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Introduction Experiment of Annual Oat Forage and Screening of Microbial Fertilizer in Qinghai–Tibet Plateau

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Abstract: We conducted experiments to screen annual forage oats suitable for cultivation at high altitude (4200 m), and to establish a green fertilization system with microbial fertilizers and manure organic fertilizers in order to provide technical support for a sustainable forage production system in the pastoral areas of the Qinghai–Tibetan Plateau. The experiment followed the principle of randomized block design to systematically analyze the agronomic traits, yield quality, and soil health of oats among different treatments, and to screen for adaptable oat varieties and the optimal application rate of microbial fertilizers with organic manure. The results showed that the following: (1) The results of the oat variety screening test showed that the yield and quality indexes of 'Qing Yin No. 2' and 'Bai Yan No. 7' introduced in high altitude areas were higher than those of other oat varieties, with high membership function values of 0.69 and 0.65, respectively. (2) The combined application of microbial fertilizer and organic fertilizer showed that the combined application could significantly improve the growth and photosynthetic characteristics of 'Bai Yan No. 7'. The combination of the two also improved the yield quality of 'Bai Yan No. 7'; the hay yield with the BHC3 treatment was 8508.00 kg·hm^{-2}, significantly higher than the BCK treatment ($p < 0.05$). Regarding soil fertility, under the BHC3 treatment, compared with the BCK, soil nutrient contents and soil enzyme activities were also significantly improved ($p < 0.05$). At the same time, the combination of the two treatments also significantly improved the growth and photosynthetic characteristics of 'Qing Yin No. 2'. The combination of the two also improved the yield quality of 'Qing Yin No. 2', and the hay yield with the QDY4 treatment was 8707.67 kg·hm^{-2}, which was significantly increased by 25.37%, compared with that of QCK. Regarding soil fertility, under the QHC2 treatment, compared with the QCK treatment, soil nutrient contents and soil enzyme activities were also significantly improved. To sum up, 'Qing Yin No. 2' and 'Bai Yan No. 7' can better adapt to the ecological environment in high altitude areas, and are suitable for planting in areas with an altitude of 4200 m. The combined application of *Trichoderma harzianum*, *Bacillus licheniformis*, and organic fertilizer can improve the yield, nutritional quality, and soil fertility of 'Qing Yin No. 2' and 'Bai Yan No. 7'. The best treatment for 'Qing Yin No. 2' is QDY4, that is, 15.00 kg of *Bacillus licheniformis* is applied per hectare, and 18,000 kg of cattle and sheep manure organic fertilizer is applied per hectare. The best treatment for 'Bai Yan No. 7' is BHC3, that is, 6.00 kg of *Trichoderma harzianum* is applied per hectare, and 18,000 kg of cattle and sheep manure organic fertilizer is applied per hectare. With the above treatment, the forage grass grows best, the soil nutrient content in the forage grass field is the highest, and the input–output ratio is the highest.

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Keywords: Tibetan Plateau; forage yield; nutritional quality; microbial fertilizer; growth development; soil nutrients

1. Introduction

The climatic conditions in high-altitude areas such as the Qinghai–Tibet Plateau in China are harsh, which is influenced by low temperatures and short plant production periods, resulting in low forage yield [1]. At the same time, excessive use of chemical fertilizers leads to the decrease of soil microbial and enzyme activities, soil hardening, and low nutrient conversion efficiency, resulting in poor forage quality [2,3]. The above-mentioned natural and human factors have become the main difficulties restricting forage production in areas more than 4000 m above sea level. Oat (*Avena sativa* L.) is an annual herbaceous plant of the grass family, Oataceae (*Avena* L.), which is highly adaptable and rich in nutritional value, and plays an important role in the development of animal husbandry [4]. At present, some researches are devoted to cultivating high-yield and high-quality oat varieties to meet the needs of animal husbandry development [5]. For example, Wang et al. [6] improved the yield and stress resistance of different oat varieties through improvement and breeding. At the same time, it was found that different oat varieties had different nutrient contents and obvious differences in palatability and digestibility [7]. Therefore, it is an urgent problem to select oat varieties suitable for the local climate and soil conditions in high altitude areas and add reasonable nutrients.

The combined application of microbial fertilizer and organic fertilizer is an effective method to improve crop production efficiency and soil quality [8]. A large amount of organic matter in organic fertilizer can be decomposed by microorganisms and release nutrients for plants to absorb and utilize. In agricultural production, the combined application of microbial fertilizer and organic fertilizer can significantly improve crop yield [8]. For example, applying rhizobia microbial fertilizer and organic fertilizer to the roots of leguminous crops (such as peas, soybeans, lentils, etc.) can increase the nitrogen fixation efficiency of rhizobia and improve plant growth and development [9]. Fang et al. [10] studied the effects of a combined application of microbial fertilizer and conventional fertilization on potatoes, and found that the combined application of microbial fertilizer could increase the potato plant height by 7.8% to 9.4%. In actual production, the combined application of microbial fertilizer and organic fertilizer has a complementary effect, which can significantly increase the crop yield and improve the soil environment [11]. Due to the different application rates, there are great differences in the oat yield and quality after the combined application of microbial fertilizer and organic fertilizer [12]. Yang et al. [13] found that different fertilization methods have different effects on the nutrient content and composition of oats. However, in the high altitude area (4000 m), such as in Dari County, the climatic environment is harsh and changeable, and the production of oats is faced with various problems, such as vague fertilizer application amount, unreasonable fertilizer structure, low fertilizer utilization rate, single fertilizer type, and the application blank of microbial fertilizer in this area, which seriously limits the sustainable development of the oat forage industry in this area.

Based on this, the experiment of oat introduction aims to explore the adaptability of different oat varieties in high altitude areas. By comparing the growth physiological indexes of different oat varieties and evaluating the differences of nutritional components, the suitable oat varieties were screened for forage production in high altitude areas. At the same time, through the screening tests of microbial fertilizer and organic fertilizer, the purpose is to enrich the fertilizer types, to improve fertilization methods, and to promote

scientific, green, and sustainable fertilization measures, thereby improving oat yield and quality, and improving the soil properties in forage fields.

2. Materials and Methods

2.1. General Situation of Test Site

The experiment was conducted in 2023–2024. The experimental sites are located in Manzhang Township and Shanghongke Township, Dari County, Guoluo Tibetan Autonomous Prefecture, Qinghai Province. It is about 4200 m above sea level and belongs to the continental semi-humid climate on the plateau. The annual average temperature is −1.5 °C, the annual precipitation is 430 mm, there is no absolute first frost, the annual sunshine is 3320 h, and the forage growing season is about 130 d.

The tested soil is classified as Haplic Calcisol following the FAO classification system, the soil conductivity EC (water–soil ratio 1:5) is 705 us·cm^{-1}, and the soil pH is 8.87. The soil nutrient contents include organic carbon 34.21 g·kg^{-1}, total nitrogen 3.33 g·kg^{-1}, total phosphorus 1.52 g·kg^{-1}, total potassium 20.84 g·kg^{-1}, alkali-hydrolyzable nitrogen 177.60 mg·kg^{-1}, available phosphorus 34.11 mg·kg^{-1}, and available potassium 395.55 mg·kg^{-1}, respectively.

2.2. Test Materials

The oat varieties tested in the oat introduction test are 'Qing Tian No. 1', 'Bai Yan No. 7', 'Jia Yan', 'Lin Na', 'Qing Tian No. 2', and 'Qing Yin No. 2', all provided by Qinghai Academy of Animal Husbandry and Veterinary Sciences. See Table 1 for the information of the tested grass species.

Table 1. Information for the oat varieties tested.

Treatment	Latin	Variety Characteristics	Germination Percentage/(%)	Seed Purity/(%)	Thousand Grain Weight/(g)	Source
QT1	*A. sativa* L. 'Qingtian No. 1'	Early-ripe	91.00	93.68	46.43	Qinghai, China
BY7	*A. sativa* L. 'Bai Yan No. 7'	Medium cooked	81.11	90.21	36.60	Jilin, China
JY	*A. sativa* L. 'Jiayan'	Medium cooked	89.00	92.91	40.10	Ottawa, Canada
LN	*A. sativa* L. 'Linna'	Late-maturing	76.67	87.69	33.85	Oslo, Norway
QT2	*A. sativa* L. 'Qingtian No. 2'	Early-ripe	79.69	89.93	35.72	Qinghai, China
QY2	*A. sativa* L. 'Qing Yin No. 2'	Early-ripe	85.56	90.49	43.90	Qinghai, China

For the experiment on the combined application of microbial fertilizer and organic fertilizer, the grass species tested were 'Bai Yan No. 7' and 'Qing Yin No. 2'. The organic fertilizer for cattle and sheep manure (organic matter 15.0~25.0%, N + P_2O_5 + $K_2O \geq 5\%$, water content 30.0~35.0%, pH = 7.95) was provided by Qinghai Runda Agriculture and Animal Husbandry Science and Technology Co., Ltd. (Xining, China). The tested microbial inoculum was provided by Hubei Qiming Bioengineering Co., Ltd. (Wuhan, China), and the effective viable count of *Trichoderma harzianum* inoculum was ≥500 million·g^{-1}. The compound microbial inoculum was mainly composed of various highly active microbial bacteria, such as *Trichoderma*, *Bacillus* and their secondary metabolites, supplemented by various nutrient elements needed for plant growth, and the effective viable count was ≥100 million·g^{-1}. In microbial fertilizer, cadmium (Cd) ≤ 0.07 mg·kg^{-1}, chromium (Cr) ≤ 0.9 mg·kg^{-1}, arsenic (As) ≤ 0.08 mg·kg^{-1}, and the number of *Escherichia coli* in cattle and sheep manure ≤ 100·g^{-1}.

2.3. Experimental Design

2.3.1. Introduction Experiment of Oats

The experiment followed the principle of random block design, and the sowing amount of the six tested varieties was 225.0 kg·hm^{-2}. There were three replications for each treatment, and the experiment consisted of 18 plots, each with an area of 15.0 m^2 (3.0 m × 5.0 m), with a sowing rate of 337.5 g and a spacing of 1.0 m. The schematic diagram of the experimental plots is shown in Figure 1a. Sowing was performed by manual furrowing and strip sowing with a row spacing of 20.0 cm and a sowing depth of 3.0 to 4.0 cm, and compression was applied after sowing. Diammonium phosphate was applied as seed fertilizer, the application amount was 100 kg·hm^{-2}, and the fertilizer and soil were evenly mixed before sowing. In order to protect the growth of the crops, fences were set up for the enclosure, and irrigation and other agronomic measures were not carried out.

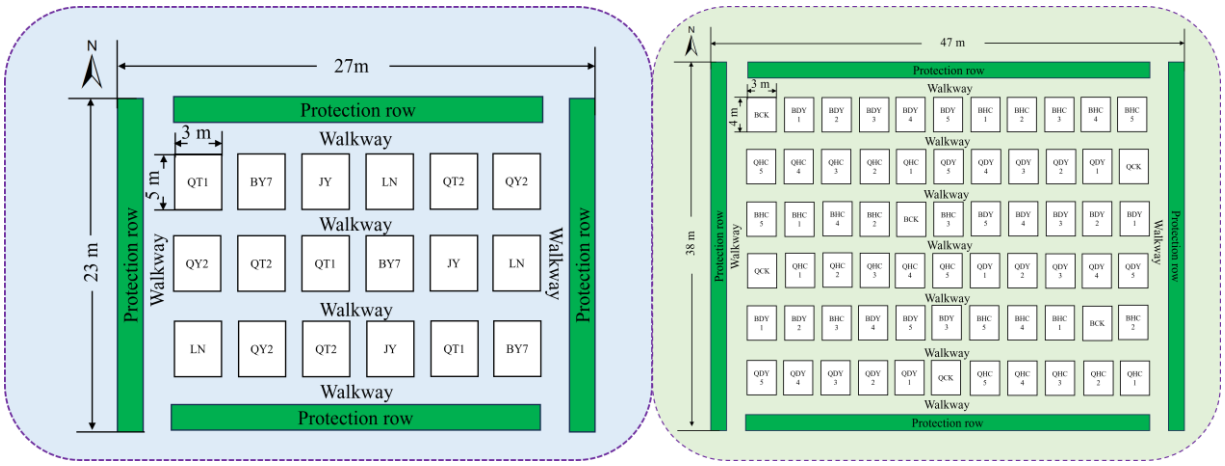


Figure 1. (**a**) Schematic diagram of oat introduction test plot. (**b**) Schematic diagram of the experimental plot of microbial fertilizer combined with organic fertilizer.

