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Screening of Suitable Mixed Grass Species and Seeding Rates of Four Native Grass Seeds in an Alpine Mining Area

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Abstract: The targeting of suitable mixed grass species and seeding rates of native grass seed in the process of ecological restoration in alpine mining areas is unclear. Four kinds of native grass seed (*Poa pratensis* cv. Qinghai, *Poa crymophila* cv. Qinghai, *Puccinellia tenuiflora* cv. Tongde and *Pedicularis kansuensis*) were selected as experimental materials to set up mixed sowing tests in the Muli mining area, which were analyzed for changes in plant coverage, biomass, forage nutrient composition, and soil physicochemical properties under different mixed grass species and seeding rates, aiming to provide a data reference and theoretical basis for the screening of suitable mixed grass species and seeding rates for artificial grassland planting in alpine mining areas. The results showed that the mixed grass species and seeding rate (HF) of *Poa pratensis* cv. Qinghai + *Poa crymophila* cv. Qinghai + *Puccinellia tenuiflora* cv. Tongde + *Pedicularis kansuensis* had the highest vegetation coverage (97.33%). At the same time, the aboveground biomass of HF was the largest (356.27 g·m^{-2}). The soil organic matter, total nitrogen, total phosphorus, and total potassium of HF increased by 37.05%, 28.11%, 34.68%, and 10.14%, respectively, compared with CK, and the difference was significant ($p < 0.05$). Principal component analysis was carried out on 23 indexes of vegetation and soil. It was found that nine indexes, including coverage, aboveground biomass, belowground biomass, soluble sugar, and soil organic matter content, were the key indexes of evaluation. By sorting the membership functions of the above indicators, it was found that among the 12 mixed grass species and seeding rates, the comprehensive evaluation value of HF was the highest (0.848). In summary, it is recommended that the mixed grass species and seeding rate of *Poa pratensis* cv Qinghai + *Poa crymophila* cv. Qinghai + *Puccinellia tenuiflora* cv. Tongde + *Pedicularis kansuensis* be adopted for ecological restoration in alpine mining areas; this mixed grass species and seeding rate can effectively promote plant growth and development and improve the physicochemical properties of the soil, which can improve the stability and sustainability of the artificial grassland in the alpine mining area.

Keywords: alpine mining area; mixed grass species and seeding rates; sustainable artificial grassland; Muli coal mine

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1. Introduction

The Muli coal mine is located in the southern part of the Qilian Mountains in Qinghai Province. It consists of 4 mining areas, namely Jiangcang, Juhugeng, Hushan, and Duoshuogongma, including 11 open-pit mines and 19 slag mountains. The total area of the pit is 1433.04 hectares, and the total area of the slag mountain is 1856.79 hectares [1,2]. The ecological restoration of the Muli mining area is the first demonstration project of large-scale mine management in extremely cold and high-altitude areas in China. Under the influence of alpine climate and fragile habitat, there is no successful experience and mature model at home or abroad that has strong exploration and experimental significance [3]. Mixed sowing of grass species can let the plant make full use of light, water, soil, and other resources, enhancing the ability of the grassland ecosystem to resist natural disasters. A reasonable mixture of grass species and seeding rates can enhance the stability of the community, improve the utilization rate of community resources, reduce competition among species [4], and improve the physicochemical properties of soil [5,6]. Research on mixed sowing of artificial grassland mainly focuses on the following three types of sowing: Gramineae–Gramineae mixtures, Gramineae–Leguminosae mixtures, and mixtures of Gramineae with other families. *Medicago sativa*, *Onobrychis sativa*, and other Leguminosae forages in the alpine mining area have poor growth status and low yield. Leguminosae has a lower regreening rate and poorer growth status than Gramineae. Therefore, the alpine mining area is mainly dominated by Gramineae–Gramineae mixed sowing and mixtures of Gramineae mixed with other families [1,4–6].

The ecological restoration of the alpine mining area on the Qinghai–Tibet Plateau is special. Limited by the special environmental conditions of extreme cold and high altitudes, research on ecological restoration in the area mainly focuses on the following two aspects: vegetation reconstruction and soil reconstruction [7]. The key to vegetation restoration in alpine mining areas is the selection of suitable grass species and mixtures of grass species and seeding rates. Climatic conditions and soil characteristics determine the selection of mixes of seed sowing, grass species, and seeding rates [8–10]. The selection of mixed grass species and seeding rates for vegetation restoration in alpine mining areas should not only adapt to alpine climate conditions but also target soil characteristics and various heavy metal pollution problems in the mining area [11].

