nitrate in soil increased sharply when N application rates exceed the crop requirements. Besides, excessive N application rates above the ‘saturation point’ could reduce NUE and even decrease crop yield [9]. However, inadequate N supply would inevitably compromise crop yield. Thus, the effective N fertilizer management was comprehensively studied [10], in order to maintain an appropriate supply N fertilizer. It was found that proper application of urea was one of the most important management methods.

Urea is the most common source of N fertilizer for farmers [11]. Low-cost, high N content and rapid N release make urea a frequently-used base N fertilizer for Chinese cabbage production [12]. However, N release from urea is relatively rapid, and soluble N is susceptible to loss, which would therefore cause plant N deficiency in long term. For this sake, multiple N applications are recommended to meet the N demand of Chinese cabbage, especially at later growth stages when more N is required for plant growth. By contrast, there is less N requirement in early growth stage of cabbage [13]. Base application of excessive urea may thus lead to N accumulation, which may not only increase leaching downward in the soil profile, but result in soil consolidation and salinization, soil aggregates reduction [14–16]. Therefore, a better management strategy is needed for employing conventional urea in crop production systems.

Seeking a rational protocol of urea application is of great significance for promoting the sustainable development of agriculture. Previous studies showed that compared with base application of urea, urea topdressing could increase NUE and thus crop yields [17,18]. The hypothesis of this study was that urea topdressing with appropriate application rates and times will improve the yield and quality of Chinese

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cabbage and reduce N loss, compared to basal urea application. In this study, a two-factor and three-level orthogonal fertilization scheme was designed for Chinese cabbage cultivation. The two factors were N application rate and topdressing times. The objectives of this research were to investigate the influence of N application rate, topdressing times on Chinese cabbage growth, NUE, soil pH and soil nitrate content under green chamber.

1. Materials and methods

1.1. Experimental sites and materials

The study was carried out from September to November, 2017 in Tai’an, Shandong, China. The average annual rainfall was 702 mm and air temperature was 13°C. Physicochemical properties of experimental soil were analyzed following standard soil testing methods [19]: pH 7.38 (soil to water ratio of 1:2.5), total N content in soil 0.81 g kg⁻¹, soil nitrate concentration 35.36 mg kg⁻¹, ammonium concentration 6.33 mg kg⁻¹, available phosphorus content 60.58 mg kg⁻¹, and available potassium content 103.37 mg kg⁻¹.

The tested fertilizers included in conventional urea (N 46%), triple superphosphate (P₂O₅ 46%) and potassium sulfate (K₂O 50%), which were purchased from commercial stores. All of fertilizers were freely produced by Kingenta Ecological Engineering Group Co.

1.2. Experimental design

The experiment was implemented in a two-way factorial design and the two factors include number of N applications (once, twice and three times, denoted as T1, T2 and T3) and N doses (15%, 30% and 45% less than conventional rates (CF), denoted as F1, F2 and F3, respectively). The treatments were also compared with a control (CF) and a no-fertilizer blank. In CF treatment, urea was applied as basal N fertilizer at rate of 170 kg hm⁻² (N). In other fertilizer treatments, 50% of total urea was applied as basal fertilizer, and the remaining 50% were then split into one, two and three times. The phosphorus and potassium fertilizer was used as base fertilizer at rate of 75 kg hm⁻² (P₂O₅) and 98 kg hm⁻² (K₂O) respectively. Each treatment was repeated 4 times and randomly arranged in 44 plots, each plot 4.76 m². The treatments were arranged in an orthogonal experimental design.

Thus, the experiment included eleven fertilizer treatments, including: CK (no N fertilizer), CF (with only basal N application at 170 kg hm⁻²), T1F1 (urea was applied at one time, and the N application rate was reduced by 15% than CF), T1F2 (once topdressing and reduced urea by 30%), T1F3 (once topdressing and reduced urea by 45%), T2F1 (twice topdressing and reduced urea by 15%), T2F2 (twice topdressing and reduced urea by 30%), T2F3 (twice topdressing and reduced urea by 45%), T3F1 (three times topdressing and reduced urea by 15%), T3F2 (three times topdressing and reduced urea by 30%), T3F3 (three times topdressing and reduced urea by 15%).