2.3.2. Screening Test of Combined Application of Microbial Fertilizer and Organic Fertilizer

The experimental plots followed the principle of randomized block group design, with five different application rates of *Bacillus licheniformis* fertilizer treatments and five different application rates of *Trichoderma harzianum* fertilizer treatments set in the experimental site of the oat cultivar 'Bai Yan No. 7'; the same fertilizer treatment was applied to 'Qing Yin No. 2'. There were a total of 20 fertilizer treatments and 2 control treatments (BCK, QCK), for a total of 22 treatments; the fertilizer application rate for each treatment is shown in Table 2. There are 66 plots with 3 replicates per treatment, with a plot area of 12.0 m^2 (3.0 m × 4.0 m), a plot seeding amount of 270.0 g, and a plot spacing of 1.0 m. See Figure 1b for the schematic diagram of the experimental plot. Sowing was performed by manual furrowing and strip sowing with a row spacing of 20.0 cm and a sowing depth of 3.0 to 4.0 cm, and compression was applied after sowing. The bottom fertilizer was cattle and sheep manure at a rate of 18,000 kg·hm^{-2}, which was mixed with different application rates of microbial fertilizers and tilled into the soil. Irrigation and other agronomic measures are not carried out in the experimental site.

Table 2. Application amount of test microbial fertilizer and organic fertilizer.

Treatment	Types of Microbial Agents Microbial Bacterial Fertilizer Types	Application Amount of Microbial Fertilizer/(kg·hm^{-2})	Application Amount of Microbial Fertilizer in the Experimental Plot/(g)	Application Amount of Cattle and Sheep Manure in the Experimental Plot/(g)
BCK, QCK				21,600
BDY1, QDY1	*Bacillus licheniformis* fertilizer	3.75	4.50	21,600
BDY2, QDY2	*Bacillus licheniformis* fertilizer	7.50	9.00	21,600
BDY3, QDY3	*Bacillus licheniformis* fertilizer	11.25	13.50	21,600
BDY4, QDY4	*Bacillus licheniformis* fertilizer	15.00	18.00	21,600
BDY5, QDY5	*Bacillus licheniformis* fertilizer	18.75	22.50	21,600
BHC1, QHC1	*Trichoderma harzianum* fertilizer	3.00	3.60	21,600
BHC2, QHC2	*Trichoderma harzianum* fertilizer	4.50	5.40	21,600
BHC3, QHC3	*Trichoderma harzianum* fertilizer	6.00	7.20	21,600
BHC4, QHC4	*Trichoderma harzianum* fertilizer	7.50	9.00	21,600
BHC5, QHC5	*Trichoderma harzianum* fertilizer	9.00	10.80	21,600

2.4. Sample Collection and Determination

2.4.1. Introduction Experiment of Oats

Plant height: The plant height of oat was measured with a tape measure. A total of 10 oat plants without disease were measured in each plot, and the average value was taken. Hay yield: Excluding the marginal range of 1 m in each plot, select five uniform 1 m sample sections, mow them flush with the ground, and weigh the fresh weight of forage grass. Bring the collected fresh grass samples back to the laboratory, deactivate them at 105 °C for 30 min, then dry them at 75 °C to constant weight, and weigh the dry weight of the forage grass. Nutritional determinations: crude protein (CP) content was determined by the Kjeldahl method; crude fat (EE) content was determined by the Soxhlet extraction method; soluble sugars (SS) and lignin (L) were determined by the near infrared method. Photosynthetic characteristics: A sunny and windless day was chosen to measure the photosynthetic characteristics, such as net photosynthetic rate (Pn), transpiration rate (Tr), leaf stomatal conductance (Gs), intercellular CO_2 concentration (Ci), and water utilization (WUE), of the flag leaves of the sample plants using the Li-COR 6400 portable photosynthesizer.

2.4.2. Experiment on Combined Application of Microbial Fertilizer and Organic Fertilizer

Agronomic traits: A total of 10 disease-free oat plants were randomly selected from each plot to determine the conventional agronomic traits of the oats. Measure the oat plant height with a tape measure; measure the flag leaf area with a hand-held leaf area measuring instrument; measure the flag leaf length and width with a ruler; and measure the diameter of the oat stem base with a vernier caliper. A total of 10 oat plants were randomly dug in each plot, and their roots were washed clean. The total length of the roots was measured by EPSON Perfection V850 Pro root scanner.

Photosynthetic characteristics: The SPAD value of the flag leaf was measured by hand-held SPAD-502Plus chlorophyll meter. The flag leaf was measured three times at the tip, middle, and base of the leaf, and the average value was taken. The photosynthetic characteristics of the flag leaves Pn, Tr, Gs, and Ci were measured by Li-COR6400 portable photosynthetic analyzer.

Production performance: Excluding the marginal 1 m range in each plot, five uniform 1 m sample sections were selected, mowed on the ground, and the fresh weight of the forage was weighed. Bring the collected fresh grass samples back to the laboratory, deactivate them at 105 °C for 30 min, then dry them at 75 °C to constant weight, and weigh the dry weight of the forage grass.

Nutrition determination: CP content was determined by the Kjeldahl method, and the content of EE was determined by Soxhlet extraction. Soluble sugar was determined

by near infrared method, while the contents of the neutral detergent fiber (NDF) and the acid detergent fiber (ADF) were determined by Fahrenheit's washing-up of fibers method. The following calculation formulas were used to determine the total digestible nutrients (TDN), the relative feeding value (RFV), the relative forage quality (RFQ), the dry matter digestibility (DDM), and the dry matter intake (DMI).

The total digestible nutrients (TDN) calculation formula is as follows:

$$\text{TDN} = 82.38 - (0.7515 \times \text{ADF}) \quad (1)$$

The relative feeding value settlement (RFV) calculation formula is as follows:

$$\text{RFV} = \frac{\text{DMI} \times \text{DDM}}{1.29} \quad (2)$$

The relative forage quality settlement (RFQ) calculation formula is as follows:

$$\text{RFQ} = \frac{\text{TDN} \times \text{DMI}}{1.23} \quad (3)$$

The dry matter intake rate (DMI) calculation formula is as follows:

$$\text{DMI} = \frac{120}{\text{NDF}} \quad (4)$$

The dry matter digestibility (DDM) calculation formula is as follows:

$$\text{DDM} = 88.90 - (0.779 \times \text{ADF}) \quad (5)$$

Soil quality: Five sampling points were set in the quadrat along the diagonal and central points. Five drills of soil in 0~20 cm soil layer [topsoil layer (layer A, cultivated layer of arable land with an average thickness of 19.5 cm)] were drilled with a soil drill with a diameter of 5 cm, which were evenly mixed into one soil sample. Gravel, litter, and plant residues were picked out and passed through a 2 mm sieve. With reference to Soil Agrochemical Analysis (3rd edition), soil organic carbon (SOC), total nitrogen (TN), total phosphorus (TP), total potassium (TK), alkaline dissolved nitrogen (AN), effective phosphorus (AP), quick-acting potassium (AK), and pH were measured, and soil enzyme activity was measured using the colorimetric method with p-nitrophenol substrate [14].

2.5. Data Analysis

GraphPad Prism 9.0 was used for data processing and graphing, and SPSS 25.0 was used for ANOVA. Based on the exact membership function method, principal component analysis was first performed to screen out the indicators that significantly affect the production performance, and the value of the affiliation function of each indicator was calculated. For the indicators positively related to the production performance, the calculation formula is as follows:

$$\mu(X_{ij}) = \frac{\text{Xij} - \text{Xjmin}}{\text{Xjmax} - \text{Xjmin}} \quad (6)$$

For indicators negatively related to the production performance, the calculation formula is as follows:

$$\mu(X_{ij}) = 1 - \frac{\text{Xij} - \text{Xjmin}}{\text{Xjmax} - \text{Xjmin}} \quad (7)$$

In the above formula, Xij represents the measurement result of the i-th treatment item of the j index, Xjmax represents the maximum value among the measurement results of the item j index of all treatments, Xjmin represents its minimum value, and μ(Xij) repre-

sents the membership function value of the i-th processing of the j-th index. Accumulate the membership function values of each index and find the average membership function value. The greater the mean value, the more significant the effect of the yield increase of this fertilization treatment.

3. Results

3.1. Introduction Experiment of Oat Varieties

3.1.1. Plant Height and Yield

As can be seen from Figure 2a, the plant height of the six oat varieties tested ranged from 93.28 cm to 109.33 cm, among which QT2 was the highest and QY2 was the shortest, with a significant difference ($p < 0.05$). It can be seen from Figure 2b that the hay yield of the six oat varieties tested reached the maximum at QY2, which was 6720 kg·hm^{-2}, which was significantly higher than other tested varieties ($p < 0.05$).

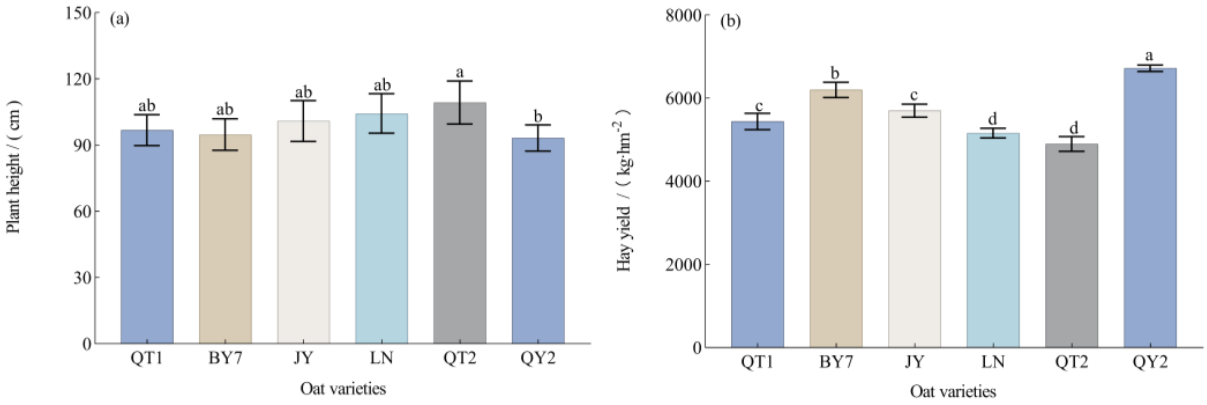


Figure 2. Analysis of plant height and hay yield of different oat varieties. Note: (**a**) Plant height of *Avena sativa* L.; (**b**) Hay yield of *Avena sativa* L. Different lowercase letters indicate significant differences at the level of $p < 0.05$. The same applies for the below figure.

3.1.2. Photosynthetic Characteristics

As can be seen from Figure 3, most of the flag leaf photosynthetic characteristics of the oats introduced at high altitude differed significantly among the oat varieties. The Pn of the six participating oat varieties varied between 8.36 and 10.96 μmol·m^{-2}·s^{-1}; QY2 had the highest levels, followed by BY7. There was no significant difference between them, but they were significantly higher than the other oat varieties ($p < 0.05$). The Ci and WUE of BY7 were the highest; there was no significant difference between BY7 and JY, and LN and QY2, but they were significantly higher than the other oat varieties ($p < 0.05$). The Tr ranged from 2.48 to 2.88 mmol·m^{-2}·s^{-1}, and the Gs ranged from 178.00 to 232.33 mmol·m^{-2}·s^{-1} for the six participating oat varieties. Both were highest in QY2 and lowest in QT1, with significant differences ($p < 0.05$). The WUE of the six participating oat varieties reached more than 3.00%, with BY7 and QY7 being the largest at 3.81%, which was significantly higher ($p < 0.05$) than QT1 and QT2.

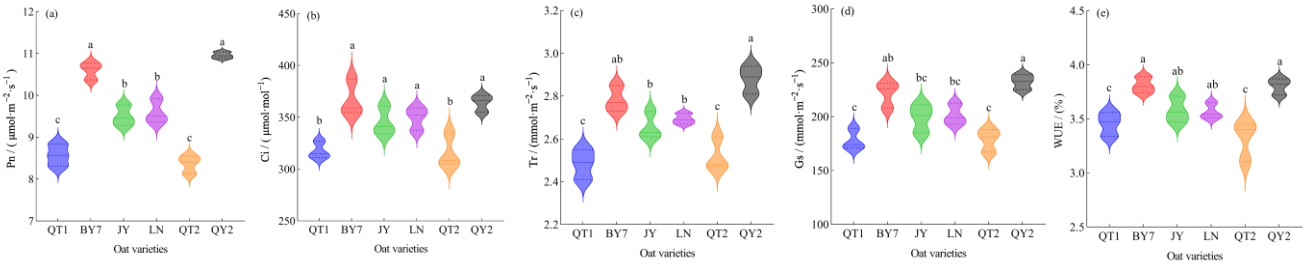


Figure 3. Analysis of photosynthetic performance of different oat varieties. Note: (**a**) Pn of *Avena sativa* L.; (**b**) Ci of *Avena sativa* L.; (**c**) Tr of *Avena sativa* L.; (**d**) Gs of *Avena sativa* L.; (**e**) WUE of *Avena sativa* L.

3.1.3. Nutritional Quality

It can be seen from Table 3 that, among the six oat varieties tested, QY2 has the highest CP content, which is 14.59%, which is significantly higher than the other oat varieties. The EE reached the maximum value in BY7, and the minimum value of QT2, with significant difference ($p < 0.05$). Among the six oat varieties tested, the SS content of BY7, JY, LN, and QY2 reached more than 10%. There were significant differences in the SS content among each variety ($p < 0.05$). Lignin (L) varied from 5.91% to 7.83%, among which, for QT2 content was the lowest, and for LN content was the highest; there was a significant difference between them.

Table 3. Analysis of nutritional quality of different oat varieties.