Many scholars in the United States, Britain, Germany, Australia, and China have found that the mixed seeding of native plants is more adaptable than the seeding of exotic species. Native plants can better adapt to the regional climate environment, making them the first choice for ecological restoration in mining areas [12–17]. At present, the main grass species selected for ecological restoration in alpine mining areas are Gramineae species *Elymus nutans*, *Festuca sinensis*, and *Poa crymophila* cv. Qinghai, due to their cold resistance and metal resistance, as well as their ability to adapt to the environment of alpine mining areas, which can significantly increase the height of the herb layer and the coverage and biomass of the grassland and reduce the risk of heavy metal pollution in the soil and was selected for ecological restoration in the copper mining area in the southeastern margin of Tibet [18]. Mixed sowing of *Elymus nutans* and *Poa crymophila* cv. Qinghai was selected for phytoremediation in the Deerni copper mine, with the community succeeding to a stable state over the years [19]. It was found that the mixed sowing of *Festuca sinensis* and *Poa crymophila* cv. Qinghai could significantly increase vegetation height, aboveground biomass, and soil nutrients and improve grassland productivity in mixed sown grassland in Qinghai Lake [20]. Pan et al. [21] found that the establishment of artificial grassland by Gramineae–Gramineae mixed sowing can significantly increase the yield and improve the quality of forage in alpine areas. In addition, several studies have shown that the establishment of mixed sown grassland in degraded grassland in alpine regions can significantly improve the physicochemical properties of soil, accelerate the recovery of degraded grassland, and improve the yield and quality of forage grass to promote the sustainable development of artificial grassland in alpine regions [22–24].

Because of the poor stability of the ecosystem, the unique climate, and the geographical location of the alpine mining area, this study considers the lack of suitable native grass seed in the ecological restoration process of the Muli mining area, with ambiguity in mixed grass species and seeding rates. With the goal of multiple grass species, low seeding rates, and high coverage, the native grass seeds of Gramineae and Scrophulariaceae were selected to carry out the mixed grass species and seeding rates screening test. To explore the effects of different mixed sowing on the characteristics of artificial vegetation communities and soil restoration in alpine mining areas, this study attempts to solve the following scientific problems: (1) screening suitable mixed grass species and seeding rates for alpine mining areas and (2) exploring the changes in community characteristics, forage nutrients, and soil physicochemical properties under different mixed grass species and seeding rates. In this experiment, the effects of vegetation and soil restoration under 12 types of mixed sowing treatments were studied and compared, and the advantages and disadvantages of the mixed grass species and seeding rates were clarified. Combined with the nutritional components of forage grass, the effects of mixed sowing were comprehensively analyzed and evaluated, which provided a scientific basis for mine vegetation restoration in alpine areas.

2. Materials and Methods

2.1. Study Area

The experimental site was located in the Juhugeng mining area (38°9′34″ N, 99°9′40″ E) in Muli Town, Tianjun County, Qinghai Province, with an average altitude of 4200 m. It has a plateau continental climate. The annual average temperature is −5.3 °C, the average temperature in the coldest month (January) is −17.2 °C, the average temperature in the hottest month (July) is 15.6 °C, and the annual rainfall is 282~774 mm, mainly concentrated in May~September, accounting for about 90% of the annual precipitation. The annual evaporation is 1049.9 mm, and the annual sunshine hours are 2551–3332 h. The growth time of forage grass was short, at approximately 120 days. The soil types were mainly swamp soil and alpine meadow soil. The original vegetation types were alpine meadows and swamp meadows. The specific geographical location is shown in Figure 1.

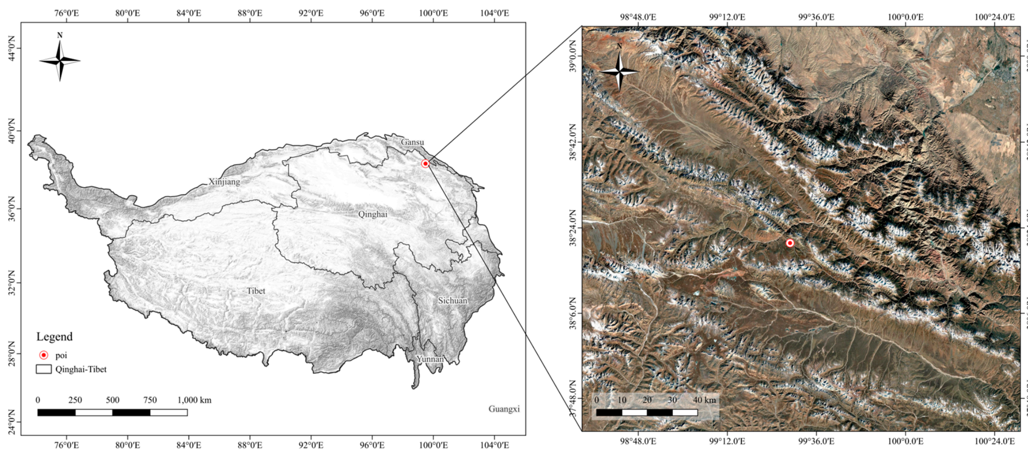


Figure 1. Geographical location of the study area.

