Pak. J. Bot., 58(7): 1600-1607, July 2026.

ARTICLE DOI: http://dx.doi.org/10.30848/PJB2026-7(18)

EFFECTS OF MICROALGAE FERTILIZER ON SOIL QUALITY AND WHEAT GROWTH

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Abstract

Under the national policy advocating "sustainable" and "low-carbon" agricultural development, microalgae fertilizer, as an ecological and environmentally friendly biological fertilizer, has gained increasing scholarly attention for its potential to improve soil quality and enhance crop growth. Nitrogen-fixing cyanobacteria, autotrophic photosynthetic microorganisms capable of fixing atmospheric nitrogen and carbon, play a vital role in global energy conversion and biogeochemical cycles. In this study, applying varying concentrations of *Anabaena* sp. to potted wheat and using the supernatant as a control group (CK) allowed researchers to examine the effects of these concentrations on the growth of wheat seedlings as well as the physical and chemical characteristics of the soil. Results indicated that wheat treated with different concentrations of *Anabaena* sp. grew better than the control group. When the concentration of *Anabaena* sp. fertilizer was 0.04 mg/cm^2, the growth of wheat was the fastest, and the chlorophyll content, root length, and fresh weight were 50.8%, 18.1%, and 84.2% higher than those of the CK. Light energy utilization efficiency in wheat leaves significantly improved. At 0.023 mg/cm^2, the soil organic matter (SOM) content, nutrient content (N, P, K), soil nitrate reductase (S-NR), soil urease (S-UE), soil acid phosphatase (S-ACP), and soil alkaline phosphatase (S-AKP) activities all reached the highest values. The pH and conductivity values were lower than those of the control group.

Key words: *Anabaena* sp.; Pot experiment; Wheat; Soil quality

Introduction

Land salinization is a worldwide problem causing soil degradation. Salinization not only reduces the productivity of cultivated land but also seriously restricts the sustainability of cultivated land use and directly affects the sustainable development of agriculture (Lin *et al*., 2024). The harmfulness of saline-alkali soil is mainly reflected in its effect on the growth and development of plant communities, reducing the yield of grain crops and deteriorating the ecological environment. When soil salinization occurs in different types of soil, with different concentrations of salt ions, different geological characteristics emerge (Zhang *et al*., 2002). A bio-fertilizer is a kind of fertilizer with high efficiency and zero pollution effects. The long-term use of bio-fertilizers is beneficial to creating a positive soil circulation system and obtaining better economic and environmental benefits. Among the different kinds of biological fertilizers, microalgae fertilizer has attracted much attention because of its small size, simple structure, fast reproduction speed, and strong adaptability (Xu *et al*., 2024). There are many kinds of microalgae. At present, about 70% of the known algae are microalgae. In addition to increasing SOM and improving soil structure, microalgae may absorb and store large amounts of CO_2 (Yang *et al*., 2021). Emanga *et al*. studied the effects of *Chlorella* sp. and *Arthrospira platensis* on soil carbon, nitrogen, phosphorus contents, and soil aggregate stability in greenhouses (Emanga *et al*., 2019). It was found that both algae types could increase the concentrations of total carbon, total nitrogen, and available phosphorus (AP) in soil; and *Arthrospira platensis* could also increase the amount of nitrate nitrogen in the soil. Meanwhile, microalgae can produce plant hormones that promote plant growth. Chittapun *et al*. isolated two strains of *Nostoc* from paddy fields (Chittapun *et al*., 2018). They can secrete high levels of extracellular polysaccharides and indole acetic acid. Extracellular polysaccharides are capable of enhancing the stability of soil aggregates and mitigating the toxicity of heavy metals via biosorption. Meanwhile, indole acetic acid can stimulate seed germination and plant growth.

Nitrogen-fixing cyanobacteria can convert the free nitrogen in soil into organic nitrogen to provide a nitrogen source for crop growth. DE *et al*. first proposed nitrogen-fixing cyanobacteria as a type of 'green manure' to improve soil fertility in paddy fields (DE *et al*., 1939). For decades, people have continuously explored the potential use of nitrogen-fixing cyanobacteria to ensure sustainable plant production. In 1959, a study by Li *et al*. researched how nitrogen-fixing cyanobacteria affected rice growth, and their results showed that cyanobacteria increased by 23.74% compared with the control group (Li *et al*., 1959). Kong *et al*. compared the effects of using *Anabaena azotica Ley*, urea, and sheep manure as fertilizers for potted wheat and tomato. Their results showed that the fresh weight and dry weight of plants treated with

Received: 28-02-2025 Revised: 19-09-2025 Accepted: 25-10-2025 Online: 10-04-2026

nitrogen-fixing cyanobacteria fertilizer were 3 times and 2 times greater than those of the control, respectively, and the nitrogen content of the soil was increased by 416% after 90 days (Kong *et al*., 2016). Therefore, in addition to secreting plant growth-promoting substances that affect plant productivity and soil fertility, nitrogen-fixing cyanobacteria can also act as an organic input source in plant farming systems by providing nitrogen and carbon (Cordeiro *et al*., 2022). In this experiment, different concentrations of *Anabaena* sp. were applied to potted wheat roots to observe their effects on wheat growth and soil physical and chemical properties, providing an experimental basis for microalgae application to improve farmland soil quality and promote crop growth.

