# Effect of Drip Irrigation with Biogas Slurry on the Yield and Quality of Chinese Cabbage

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Effects of different concentrations of biogas slurry (BS) were evaluated relative to vegetable cultivation. Five concentration levels of BS were used as organic fertilizer to grow Chinese cabbages (CA) by drip irrigation to study the effect of BS on the yield and quality. Each level was replicated three times and BS was used seven times. Results showed that the average plant height, fresh weight, dry weight, and soluble sugars and protein contents of Chinese cabbage under the T1 (BS 25%) treatment were optimal. Among them, dry weight per plant (3.53g), soluble sugar content (0.41%), and soluble protein content (0.0039%) were 1.74 times, 1.41 times, and 1.14 times more than under the CK treatment, respectively. In addition, the application of biogas slurry improved the physical and chemical properties of soil. Soil total nitrogen (TN) and available phosphorus (AP) content increased after the use of biogas slurry, and the soil total nitrogen and available phosphorus content increased with the increase in the concentration of the applied biogas slurry. The available potassium (AK) content of soil fluctuated with the concentration of biogas slurry. In addition, biogas slurry can properly improve soil pH. In conclusion, BS 25% was the best for the growth of CA and its quality, which provided scientific basis for biogas slurry as fertilizer.

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## INTRODUCTION

China has produced nearly 900 million tons of pig manure, 155 million tons of chicken manure, and 900 million tons of straw-type materials in agriculture per year (Bi *et al.* 2019; Liu *et al.* 2020; Zhao *et al.* 2020). Abundant agricultural and forestry biomass resources are important energy sources for China to replace fossil fuels and achieve the goals of carbon peaking and carbon neutrality goals (Zhang *et al.* 2023a).

Biomass utilization has many forms, including biomass gasification (AlNouss *et al.* 2023; Sun *et al.* 2023) biomass pyrolysis (Liu *et al.* 2023; Zhang *et al.* 2023b), and biomass-based materials (Li *et al.* 2023; Xu *et al.* 2021a). Anaerobic digestion (AD) is a common biomass utilization form, which uses rural biomass and produces clean energy biogas. Biogas has significant environmental and social benefits (Sun *et al.* 2022) and is considered one of the most promising bioenergy alternatives for solving the current environmental challenges (Kapoor *et al.* 2019; Werkneh, 2022). Since the 21st century, the total investment in biogas construction has reached 40.4 billion yuan, which has made great achievements in energy conversion, waste disposal and promotion of the construction of rural ecological civilization (Xia & Wang, 2020).

Biogas slurry (BS) is a liquid by-product of anaerobic fermentation of organic matter, such as swine manure and straw. It is weakly alkaline (Wang *et al.* 2024) and contains a very small amount of solids. An 800 $m^3$ biogas plant can produce 15 tons of BS per day (Xu *et al.* 2021b; Yan *et al.* 2019). The challenges related to the use of BS for biogas engineering have two major aspects. First, the massive volume and fluid properties of BS can incur extensive storage requirements and transportation costs (Tang *et al.* 2022b); moreover, the increasing transportation cost and BS management are becoming a challenge to the development of the biogas industry in some countries, including China (Dahlin *et al.* 2015; Monlau *et al.* 2015). Second, the excessive amount of BS goes beyond the carrying capacity of the natural ecosystem, thus posing a new pollution risk to the environment (Lin *et al.* 2018). For example, extreme BS addition may cause eutrophication of water bodies (Niyungeko *et al.* 2019). Therefore, in consideration of the environment and sustainable development, BS must be treated in an appropriate manner.