Oat Varieties	CP/(%)	EE/(%)	SS/(%)	L/(%)
QT1	11.30 ± 1.11b	6.15 ± 0.28b	8.67 ± 0.15f	6.80 ± 0.62c
BY7	11.80 ± 0.36b	8.05 ± 0.34a	10.00 ± 0.08d	7.14 ± 0.08bc
JY	10.10 ± 0.36c	6.37 ± 0.50b	11.03 ± 0.09b	7.50 ± 0.17ab
LN	7.65 ± 0.08d	6.71 ± 0.21b	10.57 ± 0.06c	7.83 ± 0.13a
QT2	7.10 ± 0.72d	5.36 ± 0.23c	9.72 ± 0.13e	5.91 ± 0.08d
QY2	14.59 ± 0.36a	7.52 ± 0.19a	13.02 ± 0.17a	7.65 ± 0.12ab

Note: data are mean standard deviation; different lowercase letters between data in the same column indicate significant differences at the level of $p < 0.05$. This applies similarly for the tables hereinafter.

3.1.4. Principal Component Analysis and Comprehensive Evaluation of Membership Function

The eigenvalues and contribution rates of principal component analysis are the basis for selecting principal components. Eleven indexes related to oat growth and development are transformed into three principal components, and the eigenvalues and contribution rates of each principal component are shown in Table 4. The contribution rate of the first principal component is 68.95%, the second principal component is 10.59%, and the third principal component is 5.98%, which can be explained as a total variation of 85.52%. The characteristic value of the first principal component is 7.58, and the absolute values for hay yield, CP, EE, SS, L, Pn, Ci, Tr, Gs, and WUE are higher, all of them exceed 0.65, and they have a high load. The eigenvalue of the second principal component is 1.17, and only the absolute value of plant height is 0.72, which has a high load. The eigenvalue of the third principal component is only 5.98, and the absolute values for each index are low.

The membership function method was used to comprehensively evaluate the six oat varieties tested (Figure 4). The results showed that the productivity of the six oat varieties from strong to weak was QY2 > BY7 > JY > LN > QT2 > QT1. Oat varieties 'Qing Yin No. 2' and 'Bai Yan No. 7' were introduced in high altitude areas with high yield, good quality, and the best production performance, followed by 'Jia Yan' and 'Lin Na'; 'Qing Tian No. 2' and 'Qing Tian No. 1' were the worst.

Table 4. Principal component analysis of the different oat varieties.

Item	Principal Component		
	PC1	**PC2**	**PC3**
Plant height	−0.51	0.72	0.11
Hay yield	0.92	−0.18	0.26
CP	0.77	−0.45	0.29
EE	0.90	−0.12	−0.29
SS	0.75	0.37	0.38
L	0.68	0.24	−0.42
Pn	0.98	0.07	−0.03
Ci	0.85	0.24	−0.20
Tr	0.90	0.30	0.09
Gs	0.90	0.17	0.13
WUE	0.89	−0.17	−0.16
Eigenvalue	7.58	1.17	0.66
Contribution rate/%	68.95	10.59	5.98
Cumulative Contribution rate/%	68.95	79.54	85.52

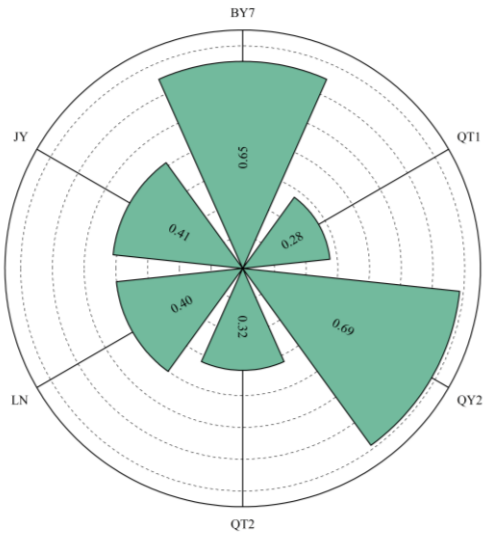


Figure 4. Comprehensive evaluation of the membership function of the different oat varieties.

3.2. Experiment on Combined Application of Microbial Fertilizer and Organic Fertilizer

3.2.1. Phenotypic Traits

It can be seen from Figure 5a that the diameter of the stem base of 'Bai Yan No. 7' in 10 microbial fertilizer addition treatments is between 7.20 and 8.46 mm. Except for the BDY1 treatment, the other nine microbial fertilizer addition treatments are significantly higher than the BCK treatment. The plant height of 'Bai Yan No. 7' with 10 microbial fertilizers varied from 82.33~105.00 cm, and the highest plant height was 105.00 cm in the BHC2 treatment, which was 36.95% higher than the BCK treatment, with significant difference ($p < 0.05$). The root length of 'Bai Yan No. 7' reached the maximum in the BHC3 treatment, while the BCK treatment was the smallest, with significant difference ($p < 0.05$). It can be seen from Figure 5b that the leaf area and width of 'Bai Yan No. 7' treated by BHC3 are the highest among the 10 microbial fertilizer addition treatments, which are 58.47 cm^2 and 23.77 cm, respectively, which are significantly higher than the BCK treatment ($p < 0.05$). Among the 10 microbial fertilizer treatments, the leaf length of the BHC2 treatment was the largest, at 61.97 cm, which was significantly increased by 37.71% compared with the BCK treatment ($p < 0.05$).

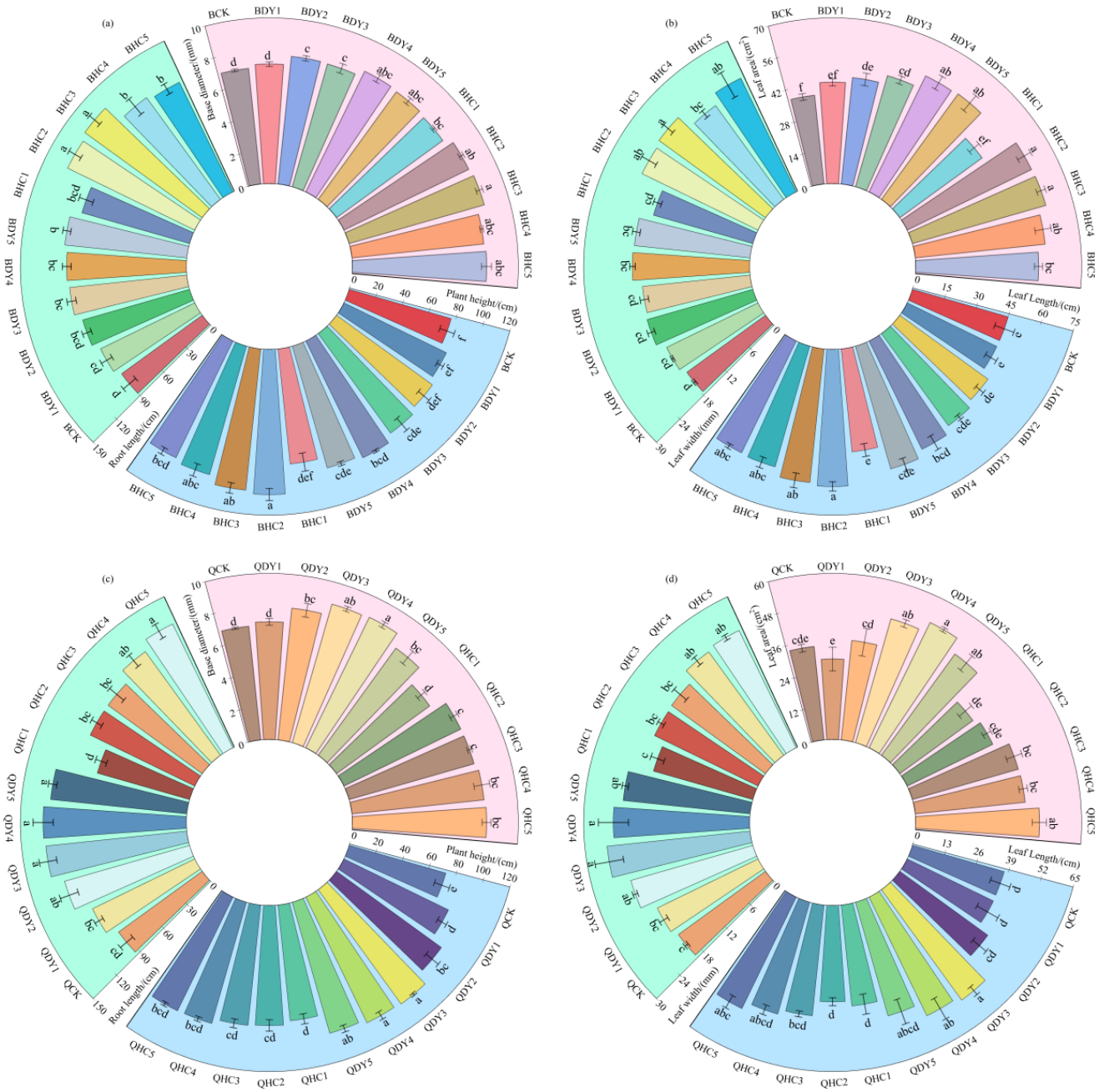


Figure 5. Analysis of phenotypic characteristics of the oat under different microbial fertilizer treatments. Note: (**a**) Morphological parameters of *Avena sativa* L. 'Baiyan No. 7': plant height, basal diameter, and root length; (**b**) Leaf traits of *Avena sativa* L. 'Baiyan No. 7': leaf length, leaf width, and leaf area; (**c**) Morphological parameters of *Avena sativa* L. 'Qingyin No. 2': plant height, basal diameter, and root length; (**d**) Leaf traits of *Avena sativa* L. 'Qingyin No. 2': leaf length, leaf width, and leaf area. Different lowercase letters in the same treatment group showed significant differences at the level of $p < 0.05$. The same applies for the below figures.

It can be seen from Figure 5c that the stem base diameter and root length of 'Qing Yin No. 2' with 10 microbial fertilizers were the highest in the QDY4 treatment, followed by the QDY3 treatment, and there was no significant difference between them, but they were significantly higher than those in the QCK treatment ($p < 0.05$). With the addition of 10 microbial fertilizers, the plant height of 'Qing Yin No. 2' reached the maximum value of 102.00 cm under the QDY3 treatment, which was significantly increased by 40.36% compared with the QCK treatment ($p < 0.05$). According to Figure 5d, the leaf area of 'Qing Yin

No. 2′ treated with 10 microbial fertilizers reached the maximum value of 50.33 cm^2 under the QDY4 treatment, which was significantly increased by 48.47% compared with the QCK treatment ($p < 0.05$). Among the 10 microbial fertilizer addition treatments, the leaf length and width of the QDY3 treatment for 'Qing Yin No. 2' were the highest, they were significantly higher than the QCK treatment, with increases of 43.05% and 33.59%, respectively.

3.2.2. Photosynthetic Characteristics

From Table 5, after 10 microbial fertilizers were added, the SPAD value of 'Bai Yan No. 7' reached the maximum value of 59.80 under the BDY4 treatment, which was 42.96% higher than that under the BCK treatment ($p < 0.05$). The Pn and Tr of 'Bai Yan No. 7' treated with BHC3 were the highest, which were 14.27 $\mu mol \cdot m^{-2} \cdot s^{-1}$ and 3.54 $mmol \cdot m^{-2} \cdot s^{-1}$, respectively, which were significantly higher than those treated with BCK, with increases of 40.31% and 33.58%. The Ci of 'Bai Yan No. 7' ranged from 372.33 to 428.00 μmol·mol-1, and the Ci for the BDY5 treatment was the highest, 19.00% higher than the BCK treatment ($p < 0.05$). The Gs of 'Bai Yan No. 7' was approximately between 234.33 and 330.00 $mmol \cdot m^{-2} \cdot s^{-1}$, which was significantly higher than the BCK treatment, and the increment was between 9.84% and 54.84% ($p < 0.05$).

Table 5. Analysis of the photosynthetic characteristics of the oat 'Bai Yan No. 7' under different microbial fertilizer treatments.