Material and Methods

Experimental materials: We collected saline-alkali soil (0~20 cm depth) from rice fields near Xiaobai River, Baotou, Inner Mongolia, China 40°31.614’N, 109°27.064’E）. We acquired the *Anabaena* sp. used in this experiment from the Chinese Academy of Sciences' freshwater algal species bank.

Experimental methods: Preparation of microalgae liquid fertilizer：We used BG11 medium for expansion (Rippka *et al*., 1979). After inoculating, we placed it on a culture rack and cultured it under artificial light conditions up to the logarithmic growth phase with intermittent ventilation. The cycle of light and dark was 12:12 h. We centrifuged the logarithmic-phase *Anabaena* sp. culture media (8000 r/min, 10 min), and the control group was the supernatant. *Anabaena* sp. in the logarithmic growth phase were diluted with the medium to different concentrations.

Determination of *Anabaena* sp. Biomass: *Anabaena* sp. solutions with gradient concentrations (OD680 values of 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, and 0.9) were made, and 50 mL was taken from each concentration. After passing through a glass fiber membrane, the solution was left in an oven set to 105°C for the entire night. After drying, the mass of the filter paper and sample was recorded as B and Y, respectively. We calculated the sample dry weight (DW) as the difference between the values of B and Y. The following regression equation was derived from SPSS analysis to examine the relationship between DW and liquid concentration (OD_{680}) of *Anabaena* sp.: DW (g/L) = 0.2378x – 0.0048 (R^2 = 0.9927). This equation was applied to calculate the biomass of *Anabaena* sp.

Application amount of potted wheat microalgae fertilizer: We took liquid samples of *Anabaena* sp. during its logarithmic growth phase. We applied *Anabaena* sp. fertilizer at concentrations of 0.008 mg/cm^2 (A1), 0.023 mg/cm^2 (A2), and 0.04 mg/cm^2 (A3). Three parallels were set for each treatment group. The supernatant of *Anabaena* sp. (CK) was used in the control groups. Each test basin was filled with soil weighing about 1 kg (12 cm high, 10.5 cm lower diameter, 15 cm upper diameter), and 30 wheat seeds were evenly planted in each test basin. The time of application of the microalgae solution in each group was 3 days before wheat seed sowing and 35 days after wheat seed sowing. On the 10th, 35th and 74th days, the plant height and leaf number of wheat were recorded. On the 74th day, we harvested the seedlings and measured the soil's physical and chemical indices, soil enzyme activities, and plant physiological indices.

Determination of chlorophyll content in wheat leaves: Using the ethanol extraction method, the amount of chlorophyll in wheat leaves was determined (Wang & Huang, 2015). We weighed 0.2 g of fresh leaves, transferred them into a mortar, added 3 mL of 95% ethanol solution along with a small amount of quartz sand and calcium carbonate powder, and ground the mixture to homogenize it. After adding 10 milliliters of a 95% ethanol solution, the leaf tissue was ground until it turned white. After being left to stand for 5 min, the mixture was centrifuged (6000 r/min) for 10 min (TG16-WS, Hunan Xiangyi Experimental Instrument Development Co., Ltd., Changsha, China). A 25 mL volumetric flask was filled with the supernatant, which was then diluted with a 95% ethanol solution. With the 95% ethanol solution as a blank, the absorbance of chlorophyll a and b was measured using a spectrophotometer at 665 nm and 649 nm (T 6-New Century, Beijing Puxi General Instrument Co., Ltd., Beijing, China). The contents of chlorophyll a and b and carotenoids were calculated according to Formulas (1) and (2), and the Formula (3) was used to determine the amounts of chloroplast pigments in leaves.

$$C_a \text{ (mg/L)} = 13.95 \times OD_{665} - 6.88 \times OD_{649} \quad (1)$$
$$C_b \text{ (mg/L)} = 24.96 \times OD_{649} - 7.32 \times OD_{665} \quad (2)$$
$$C \text{ (mg/g)} = (C_a + C_b) \times V / (m \times 1000) \quad (3)$$

The formula shows that C_a and C_b refer to the concentrations of chlorophyll a and chlorophyll b (mg/L). C indicates the content of chloroplast pigment in the leaves (mg/g). *V* represents the volume of the extract (mL), and m is the mass of the sample (g).