The comprehensive utilization of BS is one of the urgent problems to be solved in the development of biogas engineering. BS contains not only nutrients such as nitrogen (N), phosphorus (P) potassium (K), and trace elements (Yan *et al.* 2019; Xu *et al.* 2021b), but also substantial organic matter, lysine, leucine, glutamic acid, and humic acid (Guo *et al.* 2012; Yang *et al.* 2020; Yan *et al.* 2021). Previous research has shown that BS application promotes the physical, chemical, and biological properties of soil, increase crop yield and quality, and it promotes rapid response from the crop (Niyungeko *et al.* 2019; Tang *et al.* 2019; Xu *et al.* 2019; Zhang *et al.* 2022). Zhu *et al.* (2023) attempted use pig farm BS to regulate the pH of saline-alkali soil and found that it is feasible and sustainable. Slepetiene *et al.* (2023) showed that BS can remarkably increase soil organic carbon content. Zhang *et al.* (2022) grew apple orchards with BS substitute chemical fertilizer and found that treatments with BS application increased the single fruit weight, fresh weight, and dry weight of apples and enhanced the relative abundance of some beneficial taxa functional groups related to carbon and nitrogen cycling. Zhao *et al.* (2021) used the total amount of N fertilizer with vegetable waste BS plant cauliflower and found that the yield and quality are better than conventional N fertilizer treatment. Zhao *et al.* (2023) found that BS can reduce the root exudation rates of oilseed rape and retains more C and N to improve reproductive growth, promoting the increase in yield. Furthermore, the presence of heavy metals and salts in the BS may result in soil contamination. Wang *et al.* (2013) observed that high concentrations of BS led to nitrate accumulation in the near aquifer. However, the nitrate content in the influent aquifer of the low concentration treatment remained within the safe range. A five-year study by Tang *et al*. (2020) demonstrated that the application of BS resulted in an increase in heavy metals in the soil. However, the levels remained within the safe range. Zhang *et al*. (2024) demonstrated that two years of successive application of BS led to an increase in the levels of heavy metals and salts in the soil. Nevertheless, this did not result in soil contamination. Based on these reports, the use of BS in agricultural cultivation is feasible.

Substantial research has been conducted on the application of BS as a soil amendment or organic fertilizer; however, research focusing on the application of BS in the form of drip irrigation is limited. Thus, this study applied different BS concentrations as fertilizer to grow Chinese cabbage (CA) in a farm in the form of drip irrigation. When the cabbages had ripened, measurements were made of the quality and yield of CA and the indicators of soil physical and chemical properties to study the influence caused by BS application. In this preliminary study, the objective was to provide theoretical guidance for the agricultural application of BS.

## EXPERIMENTAL

### Material

*Biogas slurry*

The BS was taken from an anaerobic digester at the Lanke Mountain Plantation Specialized Cooperative in Xin'an County, Luoyang City, Henan Province. The raw materials for biogas fermentation mainly include livestock and poultry manure and crop residues. The fermentation cycle is about 70 days at room temperature outdoors. The resulting digestate was stored for a period exceeding two months in order to permit natural sedimentation, thereby facilitating the separation of the digestate into BS and biogas residue. After this process, the BS is pumped into another pool for the cultivation of wheat and corn. The basic physical and chemical properties of the BS are shown in Table 1.

**Table 1.** Physical and Chemical Properties of BS

| | pH | TS (%) | VS (%) | AP (g/L) | AK (g/L) | TN (mg/L) | OC (mg/L) |
|---|---|---|---|---|---|---|---|
| BS | 8.35 | 0.43 | 34.92 | 18.08 | 0.84 | 375.54 | 645.26 |

*Chinese cabbage*

Four-season cream cabbages were used in this study; this crop belongs to Cruciferae, nonballing cabbage, is commonly consumed, and can be grown in all seasons. CA is a vegetable that is hard, heat resistant, and has strong environmental adaptability. The seed germination rate was determined before sowing, and the results showed that the germination rate was above 97%. CA is susceptible to pests and diseases, and pesticides should be used immediately as soon as the disease occurs.

### Methods

*Experimental design*

This study was conducted in the farm in Henan University of Science and Technology, Kaiyuan Campus, Luoyang City, Henan Province, China (34°35′N, 112°25′E). Soil physical and chemical properties are shown in Table 2. The soil was prepared by removing weeds and plowing before sowing. Five treatments were set up in the experiment (Table 3), namely, no application of BS (CK), application of 25% concentration of BS(T1), 50% concentration of BS(T2), 75% concentration of BS(T3), 100% concentration of BS(T4). Three replicates were set up for each treatment, totaling 15 experimental plots. The size of each plot was 1 m × 1 m and there was a 0.5 m separation zone between each plot under the same treatment condition, and the sample arrangement is shown in Fig. 1. The planting cycle for CA was 40 days, during which time the BS with different concentrations was applied every three days. The total amount of irrigation was 80 tons/ha.