Chinese cabbage was seeded on 1 September 2017, and harvested on 24 November 2017. The large and small row spacing were 80 cm and 60 cm, respectively, and seeds in each row were planted 40 cm wide. The cultivating density was 84,033 plant hm⁻². The irrigation was implemented as per local farmers’ traditional irrigation methods. The water was irrigated between narrow rows for four times in the whole growth season. At the time of seeding on 1st Sep., the base fertilizer was applied and watered, and other fertilizer application were carried out for equivalently topdressing at 21th Sep., 5th Oct. and 25th Oct. prior to the irrigation. The disease control practices were implemented according to traditional methods of local farmers.

1.3. Sampling and measurement

After harvesting, three soil samples in each plot were randomly collected to a depth of 100 cm and sectioned in an interval of 20 cm. The three soil samples in each plot were homogenized, and stored in the sealed plastic bag and brought back to the laboratory.

The soil moisture content was determined by drying method and soil mineral N (NH₄⁺-N and NO₃⁻-N), extraction with 0.01 mol L⁻¹ CaCl₂ concentration were determined on an AA3-A001-02E Auto-analyzer (Bran-Luebbe, Germany) within 24 hours after collecting. The other remaining soil samples were air dried, ground and sieved through a 2 mm sieve.

Chinese cabbage was harvested and measuring total yield of the plot, unit area was calculated. In the harvest, three plot Chinese cabbage samples taken. After the ending on 24 November 2017, 2 normal plants were randomly taken, separated and washed with water. The samples were then oven-dried for 30 min at 105°C to kill enzyme, then dried to constant weight at 85°C, followed by recording dry weights. A small mill was used to crush the dry plants and the powder was used for determination total N content.

Vitamin C (Vc) content, nitrate concentration, sugar concentration in Chinese cabbage were measured after mixed samples was homogeneously smashed with a juice machine. Vc content was determined using the spectrophotometer method at the wavelength of 230 nm, nitrate concentration was determined using the spectrophotometer method at the wavelength of 260 nm. Soluble sugar concentration was measured by abbe refractometer, dripped tomato pulp onto the instrument to determination [20]. Total N contents in the cabbage plants were measured by digesting samples with concentrated H₂SO₄ and H₂O₂ and measuring N using distillation method [21].
1.4. Statistical analyses

The nitrogen use efficiency (NUE) (%) = (accumulation N uptake with N treatment - accumulation amount without N treatment)/N application amount × 100%

Statistical analyses using standard analyses of variance (ANOVAs) and Duncan tests (P < 0.05) were conducted using SAS software (SAS 2010, SAS Institute, Cary, NC, USA). Data were processed with Microsoft Excel 2016, figures were drawn out using Excel 2016 software.

2. Results and discussion

2.1. Effects of different treatments on nitrate distribution and pH in soil profile

Fertilization increased NO$_3$-N concentrations in the soil during the cabbage harvest stage, and different fertilization treatments had significantly affected the NO$_3$-N residue in the soil (Table 1). NO$_3$-N content in the 0–100 cm soil profile of post-harvest soil was significantly affected by N application rate, topdressing times and their interaction. Contents of soil NO$_3$-N in the 0–100 cm soil profile increased with increase in N application rate (Table 1). Under the same nitrogen application rate, with the increased of topdressing times, the content of NO$_3$-N in 0–20 cm soil layer increased gradually, and the content of NO$_3$-N in 20–100 cm soil layer decreased gradually. Especially in T3F1 treatment, the content of NO$_3$-N in 0–20 cm soil layer was 46.19%, 21.24% and 56.39% higher than that in T1F1, T2F1 and CF treatments, respectively. The content of NO$_3$-N in 20–100 cm soil layer was 32.07%, 23.16% and 44.04% lower than that of T1F1, T2F1, and CF, respectively. The results showed that topdressing significantly reduced the leaching of NO$_3$-N to deep soil, and residual NO$_3$-N in deep soil was more reduced with more topdressing times. Besides, reduced urea rate decreased downward leaching of urea to underlying soil, and thereby significantly decreased the NO$_3$-N concentrations. Chinese cabbage was a shallow root crop, the lower urea application rate decreased soil N content in the early growing of Chinese cabbage, however, multiple urea applications could provide adequate N supply for plant growth [22]. Topdressing also improved the absorption of N to plants, reduced the leaching of N to the deep soil caused by irrigation, and slowed down the pollution of soil and groundwater by N application [23,24].