Determination of chlorophyll fluorescence parameters: Following 30 minutes of dark adaptation, the fluorescence characteristics of chlorophyll in the wheat leaves were examined using a plant efficiency device (Handy PEA, Hansatech, UK).

Determination of soil physical and chemical properties and soil enzyme activity: The soil physical and chemical properties were determined according to the method described by Bao (Bao, 2000). Soil organic matter (SOM) was determined via the external heating method. We quantified available phosphorus (AP) through sodium bicarbonate extraction combined with molybdenum-antimony colorimetry, and analyzed available potassium (AK) with a flame atomic absorption spectrophotometer (ZA3000, Hitachi Hi-tech Science, Tokyo, Japan). For alkaline hydrolysis nitrogen (AHN), we employed the alkaline hydrolysis diffusion method, while pH values were recorded directly using a calibrated pH meter. We measured electric conductivity (EC) directly with a DDS-307A conductivity meter (Shanghai Yidian Scientific

Instrument Co., Ltd., China) and quantified soil urease (S-UE) activity by applying the indophenol blue colorimetric method (Guo *et al*., 2012). Soil nitrate reductase (S-NR) was determined from the content of nitrite produced per unit time (Yu *et al*., 2022). We calculated the activities of soil acid phosphatase (S-ACP) and soil alkaline phosphatase (S-AKP) by referring to the quantities of phenols formed per unit time (Guan, 1982). The activity of soil catalase (S-CAT) was determined by measuring the absorbance of the solution at a wavelength of 240 nm after reaction with the soil (Johansson & Hakanborg, 1988). We measured all values with a microplate reader (Multiskan FC, Thermo Labsystems Co., Ltd., Middleton, WI, USA).

Data analysis

The mean ± standard deviation represents the test results. Software called SPSS 26 (IBM, USA) was used to conduct a one-way ANOVA, and the test results are presented as *P* values. *P* value less than 0.05 indicates that the tested objects show a significant difference; otherwise, the difference is not significant. Origin 2019 (Origin Lab, USA) was used for mapping.

Results and analysis

Effects of different concentrations of Anabaena sp. on plant height and root length of wheat: The plant heights and root lengths of wheat after the application of *Anabaena* sp. algae fertilizer were measured on the 10th, 35th, and 74th day after planting, and the results are shown (Fig. 1). After different concentrations of *Anabaena* sp. were applied, the plant heights and root lengths of wheat in each growth period could be ranked as A3>A2>A1. The plant heights in the A3 treatment group showed increases of 71.4%, 39.8%, and 32.6% on the 10^{th}, 35^{th}, and 74^{th} days, compared with the control group (CK) (p<0.05), as shown (Fig. 1(a). Similarly, the root lengths of the A3 treatment group showed increases of 56.3%, 32.7%, and 18.1%, respectively, compared with CK (p<0.05), as shown (Fig. 1(b)).

Effects of different concentrations of *Anabaena* sp. on dry weight of wheat plants: After different concentrations of *Anabaena* sp. were applied (Fig. 2), the dry weights of each treatment group increased significantly compared with CK (p<0.05). The dry weights of wheat plants were positively correlated with the treatment concentration of *Anabaena* sp.

Effects of different concentrations of Anabaena sp. on leaf number and chlorophyll content in wheat: Figure 3 illustrates the impact of varying microalgae treatment concentrations on the amounts of chlorophyll in wheat leaves. Following the application of varying concentrations of *Anabaena* sp., the A2 and A3 treatment groups exhibited a significant increase (p<0.05) in leaf number compared to the control (CK). However, the contents of chlorophyll in the leaf only increased significantly in the A3 group (p<0.05), where they were 50.8% higher than in the control group.

Effects of different concentrations of *Anabaena* sp. on chlorophyll fluorescence parameters of wheat leaves: Figure 4 illustrates the impact of *Anabaena* sp. at varying concentrations on chlorophyll fluorescence parameters in wheat. After 74 days of treatment, the maximum photochemical efficiency of photosystem II (Fv/Fm) in wheat leaves rose significantly compared to the control (CK), with the A3 group exhibiting the highest Fv/Fm value-12.3% greater than CK (p<0.05). At the point J of the fluorescence induction curve, the relative variable fluorescence intensity (Vj) in the A3 group dropped to its minimum level, showing a 15% reduction relative to the control (p<0.05). Additionally, all treatment groups displayed lower values for energy absorption per reaction center (ABS/RC) and heat dissipation per reaction center (DIo/RC) compared to CK, with both parameters declining progressively as the *Anabaena* sp. concentration increased. Conversely, the energy captured for electron transport per reaction center (ETo/RC) and the photosynthetic performance index (PI abs) of PSII in treated wheat leaves surpassed CK levels across all concentrations. The ETo/RC and PI abs values of the A3 experimental group increased by 34.7% and 64.1% compared with CK (p<0.05).