Treatment	SPAD	Pn	Ci	Tr	Gs
		/(μmol·m^{-2}·s^{-1})	/(μmol·mol^{-1})	/(mmol·m^{-2}·s^{-1})	/(mmol·m^{-2}·s^{-1})
BCK	41.83 ± 2.85b	10.17 ± 0.09g	359.67 ± 8.08c	2.65 ± 0.06h	213.33 ± 5.51e
BDY1	41.40 ± 3.26b	10.29 ± 0.10fg	372.33 ± 6.43c	2.78 ± 0.09gh	234.33 ± 8.33d
BDY2	44.68 ± 4.18b	10.76 ± 0.16efg	377.00 ± 7.21c	2.98 ± 0.11ef	256.00 ± 5.57c
BDY3	46.93 ± 3.83b	11.05 ± 0.11e	378.33 ± 5.51c	2.99 ± 0.07ef	268.67 ± 5.86c
BDY4	59.80 ± 1.28a	11.62 ± 0.24d	398.00 ± 15.39b	3.17 ± 0.07cd	292.00 ± 7.55b
BDY5	54.18 ± 2.96a	12.16 ± 0.42c	428.00 ± 7.00a	3.11 ± 0.08de	290.00 ± 5.57b
BHC1	46.50 ± 2.94b	10.85 ± 0.34ef	371.00 ± 7.00c	2.87 ± 0.09fg	261.33 ± 8.96c
BHC2	55.87 ± 0.75a	13.61 ± 0.33b	413.33 ± 9.87ab	3.37 ± 0.09b	330.33 ± 9.87a
BHC3	53.27 ± 3.08a	14.27 ± 0.33a	403.33 ± 10.97b	3.54 ± 0.07a	320.33 ± 11.37a
BHC4	57.57 ± 4.41a	12.46 ± 0.31c	396.67 ± 7.37b	3.30 ± 0.06bc	306.00 ± 4.58b
BHC5	58.86 ± 3.04a	12.44 ± 0.44c	404.33 ± 7.51b	3.30 ± 0.08bc	302.67 ± 8.02b

From Table 6, after 10 microbial fertilizers were added, the SPAD value of 'Qing Yin No. 2' reached the maximum value of 64.85 under the QDY3 treatment, which was significantly increased by 40.83% compared with the QCK treatment ($p < 0.05$). The Pn of 'Qing Yin No. 2' reached the maximum for the QDY4 treatment, reaching 14.91 $\mu mol \cdot m^{-2} \cdot s^{-1}$, significantly higher than the other treatments, the difference is significant ($p < 0.05$). The Ci was the highest for the QDY3 treatment, at 458.67 $\mu mol \cdot mol^{-1}$, which was significantly increased by 24.87% compared with the QCK treatment ($p < 0.05$). The Tr was higher for the QHC5 treatment, followed by the QDY3 treatment. There was no significant difference between the two treatments, but they were significantly higher than the QCK treatment ($p < 0.05$). The Gs for the QHC3 treatment was higher, at 376.00 $mmol \cdot m^{-2} \cdot s^{-1}$, which was significantly higher than that of the QCK treatment ($p < 0.05$), with an increase of 63.00%.

Table 6. Analysis of the photosynthetic characteristics of the oat 'Qing Yin No. 2' under different microbial fertilizer treatments.

Treatment	SPAD	Pn	Ci	Tr	Gs
		/(μmol·m^{-2}·s^{-1})	/(μmol·mol^{-1})	/(mmol·m^{-2}·s^{-1})	/(mmol·m^{-2}·s^{-1})
QCK	46.05 ± 1.84f	10.85 ± 0.15g	367.33 ± 4.04f	2.82 ± 0.07g	230.67 ± 7.37g
QDY1	49.07 ± 1.06def	11.27 ± 0.32fg	378.00 ± 8.89ef	3.03 ± 0.09f	249.67 ± 8.08f
QDY2	54.77 ± 4.59cde	13.07 ± 0.31d	416.67 ± 4.73bc	3.60 ± 0.06bc	308.00 ± 11.79d

Table 6. *Cont.*

Treatment	SPAD	Pn	Ci	Tr	Gs
		/(μmol·m^{-2}·s^{-1})	/(μmol·mol^{-1})	/(mmol·m^{-2}·s^{-1})	/(mmol·m^{-2}·s^{-1})
QDY3	64.85 ± 1.98a	14.33 ± 0.44b	458.67 ± 8.14a	3.79 ± 0.06a	350.00 ± 7.55b
QDY4	64.59 ± 2.94a	14.91 ± 0.13a	447.33 ± 8.50a	3.62 ± 0.05bc	327.33 ± 10.79c
QDY5	57.96 ± 4.18abc	13.94 ± 0.25bc	428.67 ± 13.43b	3.66 ± 0.05b	330.33 ± 7.02c
QHC1	47.65 ± 0.76ef	11.29 ± 0.36fg	380.33 ± 9.02ef	3.28 ± 0.07e	268.00 ± 9.54e
QHC2	50.44 ± 2.85def	11.71 ± 0.29ef	393.67 ± 5.03de	3.39 ± 0.07de	299.00 ± 10.58d
QHC3	55.77 ± 3.87bcd	12.01 ± 0.12e	401.67 ± 6.11cd	3.47 ± 0.05cd	376.00 ± 8.19a
QHC4	63.06 ± 0.46ab	13.34 ± 0.45cd	414.00 ± 6.25bc	3.61 ± 0.06bc	329.00 ± 9.17c
QHC5	62.52 ± 6.37ab	13.86 ± 0.27bc	423.00 ± 9.17b	3.89 ± 0.10a	323.67 ± 8.62c

3.2.3. Production Performance

It can be seen from Figure 6a–c that the combined application of microbial fertilizer and organic fertilizer can improve the fresh grass yield and hay yield of 'Bai Yan No. 7', but it has no significant effect on the fresh–dry ratio. Fresh grass yield of 'Bai Yan No. 7' for the BHC3 treatment was as high as 34,999.33 kg·hm^{-2}, which was significantly increased by 87.95% compared with the BCK treatment ($p < 0.05$) (Figure 6a). Hay yield of 'Bai Yan No. 7' was as high as 8508.00 kg·hm^{-2} under the BHC3 treatment, which was 30.17% higher than under the BCK treatment, with significant difference ($p < 0.05$) (Figure 6b). The fresh–dry ratio of the BDY5 treatment was the lowest, at only 3.98, which was 4.78% lower than the BCK treatment ($p > 0.05$) (Figure 6c).

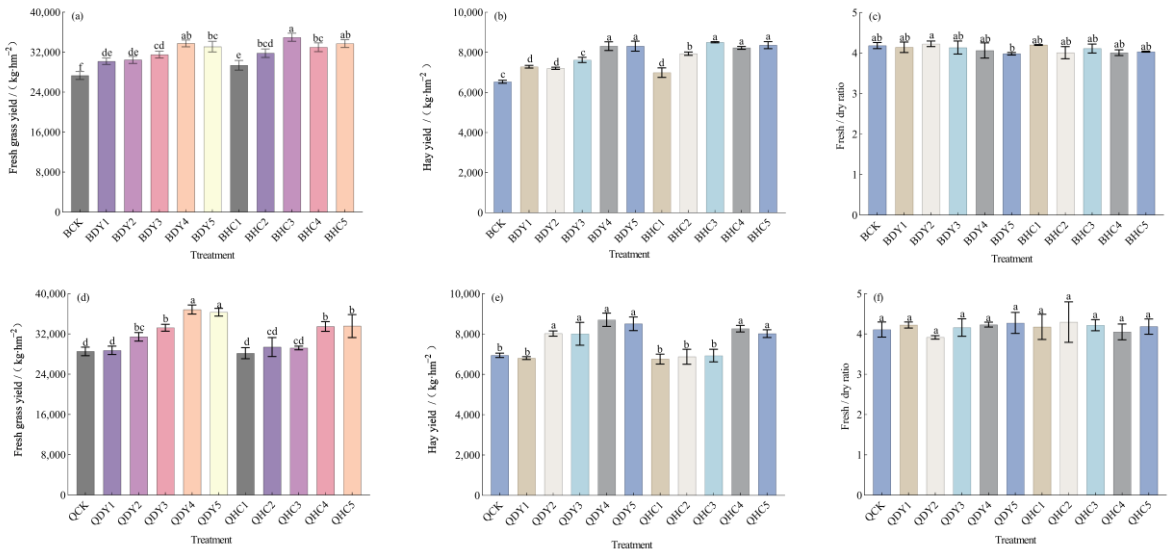


Figure 6. Analysis of oat production performance under different microbial fertilizer treatments. Note: (**a**) Freshgrass yield of *Avena sativa* L. 'Baiyan No. 7'; (**b**) Hay yield of *Avena sativa* L. 'Baiyan No. 7'; (**c**) Fresh/dry ratio of *Avena sativa* L. 'Baiyan No. 7'; (**d**) Fresh grass yield of *Avena sativa* L. 'Qingyin No. 2'; (**e**) Hay yield of *Avena sativa* L. 'Qingyin No. 2'; (**f**) Fresh/dry ratio of *Avena sativa* L. 'Qingyin No. 2'.

It can be seen from Figure 6d–f that the combined application of microbial fertilizer and organic fertilizer can improve the fresh grass yield and hay yield of 'Qing Yin No. 2', but it has no significant effect on the fresh–dry ratio. After 10 microbial fertilizers were added, the fresh grass yield of 'Qing Yin No. 2' reached the maximum value in the QDY4 treatment, which was 36,847.33 kg·hm^{-2}, significantly increased by 29.13% compared with the QCK treatment ($p < 0.05$). The oat hay yield of the QDY4 treatment was as high as 8707.67 kg·hm^{-2}, which was significantly higher than that of the QCK treatment by 25.37%

($p < 0.05$) (Figure 6e). The fresh–dry ratio for the QDY2 treatment was the lowest, at 3.92, which was 4.62% lower than that of the QCK treatment ($p > 0.05$) (Figure 6f).

3.2.4. Nutritional Quality

It can be seen from Table 7 that the combined application of microbial fertilizer and organic fertilizer can increase the contents of the CP, EE, and SS, decrease the DF, and increase the TDN of 'Bai Yan 7'. After 10 microbial fertilizers were added, the contents of the CP and SS of 'Bai Yan No. 7' were the highest for the BHC3 treatment, accounting for 11.68% and 15.48%, respectively, which was significantly higher than the BCK treatment ($p < 0.05$). The EE content of 'Bai Yan No. 7' ranged from 3.48% to 4.71%, with the highest content in the BHC5 treatment, which was 56.48% higher than the BCK treatment ($p < 0.05$). The contents of ADF for the BHC4 treatment were the lowest, which was 16.98% lower than the BCK treatment, with significant difference. The content of NDF for the BHC3 treatment was the lowest, which was significantly lower than the BCK treatment by 18.03% ($p < 0.05$). The TDN of 'Bai Yan No. 7' ranged from 56.43% to 58.15%, with the highest value for the BHC1 treatment, which was 4.17% higher than the BCK treatment ($p < 0.05$).

Table 7. Analysis of nutritional quality of oats 'Bai Yan No. 7' under different microbial fertilizer treatments.

Treatment	CP/(%)	EE/(%)	SS/(%)	ADF/(%)	NDF/(%)	TDN/(%)
BCK	8.28 ± 0.07e	3.01 ± 0.10e	10.96 ± 0.10g	35.34 ± 0.25a	42.33 ± 0.38a	55.82 ± 0.19f
BDY1	8.79 ± 0.24d	3.52 ± 0.18d	11.90 ± 0.14f	34.53 ± 0.34b	40.02 ± 0.66b	56.43 ± 0.25e
BDY2	9.60 ± 0.32c	3.48 ± 0.15d	12.72 ± 0.25e	34.39 ± 0.17b	37.52 ± 0.50c	56.54 ± 0.13e
BDY3	10.79 ± 0.28b	3.79 ± 0.11c	13.58 ± 0.25d	32.17 ± 0.60c	36.00 ± 0.62cde	58.20 ± 0.45d
BDY4	11.37 ± 0.29ab	4.17 ± 0.15b	14.21 ± 0.10c	30.33 ± 0.16e	35.68 ± 0.68de	59.59 ± 0.12b
BDY5	11.24 ± 0.33ab	4.12 ± 0.10b	14.10 ± 0.24c	30.94 ± 0.55d	37.12 ± 0.72cd	59.13 ± 0.41c
BHC1	9.31 ± 0.23c	3.70 ± 0.10cd	12.02 ± 0.39f	32.24 ± 0.22c	41.87 ± 0.80a	58.15 ± 0.17d
BHC2	11.41 ± 0.17ab	4.30 ± 0.09b	14.17 ± 0.19c	30.40 ± 0.24e	36.56 ± 1.48cd	59.53 ± 0.18b
BHC3	11.68 ± 0.26a	4.62 ± 0.15a	15.48 ± 0.25a	29.43 ± 0.37f	34.70 ± 1.42e	60.27 ± 0.28a
BHC4	11.55 ± 0.43a	4.54 ± 0.21a	15.01 ± 0.17b	29.34 ± 0.25f	37.36 ± 0.15c	60.34 ± 0.18a
BHC5	11.44 ± 0.38ab	4.71 ± 0.03a	15.14 ± 0.14ab	30.24 ± 0.22e	36.62 ± 0.51cd	59.66 ± 0.17b

It can be seen from Table 8 that the combined application of microbial fertilizer and organic fertilizer can increase the contents of the CP, EE, and SS, decrease the DF, and increase the TDN of 'Qing Yin No. 2'. After adding 10 microbial fertilizers, the contents of the CP and EE of 'Qing Yin No. 2' were the highest for the QDY4 treatment, which were significantly increased by 38.10% and 49.61%, respectively, compared with the QCK treatment ($p < 0.05$). The SS content of 'Qing Yin No. 2' was the highest for the QHC2 treatment, accounting for 15.35%, which was significantly higher than the QCK treatment. The content of ADF for the QDY5 treatment was the lowest, which was 28.78%, and the content of NDF for QDY3 treatment was the lowest, at 38.99%, which was significantly lower than the QCK treatment ($p < 0.05$). The TDN of 'Qing Yin No. 2' treated by QDY4 and QDY5 reached over 60%, which were 60.21% and 60.75% respectively, significantly higher than that of QCK ($p < 0.05$).