The effect of urea application on soil pH was significant (Figure 1). The pH values in CK treatment ranges between 6.25–7.30. Under the same N application rate, soil pH increased gradually by 0.15–0.31 units with the increased of topdressing times. With the same topdressing times, soil pH decreased gradually by 0.12–0.23 units with the increase of nitrogen application rate. The possible reason was that urea in the soil was hydrolyzed to NH$_4$$^+$. Under aerobic conditions, the NH$_4$$^+$ was nitrified into NO$_3$-, in which formation of one mol NO$_3$- was accompanied by the release of two mol H$^+$ (NH$_4$$^+$ + 3/2 O$_2$ = NO$_3$- + 2H$^+$ + H$_2$O). This resulted in soil acidification, reduced N absorption and NUE of Chinese cabbage, which affected the normal growth of Chinese cabbage [25].

| Table 1. Soil NO$_3$-N contents with different treatments. |
|-----------------------------------------------------------|
| **Treatment** | **NO$_3$-N concentration in 0–100 cm soil profile (mg kg$^{-1}$)** |
|                | 0–20 cm | 20–40 cm | 40–60 cm | 60–80 cm | 80–100 cm |
| F × T          |         |          |          |          |          |
| CK             | 14.54g  | 7.33i    | 5.59i    | 4.42h    | 3.71h    |
| CF             | 25.66de | 21.63b   | 20.00a   | 19.20a   | 18.28a   |
| T1F1           | 27.45d  | 22.45a   | 16.99b   | 14.37b   | 12.11b   |
| T1F2           | 25.03e  | 17.60d   | 14.76c   | 12.01c   | 10.84d   |
| T1F3           | 23.20f  | 15.51e   | 12.46e   | 10.62e   | 7.10g    |
| T2F1           | 33.10b  | 20.22c   | 14.49c   | 12.11c   | 11.57c   |
| T2F2           | 29.68c  | 15.44e   | 10.30g   | 8.07f    | 8.58f    |
| T2F3           | 25.81de | 12.40h   | 9.29g    | 8.47g    | 7.40g    |
| T3F1           | 40.13a  | 17.51d   | 13.48d   | 11.20d   | 9.62e    |
| T3F2           | 31.90b  | 13.46f   | 11.29f   | 9.32f    | 7.07g    |
| T3F3           | 27.14d  | 12.89g   | 10.37g   | 8.63g    | 7.42g    |
| Nitrogen application rate |          |          |          |          |          |
| **F1**         | 33.56a  | 20.06a   | 14.98a   | 12.56a   | 11.10a   |
| **F2**         | 28.87b  | 15.50b   | 12.12b   | 10.33b   | 8.83b    |
| **F3**         | 25.38c  | 13.60c   | 10.70c   | 9.24c    | 7.30c    |
| Topdressing times |         |          |          |          |          |
| **T1**         | 25.23c  | 18.52a   | 14.74a   | 12.33a   | 10.01a   |
| **T2**         | 29.53b  | 16.02b   | 11.36c   | 10.08b   | 9.18b    |
| **T3**         | 33.06a  | 14.62c   | 11.71b   | 9.71c    | 8.03c    |
| Source of variance |        |          |          |          |          |
| **F**          | <0.0001 | <0.0001  | <0.0001  | <0.0001  | <0.0001  |
| **T**          | <0.0001 | <0.0001  | <0.0001  | <0.0001  | <0.0001  |
| **F × T**      | <0.0001 | <0.0001  | <0.0001  | <0.0001  | <0.0001  |

Note: Means followed by the similar lowercase letters within same column of each item were not significant in difference at 5% level, and the $P < 0.01$ indicated the very significant level of 1%, 'i' - no valid value.
2.2. Effects of different treatments on NUE of Chinese cabbage

The dry matter of Chinese cabbage was the basis of yield formation. The dry matter, N accumulation and NUE of Chinese cabbage under different treatments were determined (Table 2). Under the same of topdressing times, NUE increased with the decrease of N application rate. The NUE in F3 treatments was the highest (51.98%), which significantly increased by 7.27%-14.62% and 2.38%-11.37% compared with F1 and F2 treatments, respectively. With the equal N rate, NUE increased with the increase of number of topdressing events. The highest NUE was observed in T3 treatments with averaged NUE as 53.82%, which was 12.66%-21.65% and 5.46%-12.97% significantly greater than compared with T1 and T2 treatments, respectively. The NUE in topdressing treatments increased by 4.46–33.38% compared with CF treatment. Statistical results showed that N application rate, topdressing times, topdressing times × N application rate interaction pronouncedly influenced dry weight and N accumulation of Chinese cabbage. Each factor’s contribution to the total variation was ranked as: topdressing times > N application rate > their interaction.