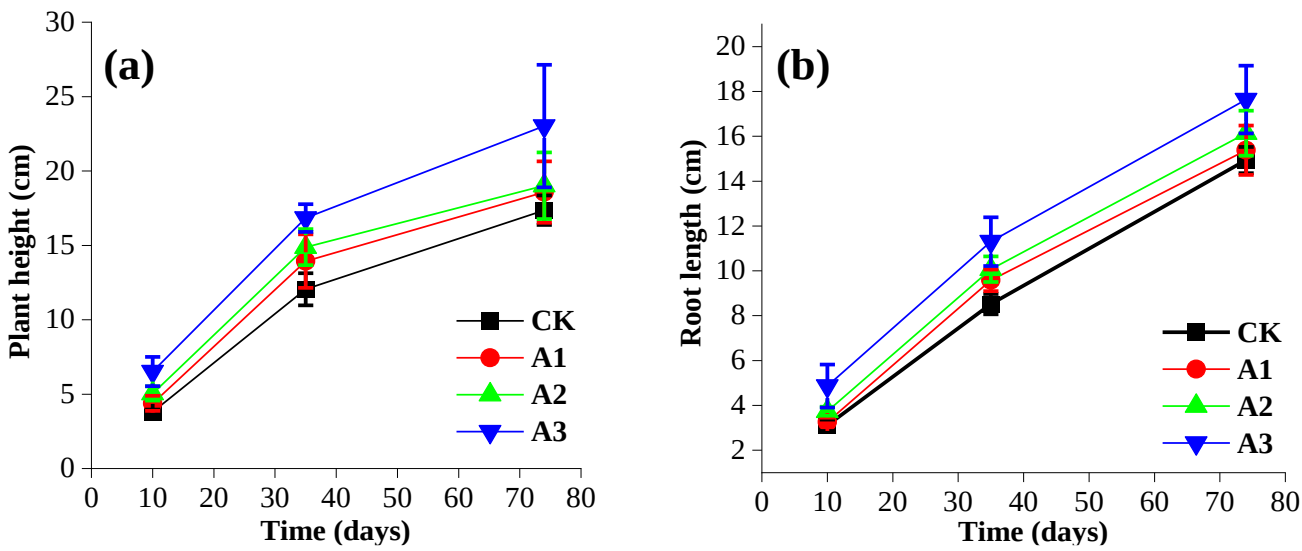

Fig. 1. Effects of different concentrations of *Anabaena* sp. on plant height and root length of wheat.

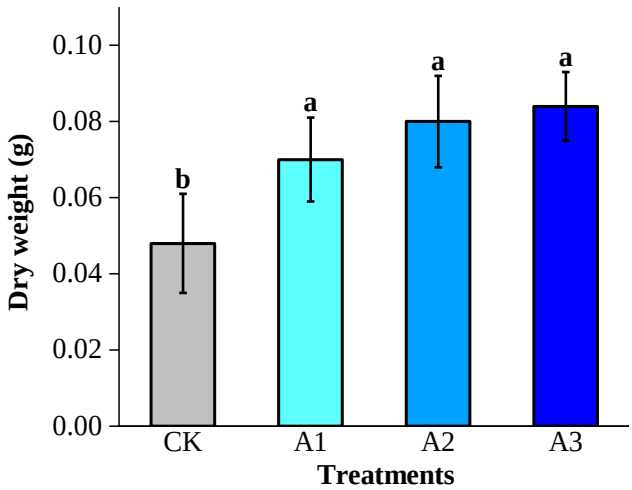

Fig. 2. Effects of different concentrations of *Anabaena* sp. on dry weight of wheat.