**Table 2.** Physical and Chemical Properties of Soil

| | pH | Water content (%) | AP (mg/kg) | AK (g/kg) | TN(g/kg) |
|---|---|---|---|---|---|
| soil | 8.45 | 6.5 | 4.24 | 230.5 | 1.17 |

**Table 3.** The Concentration of BS

| Treatment | CK | T1 | T2 | T3 | T4 |
|---|---|---|---|---|---|
| BS concentration (%) | 0 | 25 | 50 | 75 | 100 |

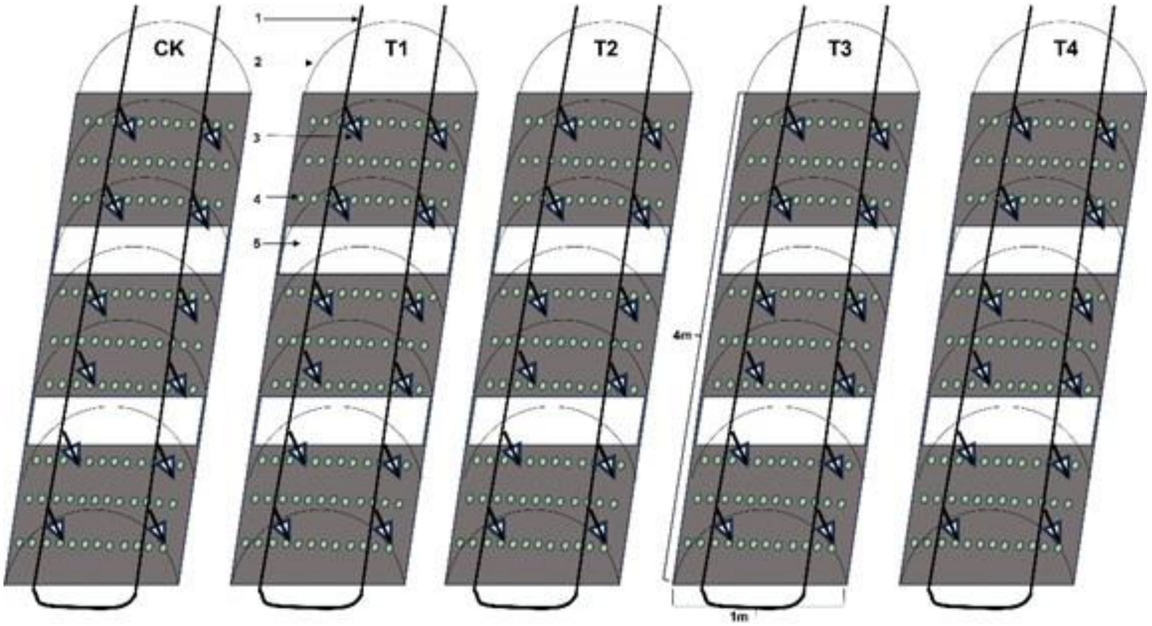


**Fig. 1.** Design of the experimental sample. 1. Drip irrigation pipes; 2. Fiberglass skeleton; 3. Drip sprinkler; 4. CA seed; 5. Spacing bands between same treatments

*Chinese cabbage samples*

Five cabbages were collected from each plot. When the collected samples had been cleaned by distilled water, the surface moisture of samples was immediately sucked dry with clean absorbent paper, and then the plant height, root length, fresh weight, and dry weight were measured. Chlorophyll was measured by a handheld Chlorophyll Tester (SPAD-502Plus). The Anthrone colorimetric method was utilized to determine the content of soluble sugars in cabbage, and the Coomassie brilliant blue method was used to measure the content of soluble proteins.

*Soil samples*

Soil samples were collected before planting and harvesting. Three subsamples of topsoil (0 to 20 cm) were randomly collected from each plot using a stainless-steel corer and were bulked to form one composite sample. After plant residues and stones were removed, soil samples were air-dried and passed through a 0.15 mm sieve. In addition, samples for measuring soil moisture content were collected with a ring knife near the above sampling points.

