Efficacy of vegetable waste biogas slurry on yield, quality and nitrogen use efficiency of cauliflower

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Abstract. Biogas slurry can be used as a nitrogen (N) fertilizer, and has been suggested to reduce chemical fertilizer input and improve vegetable quality. The present study aimed to evaluate the effects of vegetable waste biogas slurry topdressing on the yield, quality and nitrogen (N) use efficiency of cauliflower. A field experiment consisting of five treatments during topdressing (CK: no N input, CON: farmer’s conventional N fertilizer input, HBS: substitution of half the amount of N fertilizer with vegetable waste biogas slurry, BS: substitution of the total amount of N fertilizer with vegetable waste biogas slurry, and DBS: substitution of double the amount of N fertilizer with vegetable waste biogas slurry) was conducted. When compared with that of the CON treatment, the HBS, BS, and DBS treatments increased the yield of cauliflower by 4.7%, 13.7%, and 15.3%, respectively. Furthermore, the BS and DBS treatments improved cauliflower quality compared with that of the CON treatment. The HBS and BS treatments increased the N use efficiency and the DBS treatment reduced the N use efficiency compared with that of the CON treatment. Considering the increased fruit quality and N use efficiency, the substitution of fertilizer N with equal amount of vegetable waste biogas slurry during topdressing in the production of cauliflower is recommended in northern China.

1. Introduction  
China is a large agriculture-based country, and has emerged as the world’s largest vegetable producer. A lot of vegetable waste (including vine, diseased plants, and defective products) is obtained during vegetable production. It has been estimated that about 600 million tons of vegetable waste is produced annually in China, and its resource utilisation is less than 30%[1]. Most of the vegetable waste is disposed randomly, which not only causes environmental pollution, but also results in resource waste. Biogas engineering is considered an effective approach to solve the problems associated with vegetable and farm wastes. It not only helps dispose vegetable waste effectively and harmlessly, but also helps produce clean energy (biogas) and organic fertilizer (biogas slurry)[2]. The North China Plain (NCP) is the main vegetable producing area in China. Local farmers use a large amount of chemical fertilizers to increase
vegetable yield, thus lowering N use efficiency (NUE) of plants and causing environmental pollution. Furthermore, it also increases the concentration of nitrate in vegetables beyond the standard limit, thus decreasing vegetable quality, which significantly restricts the safety and sustainable development of vegetables[3].

Studies have revealed that biogas slurry can be used as irrigation water and fertilizer as it is rich in N, phosphorus (P), potassium (K), and other nutrients required by plants. Its use can improve the physicochemical and biological characteristics of soil, thus improving the yield and quality of vegetables. Studies have mainly focused on the effects of biogas slurry on vegetable yield and soil properties. However, its integrated effect on vegetable yield, quality, nutrient use efficiency is rarely investigated. Cauliflower (Brassica oleracea L. var. botrytis L.) is a major horticultural crop in the NCP, which has a high reputation among proponents of healthy nutrition and sustainable food production, and has anti-cancer properties[4]. Therefore, we carried out a field experiment in a vegetable planting park in northern China. The present study aimed to evaluate the effects of vegetable waste biogas slurry topdressing on cauliflower yield, quality and N use efficiency in cauliflower production.

2. Material and methods

2.1. Experimental materials and design

The following fertilizers were used in the present study: chemical fertilizer (urea (46% N), calcium superphosphate (16% P2O5), and potassium sulphate (50% K2O) and biogas slurry from anaerobic digestion of vegetable wastes. A field experiment was established in July 2018 at a vegetable planting park in Jinan, Shandong Province (36.58°N, 116.84°E). The climate of this region is a typical temperate monsoon, with an annual mean air temperature and precipitation of 13.8°C and 623 mm, respectively. The soil in the experimental field (0–20 cm) was moist, with a bulk density of 1.4 g cm$^{-3}$, pH of 8.4, soil organic matter content of 16.2 g kg$^{-1}$, and total N content of 1.2 g kg$^{-1}$. The experiment consisted of five treatments during topdressing: CK (no fertilizer N input), CON (farmer’s conventional N fertilizer input), HBS (substitution of half the amount of N fertilizer with vegetable waste biogas slurry), BS (substitution of the total amount of N fertilizer with vegetable waste biogas slurry), and DBS (substitution of double the amount of N fertilizer with vegetable waste biogas slurry). Each treatment was a randomized block with 3 replications, and the area of each plot was 1.5 × 7 m$^2$.