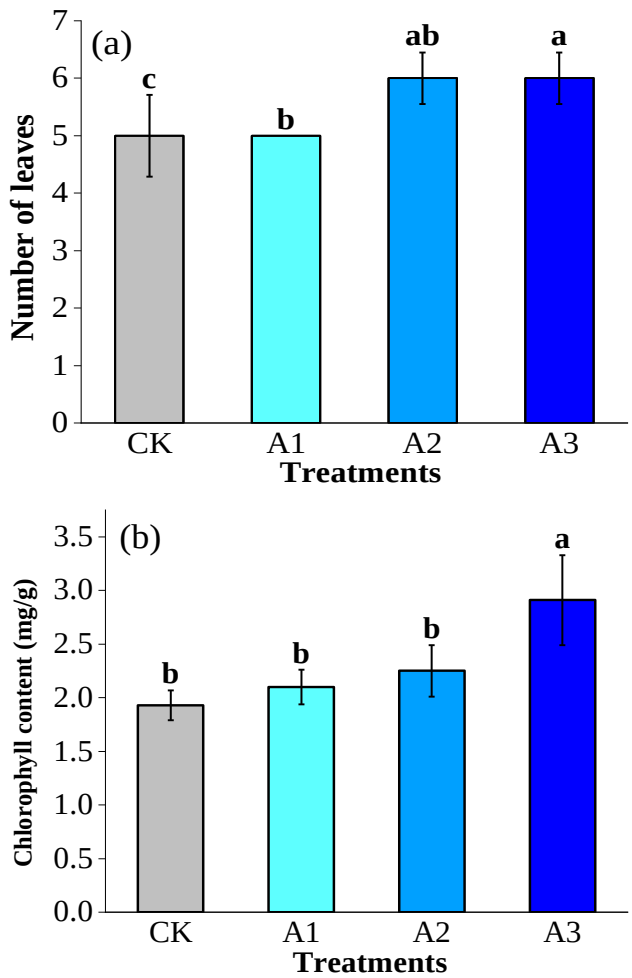

Fig. 3. Effects of different concentrations of *Anabaena* sp. on leaf number and chlorophyll content in wheat.

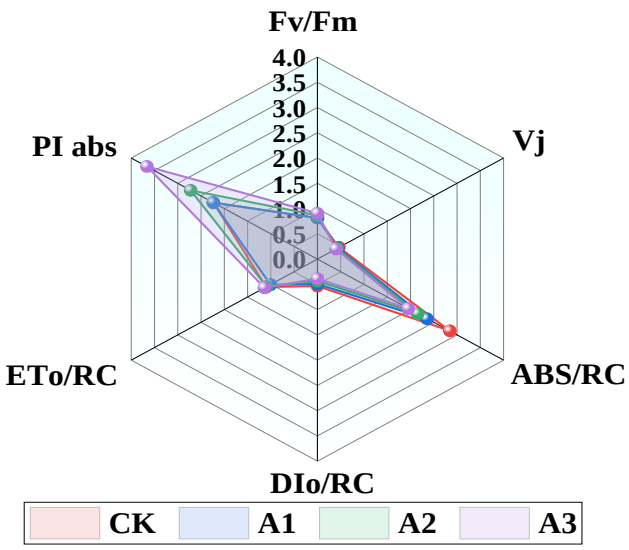

Fig. 4. Effects of different concentrations of *Anabaena* sp. on fluorescence induction kinetic parameters in wheat leaves.

Effects of different concentrations of *Anabaena* sp. on soil physical and chemical properties: Following wheat harvest, we analyzed physicochemical properties of potted soil treated with varying *Anabaena* sp. concentrations (Table 1). Compared to the original soil (OS), the CK group amended with *Anabaena* sp. supernatant exhibited significantly elevated soil organic matter content and nutrient levels (N, P, K) (p<0.05). Concurrently, CK displayed marked reductions in EC and pH (p<0.05). All treatment groups exhibited elevated levels of SOM, AHN, AP, and AK compared to the CK, alongside significant reductions in EC and pH (p<0.05). The A2 treatment group showed the highest concentrations of SOM and nutrients (N, P, K), with respective increases of 28%, 46.6%, 139.1%, and 47.5% relative to CK, while concurrently achieving reductions of 9.52% in pH and 25.53% in EC compared to CK.

Effects of different concentrations of *Anabaena* sp. on soil enzyme activities: As the treatment concentration went up, the activities of S-CAT in the presence of various concentrations of *Anabaena* sp. gradually increased. The S-CAT activity of the A3 treatment group was the highest at 7.026 U/g, which was 49.9% higher than that of the control group (Fig. 5(a)). The changes in S-UE, S-NR, S-ACP and S-AKP activities with different concentrations of *Anabaena* sp. manifested a single-peak curve, with the A2 treatment group reaching the peak, as shown in Fig. 5(b)~(e). Moreover, the activities of S-UE, S-NR, S-ACP and S-AKP in soil were increased by 64.9%, 108.9%, 97.1% and 33.7% compared with the control group (p<0.05).

Table 1. Effects of different concentrations of *Anabaena* sp. on soil physical and chemical properties. Annotation: OS (original soil).