*Data analysis*

The data were analyzed using SPSS version 27 software (IBM SPSS Statistics 27) for one-way ANOVA, LSD multiple comparison, and Waller-Duncan tests to assess the degree of difference between treatments and the statistical significance of the test data. The level of significance between treatments was set at $p < 0.05$.

## RESULTS AND DISCUSSION

### Agronomic Characters and Yield of CA

The effects of BS concentration on the yield of the CA are shown in Fig. 2. Significant differences (P=0.05) were observed in the yield of CA between treatments, except for T1 and T2 (fresh weight), as well as T2 and T3 (dry weight). The yield of the cabbage decreased with the increase in BS concentration. The fresh weight (Fig. 2a) and dry weight (Fig. 2b) of the cabbage per plant after applying different concentrations of BS were higher than that of CK group. Among them, the fresh weight and dry weight from T1 had the largest increase relative to the CK group that applied clean water. The fresh weight and dry weight per plant increased by 56.5% and 73.9%, respectively. For the cabbages from the T2, T3, and T4 groups, the fresh weight per plant increased by 49.3%, 33.5%, and 16.3%, and the dry weight per plant increased by 57.6%, 47.8%, and 26.6%, respectively. The T4 group had the lowest increase in fresh weight and dry weight.

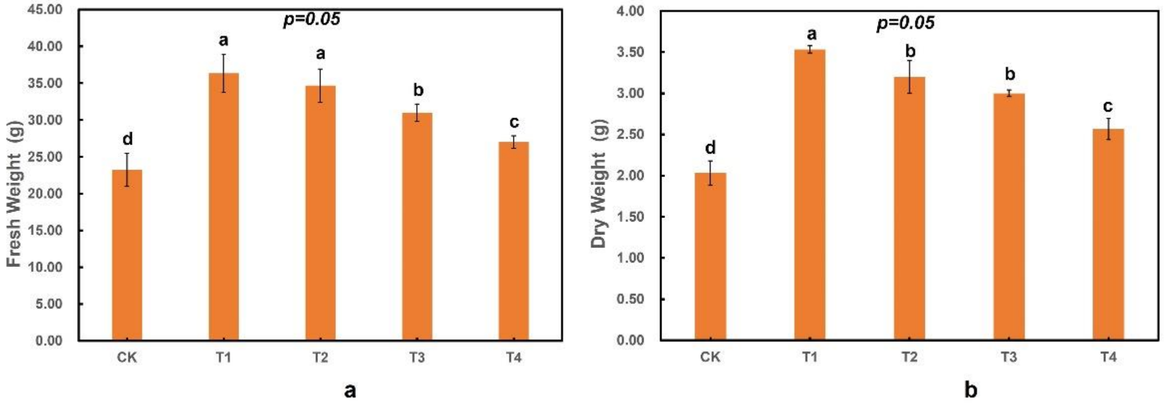
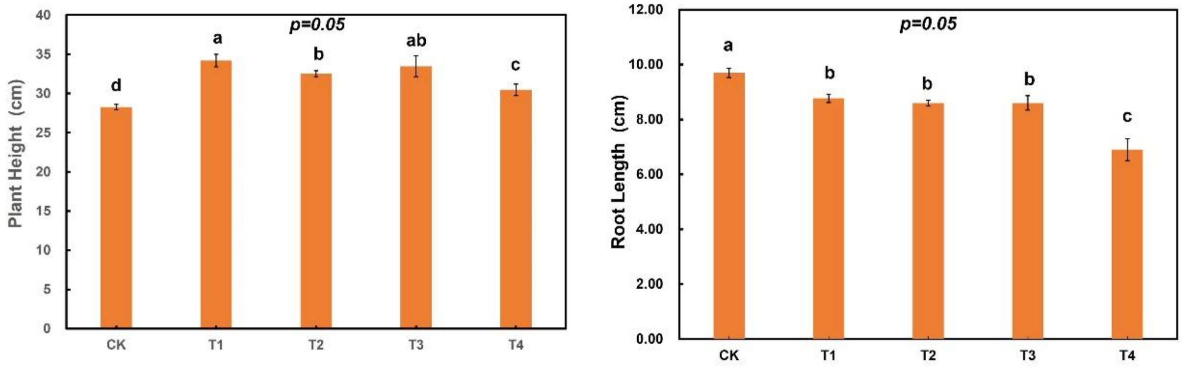