Figure 7a shows that the RFV of 'Bai Yan No. 7' was significantly improved after 10 microbial fertilizers were added. The RFV of BDY3, BDY4, BDY5, BHC2, BHC3, BHC4, and BHC5 were higher, which were 164.96, 170.21, 162.43, 166.12, 177.06, 164.45, and 166.02, respectively. There was no significant difference among the above treatments, but they were significantly higher than the BCK treatment ($p < 0.05$). The RFQ of 'Bai Yan No. 7' treated with BHC3 was the highest, at 169.62, which was 31.86% higher than that treated with BCK, with significant difference ($p < 0.05$) (Figure 7b). The RFV of 'Qing Yin No. 2' ranged from 129.14 to 156.37, and the RFV of the QDY5 treatment reached the highest value, which was 23.48% higher than the QCK treatment, with significant difference

($p < 0.05$) (Figure 7c). The RFQ of the QDY5 treatment for 'Qing Yin No. 2' was the highest, at 149.86, which was 23.87% higher than the QCK treatment, and the difference was significant ($p < 0.05$) (Figure 7d).

Table 8. Analysis of nutritional quality of oats 'Qing Yin No. 2' under different microbial fertilizer treatments.

Treatment	CP/(%)	EE/(%)	SS/(%)	ADF/(%)	NDF/(%)	TDN/(%)
QCK	9.03 ± 0.23g	2.54 ± 0.1d	12.30 ± 0.16f	33.48 ± 0.38a	46.18 ± 1.61a	57.21 ± 0.28e
QDY1	10.08 ± 0.31f	2.40 ± 0.02d	13.32 ± 0.32de	32.88 ± 0.15a	45.59 ± 0.62a	57.67 ± 0.11e
QDY2	10.9 ± 0.14e	3.00 ± 0.13c	13.05 ± 0.08e	31.15 ± 0.58bc	42.73 ± 1.16b	58.97 ± 0.44cd
QDY3	11.68 ± 0.13b	3.52 ± 0.12b	14.96 ± 0.23b	30.24 ± 0.22cd	38.99 ± 2.33c	59.65 ± 0.17bc
QDY4	12.47 ± 0.09a	3.80 ± 0.11a	14.81 ± 0.20b	29.37 ± 0.24de	39.31 ± 0.93c	60.31 ± 0.18ab
QDY5	12.29 ± 0.09a	3.42 ± 0.14b	14.35 ± 0.20c	28.78 ± 0.40e	39.56 ± 0.98c	60.75 ± 0.30a
QHC1	10.10 ± 0.24f	2.4 ± 0.01d	13.03 ± 0.20e	32.83 ± 0.11a	45.52 ± 0.49a	57.71 ± 0.08e
QHC2	11.59 ± 0.12bc	3.42 ± 0.12b	15.35 ± 0.09a	31.45 ± 0.16bc	40.76 ± 0.57bc	58.74 ± 0.12cd
QHC3	11.36 ± 0.28bcd	3.28 ± 0.13b	13.65 ± 0.27d	31.32 ± 0.24bc	39.59 ± 1.27c	58.85 ± 0.18cd
QHC4	11.22 ± 0.15cde	3.52 ± 0.11b	14.20 ± 0.10c	31.23 ± 1.70bc	41.94 ± 1.10bc	58.91 ± 1.28cd
QHC5	11.01 ± 0.14de	3.32 ± 0.21b	13.52 ± 0.30d	32.42 ± 0.21ab	41.03 ± 0.55bc	58.01 ± 0.16de

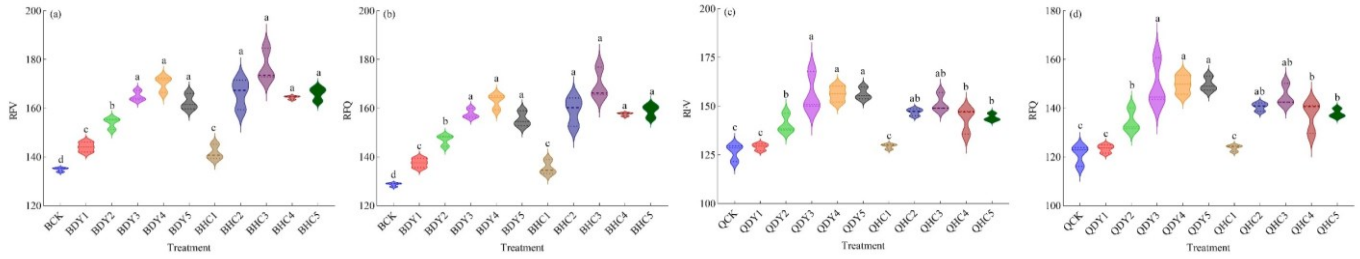


Figure 7. Analysis of the relative feeding value (RFV) and the relative forage quality (RFQ) of the oats under different microbial fertilizer treatments. Note: (**a**) relative feeding value (RFV) of *Avena sativa* L. 'Baiyan No. 7'; (**b**) relative forage quality (RFQ) of *Avena sativa* L. 'Baiyan No. 7'; (**c**) relative feeding value (RFV) of *Avena sativa* L. 'Baiyan No. 7'; (**d**) relative forage quality (RFQ) of *Avena sativa* L. 'Baiyan No. 7".

3.2.5. Soil Nutrients

It can be seen from Table 9 that the contents of SOC, AN, and AK in the forage field of 'Bai Yan No. 7' all reached the maximum values for the BHC3 treatment, which were 45.31 g·kg^{-1}, 294.27 mg·kg^{-1}, and 531.34 mg·kg^{-1}, respectively. Compared with the BCK treatment, the BHC3 treatment significantly increased by 35.58%, 60.86%, and 31.30%, respectively ($p < 0.05$). The contents of TN and AP in the soil of the 'Bai Yan No. 7' forage field were the highest for the BHC2 treatment, and the lowest for the BCK treatment, with significant differences ($p < 0.05$). The contents of TP and TK in the soil were the highest for the BDY4 treatment, at 2.17 g·kg^{-1} and 30.05 g·kg^{-1}, respectively, which were significantly higher than the BCK treatment ($p < 0.05$).

From Table 10, the content of the SOC was the highest for the QFH2 treatment, which was 39.32 g·kg^{-1}, significantly higher than the QCK treatment ($p < 0.05$). The soil TN content for the QDY5 treatment was the highest, at 4.03 g·kg^{-1}, which was significantly higher than the QCK treatment ($p < 0.05$). The contents of TP and AP in the soil treated by QDY4 were the highest, at 1.83 g·kg^{-1} and 43.37 mg·kg^{-1}, respectively, where were significantly higher than the QCK treatment ($p < 0.05$). The contents of TK and AK in the soil were the highest for the QDY3 treatment and the lowest for the QCK treatment, with significant differences ($p < 0.05$). The content of the soil AN in the forage field 'Qing Yin No. 2' was the highest for the QHC4 treatment, at 244.62 mg·kg^{-1}, which was significantly higher than the QCK treatments.

Table 9. Nutrient analysis of oat rhizosphere soil under different microbial fertilizer treatments 'Bai Yan No. 7'.

Treatment	SOC/(g·kg^{-1})	TN/(g·kg^{-1})	TP/(g·kg^{-1})	TK/(g·kg^{-1})	AN/(mg·kg^{-1})	AP/(mg·kg^{-1})	AK/(mg·kg^{-1})
BCK	33.42 ± 1.41e	3.35 ± 0.17d	1.49 ± 0.07c	21.51 ± 1.4d	182.94 ± 9.71d	33.83 ± 0.76e	404.67 ± 17.54e
BDY1	37.03 ± 1.33d	3.59 ± 0.08cd	1.63 ± 0.08bc	20.46 ± 1.46d	201.44 ± 9.52c	35.11 ± 0.56e	419.34 ± 8.21e
BDY2	40.26 ± 0.71b	3.83 ± 0.08c	1.72 ± 0.05abc	26.54 ± 1.90bc	248.29 ± 7.79b	39.28 ± 0.57bcd	445.43 ± 9.35d
BDY3	40.19 ± 0.81b	4.18 ± 0.05b	2.04 ± 0.06ab	25.10 ± 0.53c	244.15 ± 4.48b	40.36 ± 0.8abc	492.01 ± 7.91b
BDY4	42.08 ± 0.96bc	4.41 ± 0.22ab	2.17 ± 0.07a	30.05 ± 2.05a	274.15 ± 18.54a	41.91 ± 0.45ab	514.56 ± 16.67ab
BDY5	41.88 ± 0.77bc	4.35 ± 0.13ab	2.17 ± 0.06a	29.44 ± 0.61ab	272.15 ± 6.03a	40.81 ± 1.85abc	507.97 ± 4.57ab
BHC1	36.62 ± 3.18d	3.70 ± 0.27c	1.84 ± 0.09abc	25.09 ± 0.43c	229.85 ± 3.56b	37.44 ± 1.96d	470.73 ± 7.49c
BHC2	40.86 ± 0.77b	4.62 ± 0.20a	1.75 ± 0.57abc	28.50 ± 1.45ab	278.11 ± 7.05a	42.56 ± 1.54a	520.06 ± 24.00ab
BHC3	45.31 ± 0.69a	4.56 ± 0.08a	2.14 ± 0.08a	28.00 ± 0.33abc	294.27 ± 9.92a	40.33 ± 0.60abc	531.34 ± 6.22a
BHC4	44.48 ± 1.39ab	4.54 ± 0.05ab	2.05 ± 0.12ab	27.37 ± 0.46abc	276.11 ± 7.03a	39.83 ± 0.74abcd	526.17 ± 4.43a
BHC5	44.90 ± 0.82ab	4.50 ± 0.12ab	2.12 ± 0.08ab	27.91 ± 0.39abc	280.77 ± 6.98a	38.53 ± 0.87cd	509.84 ± 8.24ab

Table 10. Nutrient analysis of oat rhizosphere soil under different microbial fertilizer treatments 'Qing Yin No. 2'.

Treatment	SOC/(g·kg^{-1})	TN/(g·kg^{-1})	TP/(g·kg^{-1})	TK/(g·kg^{-1})	AN/(mg·kg^{-1})	AP/(mg·kg^{-1})	AK/(mg·kg^{-1})
QCK	32.89 ± 2.11b	3.26 ± 0.22c	1.55 ± 0.08c	23.02 ± 0.7b	173.11 ± 4.51e	34.90 ± 2.23f	398.12 ± 16.96c
QDY1	36.48 ± 2.98ab	3.57 ± 0.05b	1.62 ± 0.03bc	22.97 ± 2.47b	197.05 ± 11.5d	36.03 ± 0.73ef	421.44 ± 5.97ab
QDY2	35.27 ± 1.85ab	3.75 ± 0.18ab	1.64 ± 0.12abc	25.46 ± 1.44a	217.53 ± 6.29bc	36.21 ± 0.71ef	423.06 ± 10.69ab
QDY3	38.41 ± 0.11a	3.82 ± 0.07ab	1.77 ± 0.04ab	27.37 ± 0.13a	231.41 ± 17.83ab	40.22 ± 0.45bc	441.88 ± 13.79a
QDY4	38.96 ± 1.68a	3.96 ± 0.09a	1.83 ± 0.10a	27.35 ± 1.02a	232.34 ± 3.57ab	43.37 ± 0.47a	432.79 ± 5.40ab
QDY5	38.45 ± 2.87a	4.03 ± 0.14a	1.79 ± 0.02ab	27.26 ± 0.55a	235.63 ± 5.07ab	42.06 ± 1.05ab	435.81 ± 3.16ab
QHC1	35.84 ± 0.68ab	3.56 ± 0.07b	1.79 ± 0.04ab	25.95 ± 0.55a	204.36 ± 7.69cd	37.60 ± 0.46de	411.06 ± 4.51bc
QHC2	39.32 ± 0.69a	3.62 ± 0.09b	1.75 ± 0.14ab	25.62 ± 0.78a	230.14 ± 9.02ab	39.15 ± 1.15cd	416.34 ± 10.62abc
QHC3	38.56 ± 1.54a	3.86 ± 0.05ab	1.81 ± 0.03ab	27.06 ± 0.60a	236.43 ± 8.00ab	41.29 ± 1.25abc	437.95 ± 6.64a
QHC4	38.07 ± 1.03a	3.89 ± 0.13ab	1.80 ± 0.02ab	27.08 ± 1.29a	244.62 ± 3.65a	42.12 ± 0.23ab	432.94 ± 5.64ab
QHC5	37.72 ± 1.57a	3.82 ± 0.17ab	1.79 ± 0.01ab	26.85 ± 0.58a	232.37 ± 2.92ab	41.77 ± 1.39ab	430.40 ± 8.08ab

3.2.6. Soil Enzyme Activity and pH

It can be seen from Figure 8a with the addition of 10 microbial fertilizers, the soil pH of the 'Bai Yan No. 7' oat field was between 8.05 and 8.44, which was 2.20%~6.72% lower than the BCK treatment. The activity of soil S-βGC in 'Bai Yan No. 7' ranged from 90.55~124.61 U·g^{-1}, and the activity of S-βGC for the BHC2 treatment was the highest, which was 37.01% higher than the BCK treatment, with significant difference ($p < 0.05$). The S-NAG in the forage field of 'Bai Yan No. 7' reached the maximum value of 101.39 U·g^{-1} for the BHC3 treatment, while the BCK treatment was the smallest, at only 70.27 U·g^{-1}, with significant difference ($p < 0.05$). It can be seen from Figure 8b that the S-DHA activity of the 'Bai Yan No. 7' forage field for the BHC3 treatment was the highest, at 19.33 U·g^{-1}, which was significantly increased by 47.90% compared with the BCK treatment ($p < 0.05$). The activities of S-UE and S-NPT in the forage field of 'Bai Yan No. 7' treated by BDY4 were the highest, at 2171.02 U·g^{-1} and 0.84 μmol·d^{-1}·g^{-1}, respectively, they were significantly higher than those treated by BCK; the growth rates are 40.35% and 21.74%.