Group	SOM (g/kg)	AHN (mg/kg)	AP (mg/kg)	AK (mg/kg)	EC (μS/cm)	pH
OS	28.14 ± 0.27 d	86.57 ± 6.35 c	6.33 ± 0.18 d	265.91 ± 4.67 d	1445.33 ± 8.33 a	7.97 ± 0.06 a
CK	37.86 ± 0.77 c	96.13 ± 6.73 bc	13.92 ± 3.82 c	310.67 ± 14.10 c	1296.67 ± 89.03 b	7.77 ± 0.06 b
A1	43.18 ± 0.26 b	113.63 ± 6.35 b	21.16 ± 3.49 b	375.00 ± 24.42 b	1167.00 ± 54.29 c	7.50 ± 0 c
A2	48.47 ± 0.50 a	140.93 ± 22.49 a	33.29 ± 1.65 a	458.33 ± 11.60 a	965.67 ± 30.66 d	7.03 ± 0.06 d
A3	47.75 ± 0.92 a	139.30 ± 3.21 a	30.37 ± 0.99 a	443.71 ± 18.26 a	973.67 ± 13.20 d	7.03 ± 0.06 d

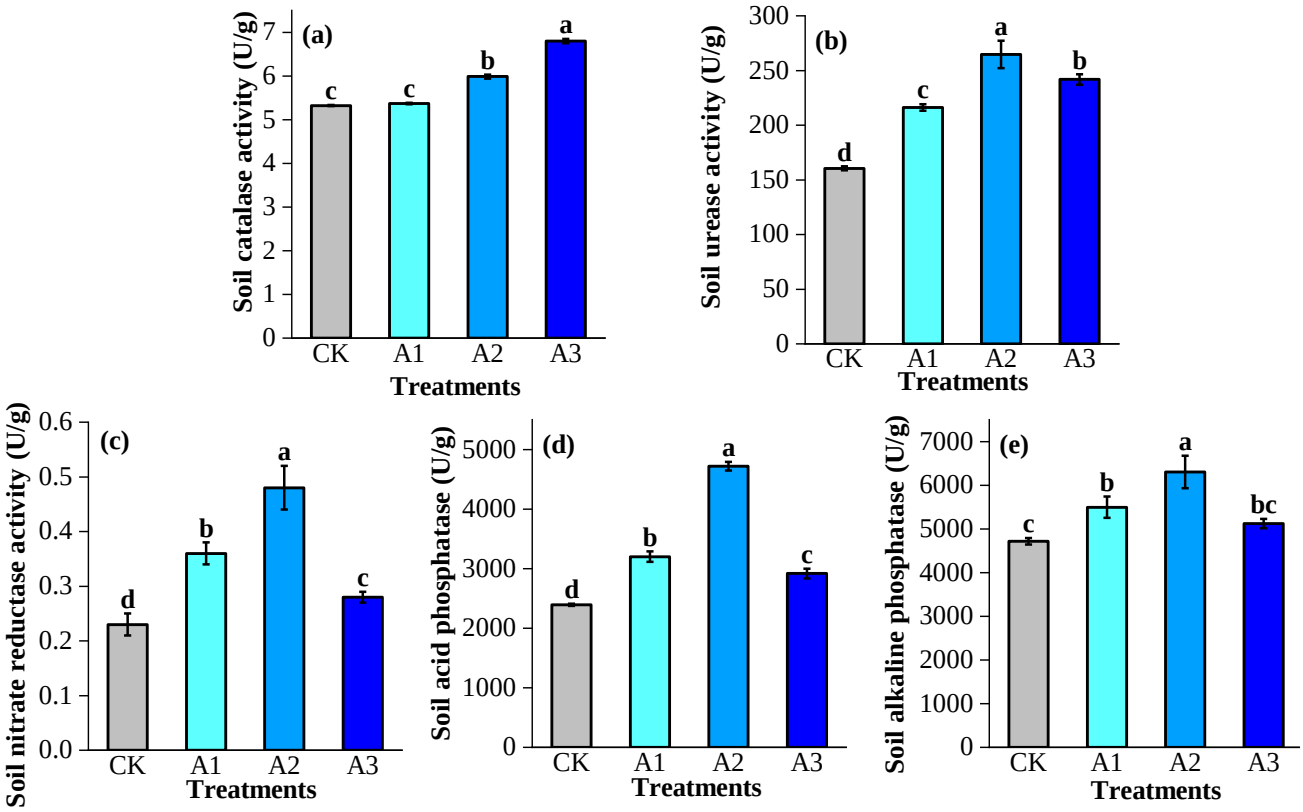

Fig. 5. Effects of different concentrations of *Anabaena* sp. on soil enzyme activities.