**Fig. 2.** Dry and fresh weight of CA under different concentrations BS. (a) Changes in fresh weight; (b) Changes in dry weight

The effect of BS on the plant height of CA is shown in Fig. 3a. There were significant differences between the BS treatment and the CK treatment. The result reveals that different BS concentrations could improve the plant height of CA. The highest plant height in T1 was 34.2 cm, whereas the lowest plant height 30.5 cm was obtained by T4. The increases in plant height of T1, T2, T3, and T4 were 21.0%, 15.1%, 18.4%, and 7.8%, respectively. With the increased concentration of BS, the trend of plant height was upward and then downward, and T1 obtained the best results among the samples.

The effect of BS irrigation on CA root is shown in Fig. 3 b. There were no significant differences between the T1, T2, and T3 treatments. BS irrigation remarkably weakened the root development, in contrast to the plant height and yield. The average length of cabbage root from the CK group was greater than that of the BS irrigation groups. The longest average root length was 8.77 cm (T1), whereas the shortest average root length was 6.90 cm (T4). Figure 3b demonstrates that the mean root length of the T3 group was equivalent to that of the T2 group. According to data present in Fig. 3b, the average root length difference between T1, T2, and T3 did not exceed 2.1%; the average root length of T1, T2, and T3 decreased by 9.6%, 11.3%, and 11.3% compared with CK, respectively; that of the T4 group decreased by 28.9% compared with CK.



a b

**Fig. 3.** Plant height and root length of CA under different concentrations BS. (a) Changes in plant height; (b) Changes in root length

## Quality of the CA

The effect of BS drip irrigation on the chlorophyll content (SPAD value) of CA is shown in Fig. 4. It is apparent that the change trend of chlorophyll content with BS concentration was a downward parabola. There was a significant difference in chlorophyll content among the five treatments. Compared with CK group, the chlorophyll content of CA in the four treated groups increased; the chlorophyll content of CA in the T2 group was the highest, increasing by 28.6% compared with the CK group; Compared with the CK group, the chlorophyll content of T1, T3 and T4 increased by 11.95%, 15.47% and 3.28% respectively.

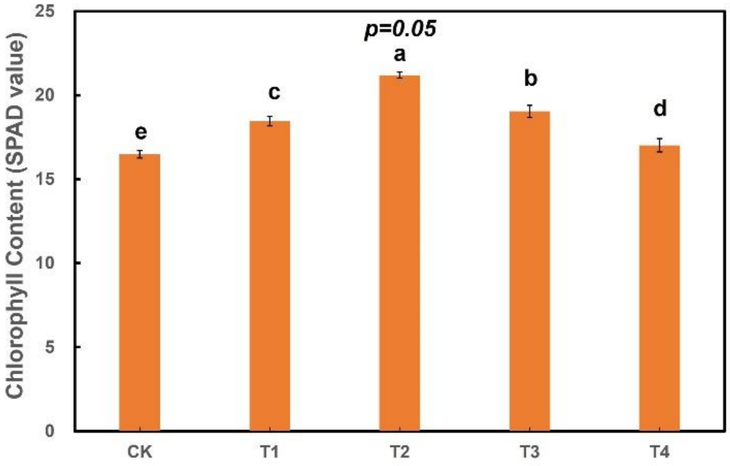


**Fig. 4.** The chlorophyll content of CA under different concentrations BS

The soluble sugar content of the samples obtained from different treatments is shown in Fig. 5a. Significant differences were observed between the BS treatments and the control (CK) group, although the differences within the methane group were relatively minor. Compared with the CK, the soluble sugar content of the four groups treated was increased. With the increase in BS concentration, the soluble sugar content gradually decreased. The soluble sugar content of the cabbage in T1, T2, T3, and T4 increased respectively by 41.4%, 27.6%, 24.1%, and 20.7% compared with the CK group. When the concentration of BS reached the original liquid state, the increase in soluble sugar content was the least. The soluble sugar content with 25% BS drip irrigation in the T1 group was the highest. The increase in soluble sugar content was 1.5 times that of 50% BS applied in T2 group, 1.7 times that of 75% BS applied in T3 group, and 2 times that of BS applied in the T4 group.