Previous studies found that NUE was pronouncedly affected by fertilizer application rate, which decreased

| Treatment | Dry weight (kg hm⁻²) | N accumulation (kg hm⁻²) | Nitrogen application rate (kg hm⁻²) | Nitrogen use efficiency (%) |
|-----------|---------------------|-------------------------|-----------------------------------|-----------------------------|
| CK        | 5824.48g            | 45.56g                  | 0                                 | -                           |
| CF        | 6973.87ef           | 96.80d                  | 170                               | 30.14                       |
| T1F1      | 7022.23ef           | 95.57de                 | 144.5                             | 34.60                       |
| T1F2      | 7012.12ef           | 92.55e                  | 119                               | 39.49                       |
| T1F3      | 6955.84f            | 84.71f                  | 93.5                              | 41.87                       |
| T2F1      | 7643.41b            | 107.40c                 | 144.5                             | 42.79                       |
| T2F2      | 7430.97c            | 101.13c                 | 119                               | 46.69                       |
| T2F3      | 7119.14e            | 92.82e                  | 93.5                              | 50.55                       |
| T3F1      | 7881.47a            | 116.22 a                | 144.5                             | 48.90                       |
| T3F2      | 7530.99bc           | 107.63b                 | 119                               | 52.15                       |
| T3F3      | 7275.07d            | 104.95b                 | 93.5                              | 63.52                       |

Nitrogen application rate

| F          | T1F1 | T1F2 | T1F3 | T2F1 | T2F2 | T2F3 | T3F1 | T3F2 | T3F3 |
|------------|------|------|------|------|------|------|------|------|------|
| F1         | 7515.71a | 106.40a | -    | -    | 42.10 |
| F2         | 7324.69b | 100.43b | -    | -    | 46.13 |
| F3         | 7116.68c | 94.16c  | -    | -    | 51.98 |

Topdressing times

| T1        | T2     | T3     |
|-----------|--------|--------|
| 6996.73c  | 7397.84b | 7562.51a |
| 90.94c    | 100.45b | 109.60a |
| Source of variance |
| F         | <0.0001 | <0.0001 |
| T         | <0.0001 | <0.0001 |
| F × T     | <0.0001 | 0.0030  |

Note: Means followed by the similar lowercase letters within same column of each item were not significant in difference at 5% level, and the P < 0.01 indicated the very significant level of 1%, - no valid value.
with increasing rate of applied N fertilizer [26–28]. In the present study, the same tendency was found that there was also a negative relationship between NUE and N application rate (Table 2). NUE in CF treatment was lower than in F1 treatment because the higher N application rate in CF treatment released more N into deep soil, which led to higher N losses than from F1 treatment. Similarly, NUE increased with increase topdressing times, three times topdressing prolonged the period of N supply, promoted the uptake of N by plants, and reduced N release into deep soil. Our observation was consistent with the result of Ghaley [29].

### 2.3. Effects of different treatments on Chinese Cabbage yield

Chinese cabbage has a great demand for N, which promoted the growth of leaf bulbs and increased Chinese cabbage yield (Table 3). Statistical results showed that N application rate, topdressing times, topdressing times × N application rate interaction significantly influenced Chinese cabbage yield. Regarding yield, the contribution of each factor to the total variation of was ranked in the following order: N application rate > topdressing times > their interaction. Compared with CK treatments, the yield in other fertilization treatments were significantly increased by 17.65%-31.72%. With 15% urea reduction, the yield in T1F1, T2F1 and T3F1 treatments increased by 20.38%, 27.52%, 31.72% compared to CK treatment, respectively, by 1.42%, 7.43% and 10.97% as compared with CF treatment, respectively. Under the condition of 30% urea reduction, the yield of T3F1, T3F2 and T3F3 increased by 31.72%, 25% and 20.59 respectively compared with CK treatment, and increased by 10.97%, 5.31% and 1.59% respectively compared with CF treatment. The yield of T3F1 was the highest in all treatments, which was 31.72% higher than CK treatment, and 10.97% higher than CF treatment.

As for the multiple topdressing protocol, the soil N availability maintains at reasonable abundant levels in later stages, in which greatest amount of N is required by plants [30–32]. This is more advantageous than basal N application alone, in which N is very susceptible to loss [33]. Topdressing was enough to provide N for the maximum N use efficiency of Chinese cabbage.