Discussions

Effects of different concentrations of *Anabaena* sp. on wheat growth: During this study, we examined how applying microalgae fertilizer affected the growth of wheat through the application of various concentrations of *Anabaena* sp. Different concentrations of *Anabaena* sp. were shown by the results to be able to promote the growth of wheat; this effect is closely related to the fact that microalgae can secrete plant growth-promoting substances and introduce organic matter into the soil. In this study, with an increase in the *Anabaena* sp. concentration, the promotional effects on the plant height, root length, chlorophyll content, and dry weights of wheat became more obvious. Gu *et al*. showed that the application amount of *Anabaena* sp. algae solution was positively correlated with the growth of arctium lappa seedlings (Gu *et al*., 2022). Grzesik *et al*. found that the growth of maize seedlings could be significantly improved by the single-plant culturing of *Microcystis aeruginosa* MKR 0105, *Anabaena* sp. PCC 7120, and *Chlorella* sp. (Grzesik & Romanowska-Duda, 2014). The main effect of microalgae on crops is that they can synthesize and secrete a variety of growth-promoting substances, such as auxin, gibberellin, and cytokinin (Hashtroudi *et al*., 2013). These bioactive substances are of great significance in plant development, metabolism, and growth regulation. They can stimulate seed germination and seedling growth, and also have an impact on fruit quality and crop yield. Microalgae are rich in trace elements and organic compounds, including plant hormones, vitamins, carotenoids, amino acids, and antifungal agents. These components have the potential to enhance soil fertility. Therefore, microalgae fertilizer can effectively promote the growth of wheat.

Effects of different concentrations of *Anabaena* sp. on chlorophyll fluorescence parameters of wheat: Chlorophyll fluorescence parameters have a close association with diverse reactions taking part in photosynthesis. As a result, they can mirror the activity of photosystem II as well as the 'inherent' traits of light-energy absorption, transmission, dissipation, and distribution in microalgae (Li *et al*., 2005). *Anabaena* sp. treatments at varying concentrations induced significantly elevated Fv/Fm and PI abs values compared to CK, demonstrating enhanced light-energy utilization efficiency in wheat leaves across experimental conditions. This photochemical improvement directly correlated with optimized photosynthetic capacity, a finding consistent with prior observations by Eisvand *et al*. (Eisvand *et al*., 2018). Vj represents the extent of closure of the active reaction center when illuminated for 2 ms. It also signifies the rate of photosynthetic electron transfer. A larger Vj indicates a lower photosynthetic electron transfer rate. In this study, the Vj values of the A3 treatment were lower than CK, indicating that applying microalgae fertilizer at this concentration can increase the photosynthetic intensity of wheat leaves by increasing the photosynthetic electron transfer rate.

The light energy absorbed by chlorophyll a in the antenna pigment protein complex of PSII is mainly dissipated in three ways: photosynthetic electron transfer, chlorophyll fluorescence emission, and heat dissipation (Abebe *et al*., 2023). The specific activity is capable of more precisely mirroring the absorption, conversion, and dissipation of light energy within the photosynthetic organs of plants. In this study, compared with CK, ABS/RC and DIo/RC decreased in the A3 treatment, but ETo/RC increased significantly (p<0.05). It can be inferred that the

number of active reaction centers increased to a higher degree than the degree of light energy absorption, and the energy used for electron transport increased in the A3 treatment. The heat dissipation energy was reduced, the light energy utilization rate of wheat leaves was improved, and the photosynthetic performance index of wheat leaves was increased; these results are similar to those obtained by Su *et al.* (Su *et al*., 2023). This improvement likely stems from *Anabaena* sp. enhancing nutrient absorptions in seedling roots, thus promoting the synthesis of chlorophyll, and this ultimately enhances the photosynthesis of plants and promotes the accumulation of photosynthetic products.

Effects of different concentrations of *Anabaena* sp. on soil physicochemical properties: The qualities of soil are dictated by its physicochemical properties. The inclusion of microalgae is an effective way to ensure the formation of organic matter. The effective reaction of the soil solution is first determined by the ratio of free carbon dioxide and carbonate. When algae proliferate, the soil's reaction also changes significantly. In this study, after different concentrations of *Anabaena* sp. were applied, compared with their respective control groups, the contents of SOM, AHN, AP, and AK increased, and the pH and conductivity decreased. The effect of the A2 treatment was particularly significant. This may be due to the fact that microalgae can form biological crusts in the soil, which is beneficial to an increase in SOM. In the soil ecosystem, the chloroplasts of algae cells can convert the CO_2 in the atmosphere into carbohydrates through photosynthesis (Guan *et al*., 2020). Dead algae can be used as a carbon source by nitrogen-fixing microorganisms and other heterotrophic microorganisms. Zhu *et al.* found that cyanobacterial sheaths can secrete viscous and negatively charged polysaccharides, which help to increase organic matter and reduce nutrient loss during leaching (Zhu *et al*., 2014). At the same time, cyanobacteria are capable of exerting a significant influence on the conversion of inorganic phosphates by secreting extracellular phosphatases and organic acids, and this can improve the plant utilization efficiency of phosphorus. Some algae can also dissolve insoluble $Ca_3(PO_4)_2$, $FePO_4$, $AlPO_4$, and hydroxyapatite in soil and sediments. In relation to increasing the phosphorus content in the soil, previous studies found that the nitrogen-fixing bacteria in biological crusts can fix the N_2 in the atmosphere as ammonia nitrogen and make it available for biological use (Belnap, 1996). The soil pH and EC decreased with different concentrations of microalgae, and the pH was maintained between 7.0 and 7.5. Because the nutrients in the soil were consumed to a certain extent, the growth of the algae cells was restricted, and the cells gradually died. At this time, the microorganisms in the soil decomposed the dead algae cells, resulting in a decrease in soil pH, while the growing algae consumed nutrients in the soil, such as soluble nutrients, including cations and anions, resulting in a decrease in EC. Liu *et al.* found that the contents of SOM, AHN, AP, and AK increased significantly when cucumber was grown with three kinds of microalgae liquid fertilizers, with results similar to those from this study (Liu *et al*., 2016).