The soluble protein content of samples obtained by different treatments is shown in Fig. 5b. The soluble protein content of CA was not significantly different between T2 and T3 treatments. Compared with the CK group, the soluble sugar content of CA in each group treated with BS increased, and the soluble protein content of CA in the T1 group was the highest (3.93 mg/g). The soluble protein content of CA in the other three treatments gradually decreased with the increase in BS concentration. The soluble protein content of CA in T1, T2, T3, and T4 increased by 14.4%, 8.1%, 7.0%, and 2.3%, respectively, compared with CK group. The increment of soluble protein content in the T1 group was 1.7 times that in the T2 group, 2 times that in the T3 group, and 6 times that in the T4 group.

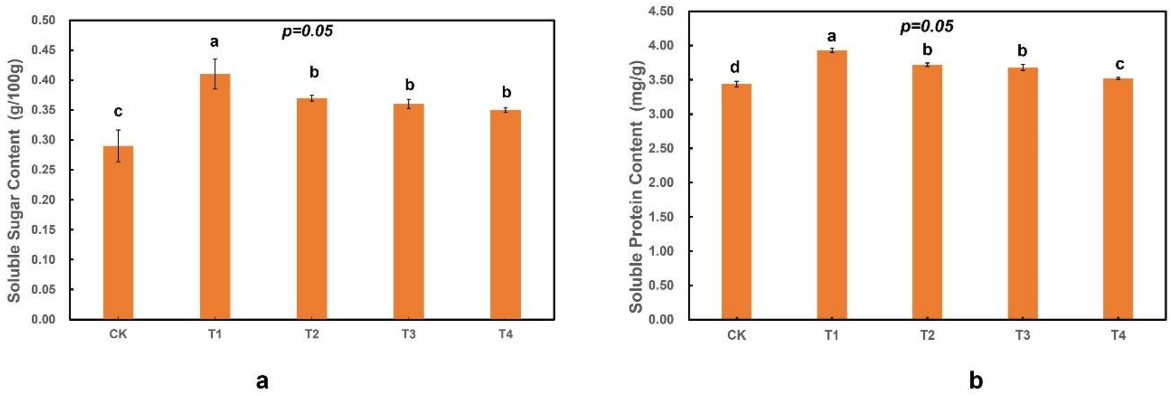


**Fig. 5.** The soluble sugar and protein content of CA under different concentrations BS. (a) Soluble sugar content; (b) Soluble protein content

## Physical and Chemical Properties of Soil

Different treatments had significant effects on soil physicochemical properties. The effects of different treatments on the pH of soil samples are shown in Fig. 6a. Before the test, the soil pH of the sample plot was 8.45, which was alkaline, and the BS pH was 8.35, which was also alkaline. After the application of BS, the soil pH content of each group decreased, and the soil pH of the T1-T4 groups were 8.38, 8.27, 8.28, and 8.03, respectively. Compared with the CK group, it decreased by 0.83%, 2.13%, 2.01%, and 4.97% respectively. The reason may be that the application of BS supplemented the organic matter and inorganic salt nutrients in the soil and reduced the soil pH value under the joint action of soil microorganisms and BS microorganisms.

Soil TN, including organic nitrogen and inorganic nitrogen in soil, is an important nutrient element for plant growth. Soil nitrogen content is usually positively correlated with soil fertility. As shown in Fig. 6b, the TN content in soil changed considerably after BS was applied. The TN content in the T1 and T2 groups was basically the same. The TN content in the T1, T2, and T3 groups reached 1.25, 1.23, and 1.39 g/kg, respectively. The

TN content of the T4 group was the highest (1.55 g/kg), which was 1.32 times that of the CK group. The TN content in soil is in a state of dynamic balance, and the content is closely related to the accumulation and consumption of nitrogen elements. The TN content in BS is 376 mg/L, which can supplement a large amount of soil TN content in a short time after the application of BS.

Soil AP refers to the total phosphorus that can be absorbed by plants in the soil; it reflects the level of soil nutrients to a certain extent. The change of AP content in soil samples of different treatments is shown in Fig. 6.c. With the increase in BS concentration, the content of AP in soil increased. The highest content of AP in T4 group was 27.1 mg/kg, which was 6.38 times higher than that in the CK group. The AP content in T1, T2, and T3 groups were 11.8, 12.5, and 13.2 mg/kg, respectively.