It can be seen from Figure 8c that the soil pH of the 'Qing Yin No. 2' oat field was the smallest under the QHC4 treatment, at 8.35, which was 2.5% lower than the QCK treatment. The activity of S-βGC in the forage field of 'Qing Yin No. 2' treated by QDY4 was the highest, at 148.12 U·g^{-1}, which was significantly higher than the QCK treatment, with an increase of 56.43%. The activity of S-NAG in the forage field of 'Qing Yin No. 2' treated by QDY3 was the highest, which was 119.61 U·g^{-1}, with an increase of 63.58% compared with the QCK treatment. It can be seen from Figure 8d that the soil S-DHA activity of the 'Qing Yin No. 2' oat field reached the maximum value of 21.12 U·g^{-1} under the QDY3 treatment, which was significantly higher than the QCK treatment by 46.67% ($p < 0.05$). The activities of S-UE and S-NPT in the 'Qing Yin No. 2' oat field were the highest for the QDY4 treatment, followed by the QDY5 treatment. There was no significant difference between them, but they were significantly higher than the QCK treatment ($p < 0.05$).

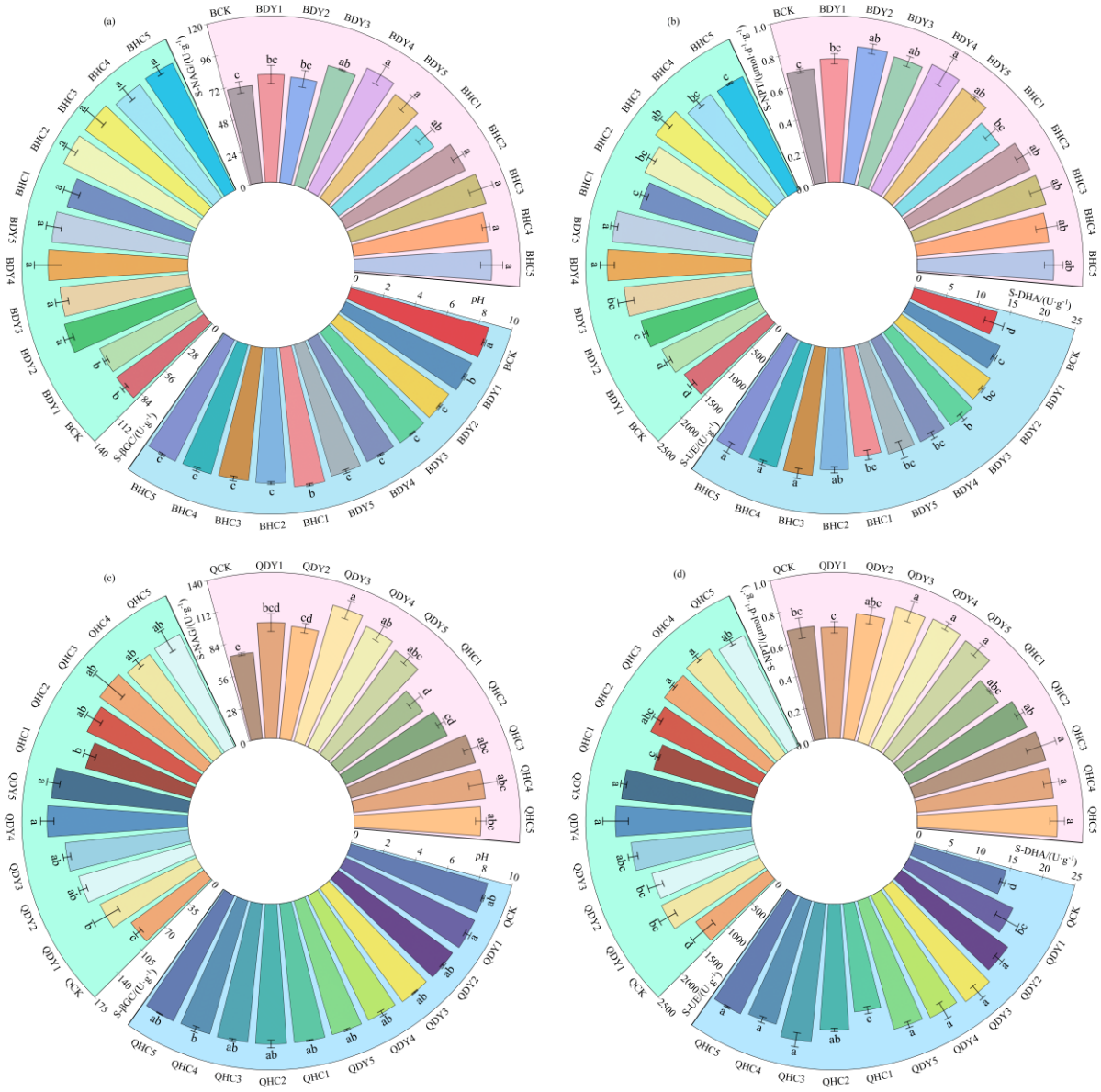


Figure 8. Analysis of soil enzyme activity and soil pH in oat rhizosphere under different microbial fertilizer treatments. Note: (**a**) Rhizosphere soil parameters of *Avena sativa* L. 'Baiyan No. 7': pH, β-glucosidase (S-βGC), and N-acetyl-β-D-glucosaminidase (S-NAG); (**b**) Rhizosphere soil enzyme activities of *Avena sativa* L. 'Baiyan No. 7': dehydrogenase (S-DHA), urease (S-UE), and neutral protease (S-NPT); (**c**) Rhizosphere soil parameters of *Avena sativa* L. 'Qingyin No. 2': pH, β-glucosidase (S-βGC), and N-acetyl-β-D-glucosaminidase (S-NAG); (**d**) Rhizosphere soil enzyme activities of *Avena sativa* L. 'Qingyin No. 2': dehydrogenase (S-DHA), urease (S-UE), and neutral protease (S-NPT).

3.2.7. Correlation Analysis

As can be seen from Figure 9a, there are 23 pairs of significant or very significant correlations between nine agronomic traits and production performance related indicators when microbial fertilizer and organic fertilizer are applied together, all of which are positive correlations. There is a negative correlation between the fresh and dry ratio and other indicators, but they have not reached a significant level. All the other indicators are positively correlated. Among them, plant height is related to root length, stem base diameter, and leaf width; root length is related to stem base diameter and leaf width; stem base diameter is related to leaf width; leaf length is related to leaf area; the yield of fresh grass is related to hay. The above reached a very significant level.

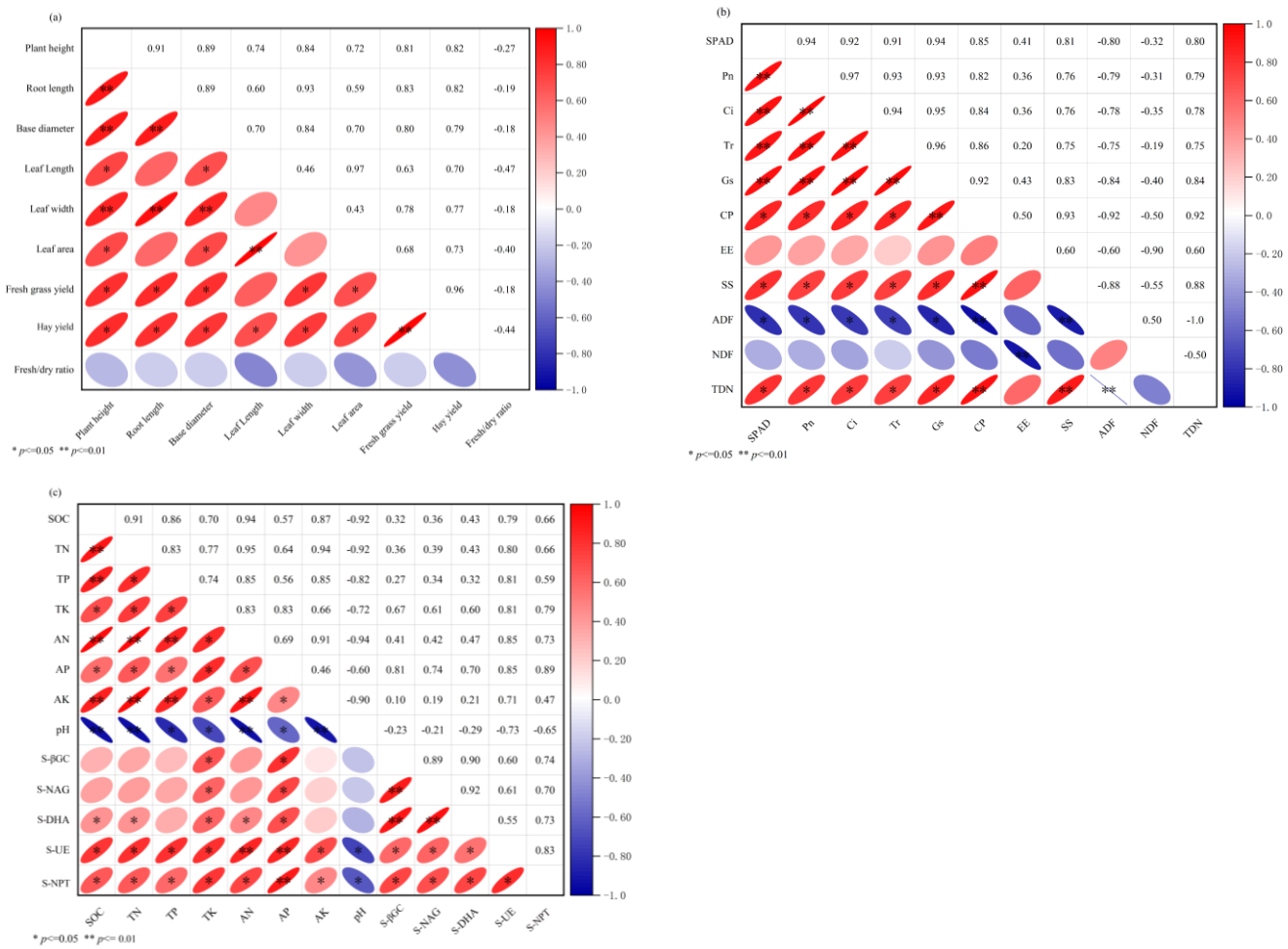


Figure 9. Correlation analysis of the agronomic characters and forage yield, the photosynthetic performance and nutritional value, and the soil chemical properties and soil enzyme activities of the oats under different microbial bacterial fertilizer treatments. Note: (**a**) Correlation analysis between oat forage yield and agronomic traits; (**b**) correlation analysis betweenphysiological characteristics and nutritional quality of oat forage; (**c**) correlation analysis between soilproperties and enzymatic activities in oat rhizosphere.

As can be seen from Figure 9b, there are 37 pairs of significant or very significant correlations between 11 photosynthetic characteristics and nutritional quality related indexes when microbial bacterial manure and organic fertilizer are applied together. Among them, there are 28 positive correlations and 9 negative correlations. There is a positive correlation between NDF and ADF. But both of them are negatively correlated with their indexes. Among them, the ADF and CP, SS, TDN were very significant, while the NDF and EE reached very significant levels. The other photosynthetic characteristics are positively correlated with the related indexes of nutritional quality. Among them, SPAD value, Pn, Ci, Tr and Gs reached a very significant level. The CP and SS, Gs, TDN reached very significant levels. There is a very significant level between the SS and TDN.

It can be seen from Figure 9c that there are 63 pairs of significant or extremely significant correlations among the 13 kinds of soil physical and chemical properties related indexes when microbial fertilizer and organic fertilizer are applied together, of which 54 pairs are positive correlations and 9 pairs are negative correlations. The soil pH has a negative correlation with the other soil nutrients and soil enzyme activities. Among them, the soil pH reached a very significant level with SOC, TN, AN, and AK. The other indexes related to soil physical and chemical properties are positively correlated. Among which the

SOC is related to TN, TP, AN, and AK; TN is related to AN and AK; TP is related to AN and AK; AN is related to AK and S-UE; AP is related to S-UE and S-NPT; S-βGC is related to S-NAG and S-DHA; S-NAG is related to S-DHA. All the above indicators reached a very significant level.