Effects of different concentrations of *Anabaena* sp. on soil enzyme activities: Soil enzymes are mainly derived from the secretion of microorganisms and plant roots. An increase in microbial activity stimulates an increase in soil enzyme activity. S-UE and S-NR are directly involved in the conversion of soil nitrogen, and their activities directly reflect the content of nitrogen in soil (Huang *et al*., 2017). In the course of this study, compared to CK, *Anabaena* sp. treatment significantly increased S-UE and S-NR activities, indicating that the application of microalgae fertilizer increased the substrate of the enzymatic reaction and caused an increase in soil enzyme activity. Therefore, the content of nitrogen released into the soil was increased, and the nitrogen supply capacity of the soil was also improved (Sun *et al*., 2021). At the same time, it was also shown that S-UE and S-NR had common effects on the soil and could be used to reflect the fertility status of the soil to a certain extent. In this study, the activities of S-UE and S-NR manifested a single-peak curve in the application of different doses of *Anabaena* sp. The activity under the A2 treatment reached the peak, and the activity under the A3 treatment decreased but was higher than that in the control group. This phenomenon might be attributed to the fact that *Anabaena* sp. fertilizer is rich in organic matter. To some degree, this organic matter can enhance the activity of S-UE; however, high urease activity may increase the loss of nitrogen, and the metabolism of *Anabaena* sp. can change the activity of urease, thereby increasing the utilization rate of nitrogen. This effect is similar to that of biological bacteria water-soluble fertilizer on soil microorganisms, soil enzyme activity, and radish yield and quality, as studied by Song *et al.* (Song *et al*., 2017).

Soil phosphatase activity can be used to characterize soil organic phosphorus transformation ability. Soil phosphatase contributes to an increase in the inorganic phosphorus content, increases the content of AP in soil, and is beneficial to the absorption of phosphorus by plant roots. In the course of this study, it was found that after different concentrations of *Anabaena* sp. fertilizer were used, the activities of S-ACP and S-AKP grew. Compared with treatment A2, in treatment A3 after the application of *Anabaena* sp. fertilizer, the soil phosphatase activity decreased, but it was still higher than that in the control group, indicating that algae can transform the insoluble phosphate in soil and release AP for plants and microorganisms (Liu *et al.*, 2004). Relevant studies have shown that excessive levels of AP inhibit phosphatase; thus, phosphatase should be taken as a reference to evaluate soil fertility (Zhang *et al.*, 2001).

There is a close connection between S-CAT and the content of organic matter as well as the number of microorganisms in the soil (Guo *et al.*, 2022). In this research, we discovered that when fertilizers of varying concentrations of *Anabaena* sp. were used, the S-CAT rose in comparison with that in the control group. This might be because of the application of microalgae fertilizer, since *Anabaena* sp. is capable of creating crusts on the soil surface. Algae crusts can input organic matter into the soil and increase the number and activity of microorganisms, thereby increasing S-CAT.

Conclusion

Anabaena sp. promoted wheat growth, increased Fv/Fm, ETo/RC, and PI abs of the wheat leaf unit reaction center; and promoted chlorophyll accumulation. In addition, appropriate concentrations of *Anabaena* sp. fertilizer increased the contents of SOM, AHN, AP, and AK in soil used for wheat cultivation, along with enhancing soil enzyme activity, improving the soil ecological environment, and optimizing water and fertilizer retention.

Acknowledgement

This study was supported by the National Natural Science Foundation of China (No.42367057, 31660151), and the Basic Scientific Research Foundation for Universities Directly under the Inner Mongolia Autonomous Region (No.0406082407).

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