Soil AK refers to the potassium element that is easily absorbed and utilized by plants in soil. AK content is an important indicator of potassium supply in soil. The changes of AK content in soil samples of different treatments are shown in Fig. 6d. After BS application, the AK content of the T1 and T3 treatments were 219 and 221 mg/kg, respectively, and their potassium content slightly decreased in comparison with the CK group (230 mg/kg). The AK contents in the T2 and T4 treatments were 257 and 426 mg/kg, respectively, which were higher than those in the CK treatment. The AK content in the T4 group was 1.85 times higher than that in the CK treatment.

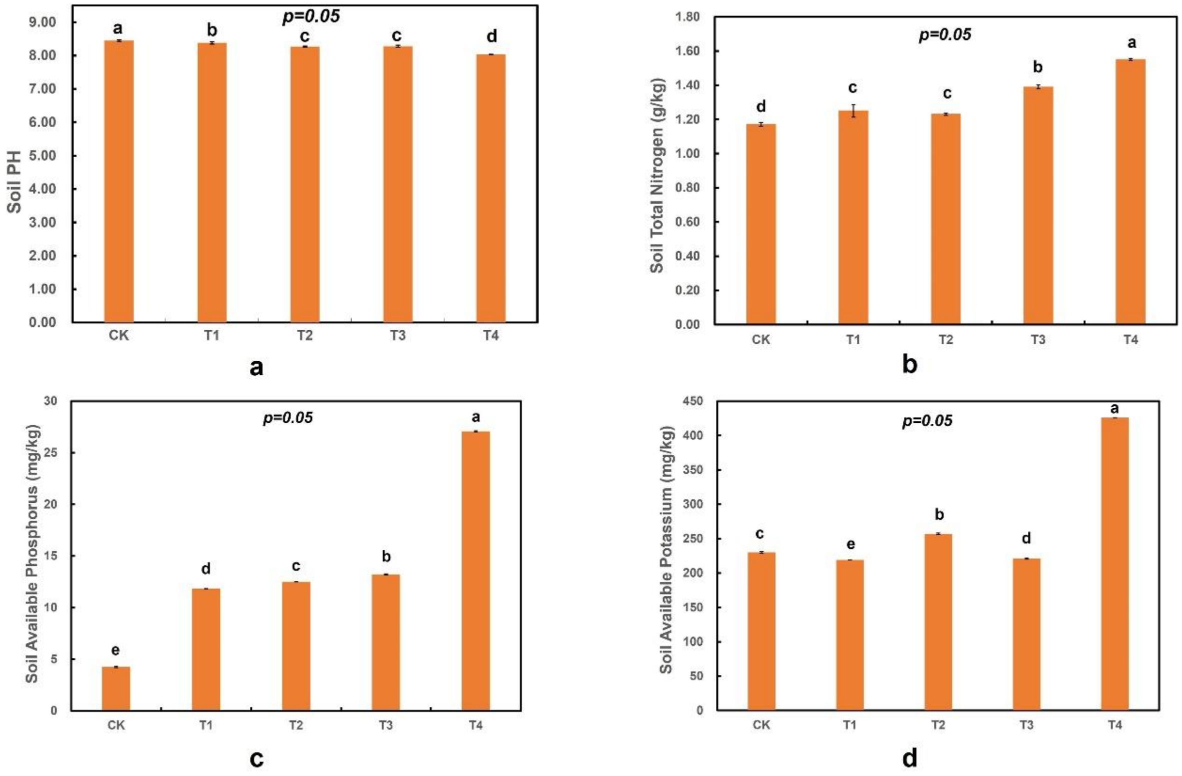


**Fig. 6.** Physical and chemical properties of soil under different concentrations BS. (a) Soil pH; (b) Soil TN content; (c) Soil AP content; (d) Soil AK content