Urea (136 kg N ha$^{-1}$) as a basal fertilizer was applied to the soil surface, and the soil in each treatment plot was subjected to rotary tillage before planting cauliflower on 20 July 2018. Chemical fertilizers and biogas slurry were thoroughly mixed in irrigation water, and then applied to the soil. Average total nutrient content of slurry was 0.90, 0.21 and 0.90 kg m$^{-3}$ for N, P2O5 and K2O, respectively. The rate of fertilizers (chemical fertilizers and biogas slurry) applied in the five treatments is listed in Table 1. The application of insecticides was similar to that of the local conventional farming practice.

Table 1 N, P2O5 and K2O input rate (kg ha$^{-1}$) from chemical fertilizer and vegetable waste biogas slurry of different treatments

| Timing   | Chemical fertilizer | Biogas slurry | Total input |
|----------|---------------------|---------------|-------------|
|          | N      | P2O5  | K2O  | N      | P2O5  | K2O  | N      | P2O5  | K2O  |
| 2018/7/17 Basal fertilizer |          |       |      |        |       |      |        |       |      |
| CK       | 136    | 128   | 128  | 0      | 0      | 0    | 136    | 128   | 128  |
| CON      | 136    | 128   | 128  | 0      | 0      | 0    | 136    | 128   | 128  |
| HBS      | 136    | 128   | 128  | 0      | 0      | 0    | 136    | 128   | 128  |
| BS       | 136    | 128   | 128  | 0      | 0      | 0    | 136    | 128   | 128  |
| DBS      | 136    | 128   | 128  | 0      | 0      | 0    | 136    | 128   | 128  |
| 2018/8/10 Topdressing |          |       |      |        |       |      |        |       |      |
| CK       | 0      | 50    | 128  | 0      | 0      | 0    | 0      | 50    | 128  |
| CON      | 64     | 50    | 128  | 0      | 0      | 0    | 64     | 50    | 128  |
| HBS      | 32     | 42.5  | 96   | 32     | 7.5    | 32   | 64     | 50    | 128  |
### Measurement of cauliflower yield and quality

Cauliflower yield was measured at harvest on 10 October 2018, 12 October 2018, and 15 October 2018 from an area of 1.5 × 4 m² in each plot. The quality of cauliflower was measured within 24 h of sampling. The content of vitamin C, nitrate, soluble sugar, and organic acid was determined by the 2,6-dichlorophenol titration method, UV spectrophotometry, the anthrone colorimetric method, and the sodium hydroxide direct titration method, respectively [5]. The sugar-acid ratio of cauliflower was defined as the ratio of soluble sugar to acid content. The N content in cauliflower was measured using a CN analyzer (Thermo Flash EA 1112 Flash 2000; Thermo Fisher, USA) after drying the sample at 70°C.

### Calculation of PFPN and ANUE

Partial factor productivity from applied N (PFPN, kg kg⁻¹) was calculated as the ratio of cauliflower yield (fresh weight, \( Y \), kg ha⁻¹) to chemical fertilizer and biogas slurry N applied (\( RF \), kg N ha⁻¹):

\[
PFPN = \frac{Y}{RF}
\]

Apparent N use efficiency (ANUE, %) was calculated as the ratio of amount of N in cauliflower (\( Ng \), kg N ha⁻¹) to chemical fertilizer and biogas slurry N applied (\( RF \), kg N ha⁻¹):

\[
ANUE = \frac{Ng}{RF}
\]

### Statistics analyses

The SPSS version 22.0 software package for Windows (SPSS, Chicago, USA) was used for the statistical analyses of data. Statistically significant differences were tested by the one-way analysis of variance. When the differences were considered significant at \( P < 0.05 \), the mean values were subjected to Duncan’s multiple test.

### Results

#### Cauliflower yield and quality

The yield of cauliflower was significantly low when there was no N input (CK treatment) (Fig. 1A). The yield of cauliflower with the HBS, BS, and DBS treatments was 4.7%, 13.7%, and 15.3% higher than that of the CON treatment, respectively. Furthermore, the yield of cauliflower with the BS and DBS treatments were similar, with 13.5 and 13.7 Mg ha⁻¹ (fresh weight), respectively.

![Figure 1. Effect of vegetable waste biogas slurry on cauliflower fruit yield (fresh weight), PFPN, nitrogen uptake of cauliflower fruit and ANUE. Data are the means± the standard error (n=3). Different letters indicate significant differences between treatments at \( P < 0.05 \).](attachment:image.png)
3.2. Cauliflower PFPN and ANUE.
The PFPN, nitrogen uptake, and ANUE of cauliflower in the HBS treatment were 4.8%, 9.3% and 8.6% higher than those in the CON treatment, respectively (Fig. 1B, Fig. 1C), and those in the BS treatment were 13.7%, 24.2%, and 22.8%, respectively. Compared with that of the CON treatment, the BS treatment significantly (P < 0.05) improved the PFPN and ANUE. However, the PFPN and ANUE in the DBS treatment were significantly (P < 0.05) reduced by 22% and 20% compared with those in the CON treatment, respectively. Overall, the BS treatment was the best in improving the N use efficiency of cauliflower.