### 2.4. Effects of different treatments on the quality of Chinese Cabbage

The concentration of Vc, nitrate, soluble sugar in cabbage were important indexes to prove the quality of Chinese cabbage, which directly affects the nutritive value of Chinese cabbage (Table 4). Statistical results showed that N application rate, topdressing times, topdressing times × N application rate interaction significantly

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**Table 3.** Yield of Chinese cabbage with different treatments.

| Treatment | Yield(t hm⁻²) | Increase yield vs CK (%) | Increase yield vs CF (%) |
|-----------|--------------|--------------------------|--------------------------|
| F × T     |              |                          |                          |
| CK        | 125.00h      | -                        | -                        |
| CF        | 148.37g      | 18.70                    | -                        |
| T1F1      | 150.47ef     | 20.38                    | 1.42                     |
| T1F2      | 148.57e      | 18.86                    | 0.13                     |
| T1F3      | 147.06ef     | 17.65                    | −0.88                    |
| T2F1      | 159.40f      | 27.52                    | 7.43                     |
| T2F2      | 153.11b      | 22.49                    | 3.19                     |
| T2F3      | 148.11d      | 18.49                    | −0.18                    |
| T3F1      | 164.65ef     | 31.72                    | 10.97                    |
| T3F2      | 156.25a      | 25.00                    | 5.31                     |
| T3F3      | 150.74c      | 20.59                    | 1.59                     |

Nitrogen application rate

| F1        | 158.18a      | 26.54                    | 6.61                     |
| F2        | 152.64b      | 22.12                    | 2.88                     |
| F3        | 146.63c      | 18.91                    | 0.18                     |

Topdressing times

| T1        | 148.70b      | 18.96                    | 0.22                     |
| T2        | 153.54b      | 22.83                    | 3.48                     |
| T3        | 157.21a      | 25.77                    | 5.96                     |

Source of variance

| F         | <0.0001      | -                        | -                        |
| T         | <0.0001      | -                        | -                        |
| F × T     | <0.0001      | -                        | -                        |

Note: Means followed by the similar lowercase letters within same column of each item were not significant in difference at 5% level, and the *P* < 0.01 indicated the very significant level of 1%, ‘-‘no valid value.
influenced Vc and soluble sugar content of Chinese cabbage. Each factor’s contribution to the total variation was ranked according to the following sequence: N application rate > topdressing times > their interaction. Both N application rate and topdressing times significantly influenced nitrate content, there was no significant influence of their interaction observed.

Vc content of cabbage in T3F1 treatment was the highest among all treatments and significantly increased by 13.69% compared with CF treatment. Nitrate content was related to the safety of Chinese cabbage. In China, the safety limit of nitrate content in fresh vegetable was less than or equal to 432 mg kg\(^{-1}\) \[34\]. The nitrate content of different fertilizer treatments were 171.88–242.20 mg kg\(^{-1}\), which was within the safety limits. The content of nitrate in cabbage increased linearly with the increase of N application. Compared with CF treatment, T3F1 treatment significantly reduced nitrate content by 7.55%. It indicated that combination of reduced N application rate by 15% and three times topdressing could not only significantly increase the yield of Chinese cabbage but also effectively reduce the accumulation of nitrate to the Chinese cabbage. Soluble sugar concentration of cabbage was an important index to determine the taste of vegetables. High soluble sugar content means good quality. Soluble sugar content in M3F1 treatment was the highest, reaching 2.33 mg kg\(^{-1}\), and increased 17.97% compared with CF treatment.

N nutrient is the most important mineral element required by plants, and it is an important basic condition for biological construction \[35,36\]. Meanwhile, it also plays a key role in plant growth and development and material transformation \[37\]. Therefore, the effect of N fertilizer on crop quality was undoubtedly the most significant of all mineral nutrients. Excessive application of N fertilizer had a negative effect on the quality and agricultural environment \[38–40\]. The results showed that the accumulation of nitrate in Chinese cabbage was significantly reduced by reducing N application rate, and the accumulation of nitrate in Chinese cabbage was increased by increasing topdressing times (Table 4). The possible reason was that urea is a fast-acting nutrient, which was released rapidly after applying to the soil \[41\]. Excessive N could be move downward into the deep soil with the water, and consequently resulted in decreasing N content in the topsoil \[42\]. Increasing topdressing times increased the N content in the topsoil, prolong the N supply cycle, promote the uptake of N by root, and increase the nitrate content of plants \[43\]. Nevertheless, reduced N fertilization reduced the nitrate content in topsoil layer, and weakened the luxury absorption of N \[44\], and balanced the N metabolism in Chinese cabbage plants, and promoted plant growth, and finally made nitrate in plants play a dilute effect.