## Effect of Different Concentrations BS Drip Irrigation on the Agronomic Characters and Yield of CA

In this research, the plant height, fresh weight, and dry weight of CA were greater than those of the CK after BS drip irrigation with different concentrations. The maximum increase in average plant height, fresh weight, and dry weight of CA were 21.0%, 56.5%, and 73.9%, respectively, after BS application. The effect of BS on crop yield is consistent with previous results (You *et al.* 2019; Petraityte *et al.* 2022; Tang *et al.* 2022a; Zhu *et al.* 2022; Zhou *et al.* 2023). However, the crop yield growth varied because of the difference of BS composition, soil characteristic, crop type, and amount of BS. Few researchers have studied the effect of BS application on plant height. BS was shown to be beneficial to crop height in this study, which agrees with Juan *et al.* (2018) and Zhao *et al.* (2022). In this study, CA root length was reduced along with the increase in BS concentration, especially in T4, where the root was reduced 28.9% compared with that of CK treatment. The contents of N, P, and K were increased in the soil surface (0 to 30 cm) after BS application, and CA roots could absorb enough mineral elements to maintain crop growth without growing into deeper soil. Thus, the average root length of drip irrigation with BS is shorter than that of CK treatment.

## Effect of Different Concentrations BS Drip Irrigation on CA Quality

The trend of the chlorophyll content of CA leaves (at leaf maturity), increasing and then decreasing along with the increase in BS concentration, agrees with the finding of Li *et al.* (2022). The soluble sugar and soluble protein contents reached their maximum in the T1 treatment and then decreased with the increase in BS concentration. However, those in all treatments were higher than the CK treatment. The maximum content of soluble sugar was 0.41g/100g, which was 41.4% higher than that of CK; the maximum content of soluble protein was 3.93 mg/g, which was 14.2% higher than that in CK. They both appeared in T1 treatment. This result is consistent with previous research (Juan *et al.* 2018; Wang *et al.* 2022). This study concludes that the application of BS can improve the quality of CA (Zhu *et al.* 2022).

## Effect of Different Concentrations BS Drip Irrigation on Soil Physical and Chemical Properties

Soil pH did not change considerably between treatments (Fig. 6a), and the range of variation did not exceed 5%. This result is consistent with Li *et al.* (2021a). Soil TN and AP content had a different level of improvement compared with the CK group. Especially, the AP content of the T4 group increased by 538% compared with the CK treatment. Soil TN and AK content increased by 32.5% and 84.8% compared with CK, respectively. The application of BS increased soil TN, AP, AK content in this study, and this result is supported by published results (You *et al.* 2019; Chen *et al.* 2020; Li *et al.* 2021b). However, the increase in AP was much higher in this study than in others. Kang *et al.* (2022) using a single dose of BS increased the soil AP content from 6.33 mg/kg (blank control group) to 72.6 mg/kg, with an increase in AP content of 1047%. Li *et al.* (2021a) showed that diluted digestate increased AP content by 70% compared with the blank control group (the AP content of the soil sample before the test was 19.7 mg/kg). The application of BS increased soil AP (46.1 mg/kg) in 0 to 20 cm by 6.8%, the original content was 43.0 mg/kg, in the study of Zuo *et al.* (2018). The original soil AP content of the present study (4.24 mg/kg) was like the soil used in Kang's experiment, which had insufficient AP content. Thus, the sharp increase (538%) in AP increment after the application of biogas in this study is acceptable.

## CONCLUSIONS

1. The yield and nutritional quality of Chinese cabbage (CA) could be significantly enhanced by replacing water and chemical fertilizers with biogas slurry (BS). Among the five treatments, T1 (25% concentration of BS) exhibited the most favorable treatment effect.
2. The average plant height of T1 was 34.2 cm, which was 1.2 times that of the control condition (CK) (water). The average dry weight of T1 reached 3.53g, which was 1.74 times more than that of the CK. The soluble sugar and soluble protein contents were 0.41% and 0.0039%, and they were 1.41 and 1.14 times that of the CK.
3. Different concentrations of BS had different effects on the soil. Application of BS increased the content of TN, AP, and AK in soil. The contents of TN, AP, and AK in T4 (100% concentration of BS) were 1.55, 27.1, and 426 mg/kg, which were 1.32, 6.38 and 1.85 times than that of CK. Low concentration of BS is conducive to the growth of CA. High concentration of BS is conducive to nutrient accumulation in soil.

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