3.3. Cauliflower yield and quality
The application of biogas slurry significantly (P < 0.05) increased cauliflower quality (Table 2). Compared with that of the CON treatment, the BS and DBS treatments significantly (P < 0.05) increased the vitamin C content and reduced the nitrate content. The BS and DBS treatments significantly improved the soluble sugar content (69% and 75%) and sugar-acid ratio (82% and 91%), and did not reduce the diameter of cauliflower, compared with those of the CON treatment. However, the HBS treatment increased the organic acid content by 11% compared with that of the CON treatment.

| Treatment | Fruit diameter (cm) | Vitamin C (mg kg⁻¹) | Nitrate concentration (mg kg⁻¹) | Soluble sugar (g kg⁻¹) | Organic acid (g kg⁻¹) | Sugar-acid ratio |
|-----------|---------------------|----------------------|-------------------------------|------------------------|-----------------------|------------------|
| CK        | 16.3±0.9b           | 374±9 d              | 146±12c                       | 1.8±0.5a               | 3.2±0.3a              | 0.60±0.21a       |
| CON       | 21.6±0.6a           | 402±5c               | 305±19a                       | 1.9±0.2a               | 2.8±0.1a              | 0.67±0.07a       |
| HBS       | 20.5±1.3gb          | 394±11cd             | 245±13b                       | 2.7±0.4a               | 3.1±0.4a              | 0.95±0.26a       |
| BS        | 21.3±2.3a           | 455±8b               | 212±4b                        | 3.2±0.6a               | 2.6±0.1a              | 1.23±0.26a       |
| DBS       | 21.8±1.1a           | 493±6a               | 208±2b                        | 3.3±0.5a               | 2.5±0.1a              | 1.29±0.15a       |

Note: Mean ± standard error (n = 3). Different lowercase letters indicate significant differences between treatments at P < 0.05.

4. Discussion

4.1. Effects of biogas slurry on cauliflower yield and nitrogen use efficiency
The Biogas slurry can be used as a fertilizer required by plants, which is an effective approach to increase crop yield. In the present study, the application of biogas slurry increased cauliflower yield. However, there was no significant difference in cauliflower yield between the BS and DBS treatment. This indicated that the application of double biogas slurry not increase the crop yield, and This was consistent with previous studies[6].

The PFPN and ANUE were higher with the HBS and BS treatments than with the CON treatment. This might be attributed to the variation in cauliflower yield and nitrogen uptake between the three treatments. We found that the N use efficiency of the DBS treatment decreased with increase in nitrogen input. Similar observations have been made in other crops[7]. Considering that cauliflower yield did not increase significantly, we propose that the application of double the amount of N fertilizer with vegetable waste biogas slurry during topdressing is not necessary.

4.2. Cauliflower yield and quality Effects of biogas slurry on cauliflower yield and quality
The application of biogas slurry has been shown to significantly increase crop quality, which is consistent with the findings of the present study. Vitamin C, nitrate, sugars, and organic acids have been used to evaluate fruit quality, as they are related to soil properties, especially the biological properties. Biogas slurry contains carbohydrates, microelements, crude proteins, amino acids, and other beneficial substances, which play an important role in improving the biological properties of soil[8]. This might be the main reason that biogas slurry treatments (BS and DBS) significantly increased cauliflower quality compared with that of the CON treatment in the present study.
4.3. Overall performance of vegetable waste biogas slurry application
The application of biogas slurry will also improve the status of soil and growth of vegetables, and reduce plant diseases and insect pests. Furthermore, the application of biogas slurry will save a large amount of chemical fertilizer and irrigation water, reduce environmental pollution, and improve economic benefits\(^{[9,10]}\). The results suggest that the application of vegetable waste biogas slurry during cauliflower production can be employed to increase resource use efficiency, fruit quality and fruit yield in northern China. Vegetable waste biogas slurry can be used as irrigation water and fertilizer as it is rich in nutrients required by plants. This will be an effective approach for sustainable development of crops and high efficiency agriculture in North China.

5. Conclusions
The application of vegetable waste biogas slurry significantly increased cauliflower quality, while maintaining high cauliflower yield. However, excessive application of biogas slurry significantly reduced the N use efficiency. The results indicate that chemical N fertilizer can be substituted by N fertilizer from biogas slurry during topdressing to meet the requirements of cauliflower plant. Further studies should focus on the effect of vegetable waste biogas slurry application on nitrogen leaching with multi-year measurement.

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