Under the condition of reduced N application rate, Vc and soluble sugar content of Chinese cabbage increased by increasing topdressing times. The possible reason was that topdressing with urea promoted the absorption of N and increased the absorption of other elements \[45\], thus enhanced the content of Vc and soluble sugar in Chinese cabbage.

### 3. Conclusion

Under the experimental conditions, the highest yield (164.65 t hm\(^{-2}\)) of Chinese cabbage was observed in

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**Table 4.** Chinese cabbage quality under different treatments.

| Treatment | Vc concentration (g 100g\(^{-1}\)) | Nitrate concentration (mg kg\(^{-1}\)) | Soluble sugar concentration (mg kg\(^{-1}\)) |
|-----------|------------------------------------|--------------------------------------|---------------------------------------------|
| F x T     |                                    |                                      |                                             |
| CK        | 10.71g                             | 140.45g                              | 1.42g                                       |
| CF        | 13.01de                            | 242.18a                              | 1.98cd                                      |
| T1F1      | 13.82bc                            | 206.13d                              | 1.99cd                                      |
| T1F2      | 12.59e                             | 191.00e                              | 1.92de                                      |
| T1F3      | 10.92g                             | 171.86f                              | 1.61f                                       |
| T2F1      | 14.16b                             | 217.66c                              | 2.08b                                       |
| T2F2      | 12.87e                             | 206.98d                              | 1.97d                                       |
| T2F3      | 12.10f                             | 189.88e                              | 1.87ef                                      |
| T3F1      | 14.80a                             | 223.90b                              | 2.33a                                       |
| T3F2      | 13.44cd                            | 214.08c                              | 2.06bc                                      |
| T3F3      | 12.77e                             | 201.90d                              | 1.91de                                      |

**Note:** Means followed by the similar lowercase letters within same column of each item were not significant in difference at 5% level, and the P < 0.01 indicated the very significant level of 1%, '-' no valid value.
T3F1 treatment which was 10.97% higher than CF treatment. Compared with CF treatment, 30% or 45% lower N still maintained stable yield. Reduced N application rate significantly decreased the nitrate content in edible part of Chinese cabbage, and correspondingly reduced the supply of nitrate N in soil. Increased topdressing times significantly improved the content of Vc and soluble sugar in Chinese cabbage and enhanced Chinese cabbage yield. Moreover, it effectively increased NUE and maintained higher nitrate content in the topsoil due to prolonging N supply period. These results showed that increased topdressing times and reduced N fertilizer could not only keep or even improve Chinese cabbage yield and quality but also cut down environmental risk. Vegetables were a large quantity of agricultural products with high demand for fertilizers, facing severe environmental pressure in production. In future, more research should be undertaken under different environmental conditions, as well as in different soil types.