3.2.8. Principal Component Analysis, Comprehensive Evaluation of Membership Function, and Economic Benefit Analysis

Thirty-three indexes related to oat growth, yield quality, and soil quality were transformed into three principal components, and the characteristic values and contribution rates of each principal component are shown in Table 11. The contribution rate of the first principal component is 66.668%, the second principal component is 17.664%, and the third principal component is 4.196%, which can be explained as a total variation of 88.528%. The characteristic value of the first principal component is 22.000. Plant height, root length, stem base diameter, leaf length, leaf width, leaf area, fresh grass yield, hay yield, SPAD value, Pn, Ci, Tr, Gs, CP, EE, SS, ADF, NDE, TDN, SOC, TN, TP, TK, AN, AP, pH, S-βGC, S-NAG, S-DHA, S-UE, and S-NPT are higher, all exceeding 0.70, with a higher load. The eigenvalue of the second principal component is 5.829, and only the absolute value of AK is 0.71, which has a high load. The eigenvalue of the third principal component is only 1.385, and only the absolute value of the fresh–dry ratio is higher, which is 0.69.

Table 11. Principal component analysis of oats treated with different microbial fertilizer.

Item	Principal Component		
	PC1	**PC2**	**PC3**
Plant height	0.94	0.06	−0.16
Root length	0.88	0.26	−0.25
Base diameter	0.92	0.09	−0.07
Leaf length	0.74	−0.55	−0.22
Leaf width	0.83	0.43	−0.25
Leaf area	0.76	−0.56	−0.13
Fresh grass yield	0.88	0.08	−0.11
Hay yield	0.88	−0.03	−0.28
Fresh/dry ratio	−0.27	0.40	0.69
SPAD	0.86	0.41	−0.14
Pn	0.84	0.46	−0.23
Ci	0.84	0.48	−0.16
Tr	0.77	0.61	−0.02
Gs	0.89	0.43	0.03
CP	0.92	0.26	0.16
EE	0.74	−0.59	−0.05
SS	0.89	0.11	0.13
ADF	−0.90	−0.12	0.01
NDF	−0.72	0.57	−0.12
TDN	0.90	0.12	−0.01
SOC	0.77	−0.53	0.17
TN	0.83	−0.52	−0.04
TP	0.70	−0.53	0.22
TK	0.86	−0.12	0.16
AN	0.84	−0.49	0.09
AP	0.86	0.10	0.31
AK	0.66	−0.71	−0.05
pH	−0.72	0.63	−0.08
S-βGC	0.77	0.56	0.25
S-NAG	0.78	0.52	0.10
S-DHA	0.79	0.48	0.11
S-UE	0.86	−0.24	0.30
S-NPT	0.88	0.03	0.22
Eigenvalue	22.000	5.829	1.385
Contribution rate/%	66.668	17.664	4.196
Cumulative Contribution rate/%	66.668	84.331	88.528

The phenotypic characteristics, photosynthetic characteristics, yield quality, and soil quality of ‘Bai Yan No. 7’ under the combined application of microbial fertilizer and

organic fertilizer were comprehensively evaluated by the membership function method (Figure 10a). The results showed that the productivity of 'Bai Yan No. 7' and its forage field nutrients were higher than the BCK treatment; the order from strong to weak was BHC3 > BHC2 > BDY4 > BHC4 > BHC5 > BDY5 > BDY3 > BDY2 > BHC1 > BDY1 > BCK. That is to say, the combined application of microbial fertilizer and organic fertilizer can promote the growth and development of 'Bai Yan No. 7', improve the yield and quality of 'Bai Yan No. 7', and improve the soil nutrient content of 'Bai Yan No. 7'. The effect of the BHC3 treatment is the best, followed by BHC2, BDY4, and BHC4 treatment. The gap between the above treatments is small.

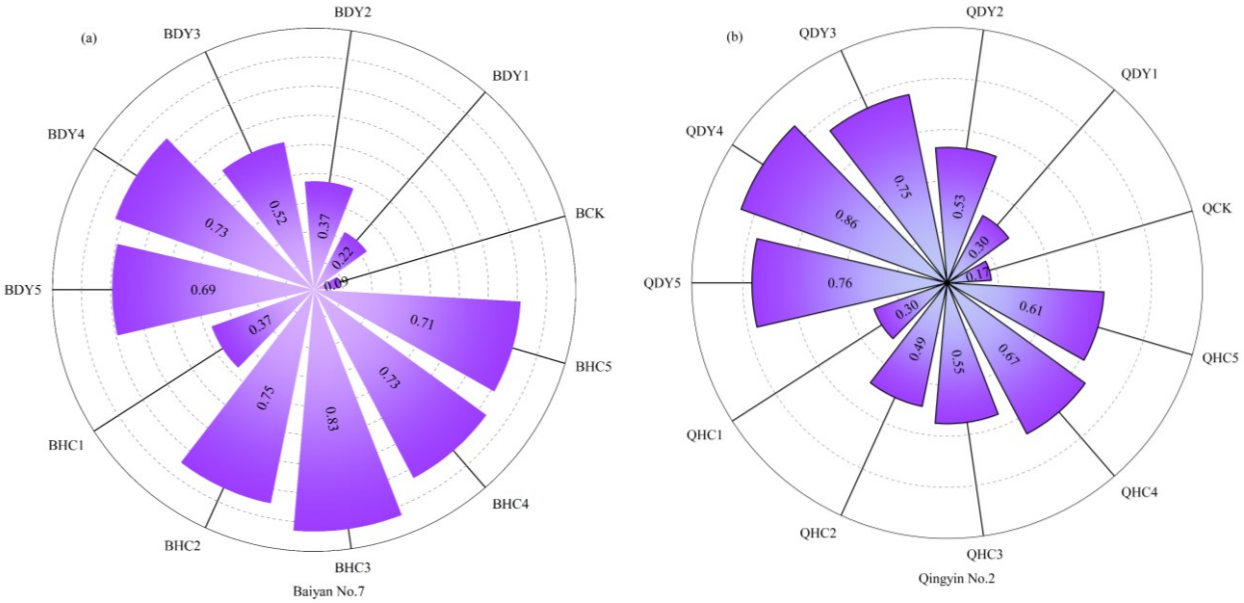


Figure 10. Comprehensive evaluation chart of oat membership function under different microbial fertilizer treatments. Note: (**a**) Membership function-based comprehensive evaluaton ot key indicators for *Avena sativa* L. 'Baiyan No. 7' across fertilization regimes; (**b**) membership function-based comprehensive evaluation of key indicators for *Avena sativa* L. 'Qingyin No. 2' across fertilization regimes.

At the same time, the membership function method was used to comprehensively evaluate the phenotypic characteristics, photosynthetic characteristics, yield quality, and soil quality of 'Qing Yin No. 2' under the combined application of microbial fertilizer and organic fertilizer (Figure 10b). The results showed that the productivity of 'Qing Yin No. 2' and its forage field nutrients were higher than the QCK treatment; the order from strong to weak was QDY4 > QDY5 > QDY3 > QHC4 > QHC5 > QHC3 > QDY2 > QHC2 > QDY1 > QHC1 > QCK. That is to say, the combined application of microbial fertilizer and organic fertilizer can promote the growth and development of 'Qing Yin No. 2', improve the yield and quality of 'Qing Yin No. 2', and improve the soil nutrient content of the 'Qing Yin No. 2' forage field. The QDY4 treatment has the best effect, followed by the QDY5, QDY3, and QHC4 treatment, and the gap between the above treatments is small.

It can be seen from Table 12 that the output value of the forage field of' Bai Yan No. 7' treated with 10 kinds of microbial fertilizers is 19,576.67~23,822.40 yuan·hm^{-2}, which is 6.97~30.17% higher than BCK. The economic benefit of the 'Bai Yan No. 7' forage field treated with 10 kinds of microbial fertilizers ranged from 17,001.67 to 21,112.40 yuan·hm^{-2}, which was 7.19~33.11% higher than that of BCK. The input–output ratio of the BHC3 treatment was the highest, at 7.79, which was 19.85% higher than that of BCK. From Table 13, it can be seen that the output value of the forage field of 'Qing Yin No. 2' treated by adding

10 kinds of microbial fertilizers is 18,926.13~24,381.47 yuan·hm^{-2}, and the economic benefit is 16,351.13~21,506.47 yuan·hm^{-2}, all of which reach the maximum at QDY4, increasing by 25.37% and 26.47% compared with QCK. The input–output ratio of the QDY4 treatment was the highest, at 7.48, which was an increase of 7.32% compared with BCK.

Table 12. Economic benefit analysis of oat 'Bai Yan No. 7' under different microbial fertilizer treatments.

Treatment	Application Amount of Organic Fertilizer/(kg·hm^{-2})	Organic Fertilizer Cost/(yuan·hm^{-2})	Application Amount of Microbial Fertilizer/(kg·hm^{-2})	Microbial Fertilizer Cost/(yuan·hm^{-2})	Fertilizer Cost/(yuan·hm^{-2})	Yield/(kg·hm^{-2})	Output Value/(yuan·hm^{-2})	Economic Benefits/(yuan·hm^{-2})	Input–Output Ratio
BCK	18,000	2440	—	—	2440.00	6536.13	18,301.17	15,861.17	6.50
BDY1	18,000	2440	3.75	108.75	2548.75	7287.33	20,404.53	17,855.78	7.01
BDY2	18,000	2440	7.50	217.50	2657.50	7206.00	20,176.80	17,519.30	6.59
BDY3	18,000	2440	11.25	326.25	2766.25	7623.67	21,346.27	18,580.02	6.72
BDY4	18,000	2440	15.00	435.00	2875.00	8314.00	23,279.20	20,404.20	7.10
BDY5	18,000	2440	18.75	543.75	2983.75	8311.33	23,271.73	20,287.98	6.80
BHC1	18,000	2440	3.00	135.00	2575.00	6991.67	19,576.67	17,001.67	6.60
BHC2	18,000	2440	4.50	202.50	2642.50	7936.67	22,222.67	19,580.17	7.41
BHC3	18,000	2440	6.00	270.00	2710.00	8508.00	23,822.40	21,112.40	7.79
BHC4	18,000	2440	7.50	337.50	2777.50	8228.33	23,039.33	20,261.83	7.29
BHC5	18,000	2440	9.00	405.00	2845.00	8361.33	23,411.73	20,566.73	7.23

Table 13. Economic benefit analysis of oat ' Qing Yin No. 2' under different microbial fertilizer treatments.

Treatment	Application Amount of Organic Fertilizer/(kg·hm^{-2})	Organic Fertilizer Cost/(yuan·hm^{-2})	Application Amount of Microbial Fertilizer/(kg·hm^{-2})	Microbial Fertilizer Cost/(yuan·hm^{-2})	Fertilizer Cost/(yuan·hm^{-2})	Yield/(kg·hm^{-2})	Output Value/(yuan·hm^{-2})	Economic Benefits/(yuan·hm^{-2})	Input–Output Ratio
QCK	18,000	2440	—	—	2440.00	6945.40	19,447.12	17,007.12	6.97
QDY1	18,000	2440	3.75	108.75	2548.75	6807.67	19,061.47	16,512.72	6.48
QDY2	18,000	2440	7.50	217.50	2657.50	8025.67	22,471.87	19,814.37	7.46
QDY3	18,000	2440	11.25	326.25	2766.25	8011.00	22,430.80	19,664.55	7.11
QDY4	18,000	2440	15.00	435.00	2875.00	8707.67	24,381.47	21,506.47	7.48
QDY5	18,000	2440	18.75	543.75	2983.75	8509.67	23,827.07	20,843.32	6.99
QHC1	18,000	2440	3.00	135.00	2575.00	6759.33	18,926.13	16,351.13	6.35
QHC2	18,000	2440	4.50	202.50	2642.50	6875.67	19,251.87	16,609.37	6.29
QHC3	18,000	2440	6.00	270.00	2710.00	6932.00	19,409.60	16,699.60	6.16
QHC4	18,000	2440	7.50	337.50	2777.50	8267.67	23,149.47	20,371.97	7.33
QHC5	18,000	2440	9.00	405.00	2845.00	8018.67	22,452.27	19,607.27	6.89

4. Discussion

4.1. Evaluation on Adaptability of Oat Varieties Introduced

Plant height is widely used to evaluate the quality and introduction adaptability of the oat germplasm resources [15]. He et al. [16] found that the plant height of oats introduced in Xining was between 80 and 146 cm, and the plant height of the six oat varieties introduced in this study was between 93 and 109 cm, which was consistent with the research results. At the same time, it was found that the plant height of QT2 was the highest among the six oat varieties tested, which indicated that the growth rate of QT2 in high altitude area (4200 m) was significantly higher than the other varieties tested. A total of 90~95% of plant dry matter comes from photosynthesis, and the photosynthesis of oat leaves directly determines the yield. Different oat varieties have different photosynthetic efficiency, which further leads to different yields [17]. In this experiment, BY7 and QY2 have the highest values in Pn, Ci, Tr, Tr, and WUE, which shows that BY7 and QY2 have stronger adaptability and faster growth and development in high altitude areas. Forage yield is an important indicator for assessing the productive and economic performance of oats. Zhao et al. [18] found that different oat varieties differed in yield, which may be due to the different adaptations of different varieties to specific habitats. There were significant differences in hay yield among the participating oat varieties in this study, with QY2 having the highest hay yield of 6720.00 kg·hm^{-2}, followed by BY7 with 6200.00 kg·hm^{-2}, which was significantly higher than the other varieties, suggesting that QY2 and BY7 performed better in terms of hay yield, with strong photosynthesis and high dry matter accumulation capacity, which was in line with the above research results. The hay yield of the six oat varieties tested in this study ranged approximately from 4900 to 6720 kg·hm^{-2}, while the oat introduction experiment made by Zhang et al. [19] in high altitude areas found that the hay yield of

each oat variety tested ranged from 8000 to 10,000 kg·hm^{-2}. The main reason for this difference in yield may be that the high altitude and low temperature in this experimental site shortened the growth period of the oats, resulting in low growth and development indexes of the oats and less sowing amount in each plot. However, the grass yield of QY2 and BY7 in this experiment was significantly higher than the average level of the county over the years.

The content of crude protein, crude fat, and soluble sugar is an important index to evaluate high-quality forage grass. High content of crude protein, crude fat and soluble sugar can provide rich nutrition for livestock, promote their development, and increase their milk yield [20,21]. In this study, it was found that the crude protein and soluble sugar content of QY2 were significantly higher than those of the other tested varieties, and the crude fat content of BY7 was significantly higher than those of the other tested varieties, indicating that QY2 and BY7 had high energy content and great feed value. The nutrient content of the different oat varieties is quite different, which may be related to the different genetic characteristics among the oat varieties or may be influenced by the natural environment [22]. To evaluate the adaptability and high yield of different varieties of forage oats introduced in high altitude areas, it is necessary to comprehensively consider multiple factors and, at the same time, comprehensively evaluate the production performance and nutritional quality [20]. Membership function is an effective method. Through a quantitative analysis and a comprehensive comparison of variety traits, the limitation of a single index is eliminated [23]. The calculation results of membership function show that QY2 and BY7 are superior in comprehensive evaluation, while QT1 is poor in overall performance. That is, 'Qing Yin No. 2' and 'Bai Yan No. 7' are two varieties with vigorous growth and high forage value, which are high-quality oat forage varieties suitable for planting in areas more than 4200 m above sea level in Dari County.

4.2. Study on Combined Application Technology of Microbial Fertilizer and Organic Fertilizer

It was found that the combined application of *Trichoderma harzianum*, *Bacillus licheniformis* and organic fertilizer could significantly promote the growth and development of the oats, especially for key indicators such as plant height, root length, and leaf area. With the increase of microbial fertilizer dosage, the plant height, root length, and leaf area of the oat were significantly improved. Under the BHC2 treatment, the plant height of 'Bai Yan No. 7' was significantly increased by 36.95% compared with the control treatment (BCK), and under the QDY3 treatment, the plant height of 'Qing Yin No. 2' was significantly increased by 40.36% compared with the control treatment (QCK). The reason for this phenomenon may be that microbial fertilizer can improve the decomposition rate of organic fertilizers, such as cattle and sheep manure, in high altitude areas, maintain the release of nutrients in forage fields, and provide sufficient nutrients for the growth and development of oats [14,24]. This is consistent with the research results of Miao Suping [25], the addition of microbial fertilizer can improve the growth and development speed of crops, and the promotion effect is different with different dosages. In addition, the combined application of microbial fertilizer and organic fertilizer can also enhance the photosynthetic efficiency and nutrient transport capacity of plants [26]. Flag leaf is the main organ of oat photosynthesis, and its area and photosynthetic characteristics directly affect the yield and quality of crops. The combined application of *Trichoderma harzianum* and *Bacillus licheniformis* microbial fertilizer and organic fertilizer can effectively improve the structure and function of leaves, improve their photosynthetic efficiency, and provide a stronger driving force for dry matter accumulation [27,28]. This is consistent with the research of Wildflush et al. [29], that is, microbial fertilizer can promote the absorption of nutrients, such as nitrogen, phosphorus and potassium, by improving soil microbial activity, thus enhancing leaf growth

and improving leaf photosynthesis. In addition, the DY4 and HC3 treatments significantly promoted the photosynthetic characteristics of the oats, but the DY5 and HC5 treatments inhibited the net photosynthetic rate, indicating that there may be a "saturation value" or a "threshold effect" in the application amount of microbial fertilizer or the density of the flora [30]. This result is consistent with the observation that "high dose of microbial fertilizer occasionally leads to internal competition of microbial communities or the reduction of soil nutrient conversion efficiency" in the related research of maize [31].

The addition of organic fertilizer, such as cattle and sheep manure, can supplement nitrogen, phosphorus, and potassium elements in the forage fields, improve soil structure, further accelerate the decomposition of organic fertilizer, improve soil microbial community structure, and improve the oat yield and quality [32,33]. In this study, it was found that microbial fertilizer with organic fertilizers significantly increased oat fresh and hay yields, especially under the BHC3 treatment. The fresh and hay yields of 'Bai Yan No. 7' were significantly increased by 87.95% and 30.17%, respectively, compared with the control treatment (BCK). Under the QDY4 treatment, the fresh grass yield and hay yield of 'Qing Yin No. 2' were as high as 36,847.33 kg·hm^{-2} and 8707.67 kg·hm^{-2}, which were significantly increased by 29.13% and 25.37%, respectively, compared with the QCK treatment. This result is consistent with Bao et al. [24], that is, the combination of microbial fertilizer and organic fertilizer can improve the soil microbial activity, promote the transformation and absorption of soil nutrients by plants, and then increase plant yield. It is worth noting that, although all the treatment groups showed a certain yield-increasing effect, the combination of different amounts of microbial fertilizer and organic fertilizer had different effects on yield synergy. The treatments of HC3 and DY4 significantly promoted the oat yield, but the treatments of HC5 and DY5 slightly inhibited the oat yield, which further showed that there might be a "saturation value" or a "threshold effect" in the application amount of microbial fertilizer or the density of flora [32]. Nutritional quality is the key to measure the feed value of oats, and the content of CP, EE, SS, and fiber directly affects the palatability and digestibility of the feed [21]. In this study, it was found that the combined application of microbial fertilizer and organic fertilizer could significantly increase the contents of CP and EE and decrease the fiber content of the oats. The CP content of 'Bai Yan No. 7' treated by BHC3 was as high as 11.68%, and the SS content was as high as 15.48%, while that of the control (BCK) was only 8.28% and 10.96%, respectively. The contents of CP and EE for the QDY4 treatment 'Qing Yin No. 2' were 12.47% and 3.80%, respectively, which were significantly higher than the QCK treatment by 38.10% and 49.61%. The fiber content decreased by 5%~40% with the addition of each microbial fertilizer. These results are similar to the existing studies on the feed quality of corn: when microbial flora and organic fertilizer work together, plants can absorb nitrogen, phosphorus, potassium, and some trace elements more efficiently, thus synthesizing protein and sugar in the body faster, while the fiber components in the cell wall are relatively reduced, thus improving the feed quality as a whole [34]. This change may also be related to the transformation of elements, such as nitrogen, phosphorus, and potassium, in the soil after the combination of microbial fertilizer and organic fertilizer. That is, fertilizer addition can promote soil microbial activities, improve soil properties, and increase the accumulation of nutrients in the oats [35].

Soil environment is one of the key factors affecting forage grass yield and quality. This study shows that the application of microbial fertilizer and organic fertilizer can effectively improve the soil nutrient content and, at the same time, regulate the pH and enzyme activity. Similar to the other scholars' research conclusions, microbial fertilizer can promote the decomposition and transformation of soil organic matter, form more stable soil aggregates, improve soil aeration and water holding capacity, and then improve the soil nutrient sta-

tus and enzyme activity, thus providing a better physical and chemical environment for crop root growth [32,33]. The experiment by Yu et al. [36] showed that the application of microbial fertilizer would increase the species and quantity of microorganisms in the soil, accelerate the decomposition of organic substances in the soil, and promote the absorption of nutrients by plant roots. In addition, the excessive or unbalanced application of microbial fertilizer would also lead to soil nutrient imbalance or pH fluctuation. In this study, the pH of the soil treated with HC1, HC5, DY1, and DY5 is high, indicating that the buffering capacity of the soil system is limited. If the amount of microbial fertilizer does not match the nutrient load, it may lead to stress on the soil ecological environment. In the experiment of Lyu et al. [37], the pH was decreased after the microbial fertilizer was applied, but when the mixed microbial fertilizer reached a certain concentration, with the increase of microbial fertilizer concentration, the pH no longer decreased but increased, which was consistent with the trend that the soil pH first decreased and then increased with the increase of microbial fertilizer concentration in this experiment. In high altitude areas, it is especially necessary to determine the best ratio of microbial fertilizer and organic fertilizer according to local conditions, so as to ensure the positive contribution to soil carbon and nitrogen cycle and avoid obvious impact on soil balance.

Based on the results of the principal component analysis and the membership function method, it can be seen that there are differences in promoting oat growth, enhancing forage quality, and improving soil quality with different microbial fertilizer types and different microbial fertilizer dosage. The treatments of BHC3 and QDY4 performed well on the whole, while the treatments of HC5 and DY5 were outstanding in some indexes, but they might show some limitations in photosynthetic efficiency or soil nutrient balance, and the input increased greatly, but the yield-increasing effect was not obvious. Similarly, in the application practice of high-yield crops, such as corn, it is often found that the input of "excessive microbial fertilizer" does not bring about a linear increase in yield or quality, but in some cases leads to an imbalance of soil microbial flora or a waste of resources [31]. Therefore, in view of the high altitude ecological environment and the cultivated land quality in different regions, it is necessary to scientifically formulate the combined application scheme of microbial fertilizer and organic fertilizer in combination with crop growth demand and ecological protection requirements. By regularly monitoring soil quality and crop growth indicators, the input strategy can be dynamically adjusted to maximize the synergistic effect of microbial fertilizer and organic fertilizer.

5. Conclusions and Prospect

5.1. Conclusions

(1) Six oat varieties planted in a high altitude area (4200 m) have obvious differences in plant height, hay yield, photosynthetic characteristics, and nutrient content. Among them, the hay yield of QY2 was as high as 6720 $kg \cdot hm^{-2}$, which was significantly increased by 37.14% compared with QT2, showing the advantage of high yield. In addition, the photosynthetic characteristics and nutrient contents of QY2 and BY7 were significantly higher than those of the other oat varieties, among which the net photosynthetic rate of QY2 was as high as 10.96 $\mu mol \cdot m^{-2} \cdot s^{-1}$, and the crude fat content of BY7 was as high as 8.05%. According to the comprehensive evaluation results of the membership function, the membership function values of QY2 and BY7 are 0.69 and 0.65, which are excellent and grade I. Comprehensive research and analysis show that QY2 and BY7 are two varieties with vigorous growth and high forage value, which are high-quality oat forage varieties suitable for planting in areas more than 4200 m above sea level in Dari County.

(2) The combined application of microbial fertilizer and organic fertilizer in high altitude areas significantly promoted the growth and development of oats and improved

the soil nutrient content in the oat field. 'Bai Yan No. 7' had the best treatment effect in BHC3, and its hay yield was 8508.00 kg·hm^{-2}, which was 30.17% higher than the control group. 'Qing Yin No. 2' had the best effect for the QDY4 treatment, and its hay yield was 8707.67 kg·hm^{-2}, which was 25.37% higher than the control group. The BHC3 and QDY4 treatments not only significantly enhanced the yield of 'Bai Yan No. 7' and 'Qing Yin No. 2', but improved their forage nutritional value, optimized soil conditions in the forage fields, and achieved the highest input–output ratio among all treatments. To sum up, the application of *Trichoderma harzianum* microbial fertilizer of 6.00 kg per hectare and manure (cattle and sheep) organic fertilizer of 18,000 kg per hectare is suitable for the popularization and application of 'Bai Yan No. 7' in high altitude areas. Applying 15.00 kg of *Bacillus licheniformis* microbial fertilizer and 18,000 kg of organic fertilizer per hectare is suitable for popularization and application in planting 'Qing Yin No. 2' in high altitude area.

5.2. Prospect

For future research, on the one hand, multi-point experiments (for example, Nagqu City, Tibet Autonomous Region, and Yushu City, Qinghai Province) or long-term monitoring (2025a, 2026a) should be carried out in a larger geographical area to determine the optimal application amount of microbial fertilizer under different soil types, climatic conditions and farming systems. On the other hand, with the development of molecular biology and genomics, the functional mechanism of microbial fertilizer in rhizosphere ecosystem can be deeply analyzed by means of metagenomics, soil microbiology, and metabonomics, including how they compete or cooperate with endogenous microorganisms, how they participate in soil carbon and nitrogen cycle and how to promote the healthy growth of crops. Finally, we should focus on the study of mixed sowing of oats and leguminous forage, so as to diversify the nutritional quality of feed and further improve the soil health. These studies will provide a more solid theoretical basis for the precise regulation of the soil–plant system and help to build an efficient and sustainable forage production system in relatively fragile ecological areas such as high altitude.

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