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References

[1] Martina S, Nina KM, Vesna Z, et al. Effect of different fertilisation and irrigation practices on yield, nitrogen uptake and fertiliser use efficiency of white cabbage (Brassica oleracea var. capitata L.) Sci Hortic-Amsterdam. 2010;125:103–109.
[2] Cao XW, Cui HM, Li J, et al. Heritability and gene effects for tiller number and leaf number in non-heading Chinese cabbage using joint segregation analysis. Sci Hortic-Amsterdam. 2016;203:199–206.
[3] Fan Y, Li H, Xue ZJ, et al. Accumulation characteristics and potential risk of heavy metals in soil-vegetable system under greenhouse cultivation condition in Northern China. Ecol Eng. 2017;102:367–373.
[4] Zhang WF, Dou ZX, He P, et al. New technologies reduce greenhouse gas emissions from genious fertilizer in China. Proc Natl Acad Sci USA. 2013;110:8375–8380.
[5] Yang YM, Li Y, Zhang JH. Chemical speciation of cadmium and lead and their bioavailability to cole (Brassica campestris L.) from multi-metals contaminated soil in Northwestern China[J]. Chem Spec Bioavaila. 2016;28:33–41.
[6] Huang B, Shi XZ, Yu DS, et al. Environmental assessment of small-scale vegetable farming systems in peri-urban areas of the Yangtze River Delta Region, China. Agr Ecosyst Environ. 2006;112:391–402.
[7] Ju XT, Xing GX, Chen XP, et al. Reducing environmental risk by improving N management in intensive Chinese agricultural systems. Proc Natl Acad Sci USA. 2009;106:3041–3046.
[8] Kuscu H, Turhan A, Ozmen N, et al. Optimizing levels of water and nitrogen applied through drip irrigation for yield, quality, and water productivity of processing tomato (Lycopersicon esculentum, Mill.). Hortic Environ Bio. 2014;55:103–114.
[9] Barton L, Colmer TD. Irrigation and fertiliser strategies for minimising nitrogen leaching from turfgrass. Agric Water Manag. 2006;80:160–175.
[10] Duncan EG, O’Sullivan CA, Roper MM, et al. Yield and nitrogen use efficiency of wheat increased with root length and biomass due to nitrogen, phosphorus, and potassium interactions. J Plant Nutr Soil Sci. 2018;181:364–373.
[11] Bortoletto-Santos R, Ribeiro C, Polito WL. Controlled release of nitrogen-source fertilizers by natural-oil-based poly(urethane) coatings: the kinetic aspects of urea release. J Appl Polym Sci. 2016;133:33.
[12] Cheng WG, Sudo S, Tsuruta H, et al. Temporal and spatial variations in N₂O emissions from a Chinese cabbage field as a function of type of fertilizer and application. Nutr Cycl Agroecosys. 2006;74(2):147–155.
[13] Yuan Y, Hu G, Zhao M, et al. Variations in the natural 15N abundance of Brassica chinenesis grown in uncultivated soil affected by different nitrogen fertilizers. J Agr Food Chem. 2014;62:11386–11392.
[14] Huang LH, Liang ZW, Suarez DL, et al. Impact of cultivation year, nitrogen fertilization rate and irrigation water quality on soil salinity and soil nitrogen in saline-sodic paddy fields in Northeast China. J Agr Sci. 2016;154:632–646.
[15] Bauder JW, Schneider RP. Nitrate-nitrogen leaching following urea fertilization and irrigation. Soil Sci Soc Am J. 1979;43:348–352.
[16] Yang XD, Ni K, Shi YZ, et al. Effects of long-term nitrogen application on soil acidification and solution chemistry of a tea plantation in China. Agr Ecosyst Environ. 2018;252:74–82.
[17] Kocon A. The effect of foliar or soil top-dressing of urea on some physiological processes and seed yield of faba bean. Polish J Agron. 2010;3:15–19.
[18] Kaschuk G, Nogueira MA, Luca MJd, et al. Response of determinate and indeterminate soybean cultivars to basal and topdressing N fertilization compared to sole inoculation with Bradyrhizobium. Field Crops Res. 2016;195:21–27.
[19] Westerman RL. Soil testing and plant analysis. 3rd ed. (J). Soil Sci Soc Am J. no. 3. 1990.
[20] Niu S Analysis of crop quality. Beijing: Agricultural Science and Technology Press, China, 1990. (in Chinese).
[21] Silva JG, Mgc F, Gomide FTF, et al. Different nitrogen sources affect biomass partitioning and quality of potato production in a hydroponic system. Am J Potato Res. 2013;90:179–185.
[22] Coufal CD, Chavez C, Niemeyer PR, et al. Effects of top-dressing recycled broiler litter on litter...
production, litter characteristics, and nitrogen mass balance. Poultry Sci. 2006;85:392–397.

[23] Johnson GA, Davis JG, Qian YL, et al. Topdressing turf with composted manure improves soil quality and protects water quality. Soil Sci Soc Am J. 2006;70:2114–2121.

[24] Chen YT, Peng J, Wang J, et al. Crop management based on multi-split topdressing enhances grain yield and nitrogen use efficiency in irrigated rice in China. Field Crops Res. 2015;184:50–57.

[25] Yu Y, Xue L, Yang L, et al. Effect of biochar application on pakchoi (Brassica chinensis L.) utilizing nitrogen in acid soil. Acta Pedologica Sinica. 2015;4:759–767, in Chinese

[26] Hartmann TE, Yue S, Schulz R, et al. Yield and N use efficiency of a maize-wheat cropping system as affected by different fertilizer management strategies in a farmer’s field of the North China Plain. Field Crops Res. 2015;174:30–39.

[27] Tian XF, Geng JB, Guo YL, et al. Controlled-release urea decreased ammonia volatilization and increased nitrogen use efficiency of cotton. J Plant Nutr Soil Sci. 2017;180:667–675.

[28] Qian S, Wm D, Yc L, et al. Characterization of humic acids derived from leonardite using a solid-state NMR spectroscopy and effects of humic acids on growth and nutrient uptake of snap bean. Chem Spec Bioavailab. 2015;27:156–161.

[29] Ghaley BB. Uptake and utilization of 5-split nitrogen topdressing in an improved and a traditional rice cultivar in the bhutan highlands. Exp Agr. 2012;48:536–550.

[30] Gao N, Liu Y, Wu HQ, et al. Interactive effects of irrigation and nitrogen fertilizer on yield, nitrogen uptake, and recovery of two successive Chinese cabbage crops as assessed using $^{15}$N isotope. Sci Hortic-Amsterdam. 2017;215:117–125.

[31] Baiga R, Rao BKR. Effects of biochar, urea and their co-application on nitrogen mineralization in soil and growth of Chinese cabbage. Soil Use Manage. 2017;33:54–61.

[32] Song S, Yi L, Zhu Y, et al. Effects of ammonium and nitrate ratios on plant growth, nitrate concentration and nutrient uptake in flowering Chinese cabbage. Bangl J Bot. 2017;46:1259–1267.

[33] Chaichi MR, Keshavarz-Afsar R, Lu B, et al. Growth and nutrient uptake of tomato in response to application of saline water, biological fertilizer, and surfactant. J Plant Nutr. 2016;40:457–466.

[34] Ma BL, Wu HM, Liu Y, et al. China-safety qualification for agricultural product-safety requirements for non-environmental pollution vegetable (GB/18406.1-2001), China Standard Press: Beijing. 2001; p. 47–48 in Chinese.

[35] Bingham AH, Cotrufo MF. Organic nitrogen storage in mineral soil: implications for policy and management. Sci Total Environ. 2016;551-552:116–126.

[36] Liu CC, Liu YG, Guo K, et al. Effects of nitrogen, phosphorus and potassium addition on the productivity of a kast grassland: plant functional group and community perspectives. Ecol Eng. 2018;117:84–95.

[37] Liang Y, Zhao X, Jones AM, et al. G proteins sclp root architecture in response to nitrogen in rice and arabidopsis. Plant Sci. 2018;274:129–136.

[38] Zhang S, Gao P, Tong Y, et al. Overcoming nitrogen fertilizer over-use through technical and advisory approaches: A case study from Shaanxi Province, Northwest China. Agr Ecosyst Environ. 2015;209:89–99.

[39] Zou Y, Babock BA, Hayes DJ. Nitrous oxide emission reductions from cutting excessive nitrogen fertilizer applications. Climatic Change. 2015;132:353–367.

[40] Emami S, Pourbabaei AA, Alikhani HA. Interactive effect of nitrogen fertilizer and hydrocarbon pollution on soil biological indicators. Environ Earth Sci. 2014;72:3513–3519.

[41] Pawlett M, Deeks LK, Sakrabani R. Nutrient potential of biosolids and urea derived organo-mineral fertilizers in a field scale experiment using ryegrass (Lolium Perenne, L.). Field Crops Res. 2015;175:56–63.

[42] Li Y, Liu HJ, Huang GH, et al. Nitrate nitrogen accumulation and leaching pattern at a winter wheat: summer maize cropping system. R. C. Sci Total Environ. 2016;551-552:116–126.

[43] Zhong YX, Yang MT, Cai J, et al. Nitrogen topdressing timing influences the spatial distribution patterns of protein components and quality traits of flours from different pearling fractions of wheat (Triticum aestivum, L.) grains . Field Crops Res. 2018;216:120–128.

[44] Xie Y, Kristensen HL. Overwintering grass-clover as intercrop and moderately reduced nitrogen fertilization maintain yield and reduce the risk of nitrate leaching in an organic cauliflower (brassica oleracea L. var. botrytis) agroecosystem. Sci Hortic-Amsterdam. 2016;206:71–79.

[45] Bohle MG. Effect of nitrogen topdressing at anthesis and the association of flag-leaf nitrogen with grain protein concentration in irrigated spring wheat. J Plant Nutr. 2006;29:1035–1046.