2.2. Experimental Design

In this experimental study that began in 2022, *Poa pratensis* cv Qinghai, a grass species with cold resistance, barren tolerance, strong tillering ability, and rhizome encroachment ability, was used as the constructive species. The mixture was then mixed with *Poa crymophila* cv. Qinghai, *Puccinellia tenuiflora* cv. Tongde, and *Pedicularis kansuensis*, with a total of 12 mixed grass species and seeding rates. The selection and sowing amounts of the mixed grasses are shown in Table 1. The experimental plot was a randomized block design with a plot area of 4 m × 5 m and a plot spacing of 0.5 m. Each experimental plot was repeated three times, for a total of 36 experimental plots.

On 5 May 2022, soil preparation was carried out on the test site, and stones larger than 5 cm were picked up by an excavator (Sany heavy industry SY335BH-S, Beijing, China). A soil layer with a thickness of 20 cm was formed. Sheep manure and granular organic fertilizer were mixed with residual soil using an excavator, disc harrow (1BQD-3.4, Beijing, China), and artificial methods, then plowed for 10 cm. The fertilizer application rate was 25 $m^3 \times 667\ m^{-2}$ of sheep manure and 1.5 $t \times 667\ m^{-2}$ of granular organic fertilizer (organic matter ≥ 45%, total nutrient: N + P_2O_5 + K_2O ≥ 5%). The tested grass seeds were mixed with fertilizer and sown on the ground using artificial broadcasting. After sowing, sample plots were harvested using mechanical and artificial methods. Then, 20 ± 2 $g \cdot m^{-2}$

non-woven fabric was laid to maintain water and heat preservation and prevent soil erosion. Non-woven fabrics were collected in late July for harmless treatments. No other treatments were performed during the growth period.

Table 1. Application amount of native grass seeds under different mixed grass species and seeding rates.

Treatment	Name of Grass Species	Seeds per (m^{-2})
HA1	*Poa pratensis* cv. Qinghai + *Poa crymophila* cv. Qinghai	17,647 + 7500
HA2	*Poa pratensis* cv. Qinghai + *Poa crymophila* cv. Qinghai	14,750 + 10,000
HA3	*Poa pratensis* cv. Qinghai + *Poa crymophila* cv. Qinghai	11,250 + 15,220
HB1	*Poa pratensis* cv. Qinghai + *Puccinellia tenuiflora* cv. Tongde	17,647 + 14,285
HB2	*Poa pratensis* cv. Qinghai + *Puccinellia tenuiflora* cv. Tongde	14,706 + 19,048
HB3	*Poa pratensis* cv. Qinghai + *Puccinellia tenuiflora* cv. Tongde	11,250 + 21,429
HC1	*Poa pratensis* cv. Qinghai + *Pedicularis kansuensis*	17,647 + 4286
HC2	*Poa pratensis* cv. Qinghai + *Pedicularis kansuensis*	14,705 + 5714
HC3	*Poa pratensis* cv. Qinghai + *Pedicularis kansuensis*	11,250 + 6429
HD	*Poa pratensis* cv. Qinghai + *Poa crymophila* cv. Qinghai + *Puccinellia tenuiflora* cv. Tongde	11,765 + 7500 + 9524
HE	*Poa pratensis* cv. Qinghai + *Poa crymophila* cv. + *Pedicularis kansuensis*	11,765 + 7500 + 2857
HF	*Poa pratensis* cv. Qinghai + *Poa crymophila* cv. Qinghai + *Puccinellia tenuiflora* cv. Tongde + *Pedicularis kansuensis*	5882 + 5000 + 9524 + 4286

2.3. Sample Collection and Determination

At the end of August 2023, during the peak period of plant growth, 3 50 × 50 cm quadrants were randomly set up in each experimental plot to collect samples, for a total of 108 quadrants.

Determination of growth characteristics

Coverage: visual method, ratio of vertical projection area in the sample. Aboveground biomass: The plants in the sample plot were cut (stubble, 2 cm), packed into envelope bags, brought back to the laboratory, and dried in an oven (GZX-9140MBE, Beijing, China) to a constant weight. The belowground biomass, with a diameter of 7 cm root drill, and root samples were collected in the sample square, and four drills were collected in each sample square to remove the soil and dried to a constant weight. Root–shoot ratio: the ratio of the dry weight of the underground part to that of the aboveground part [25–27].

Determination of plant stoichiometric ratio

The collected grass samples were dried and crushed to determine the total plant carbon, nitrogen, and phosphorus. The total carbon content of the plants was determined using potassium dichromate oxidation and thermal titration. Total nitrogen was digested by the 'sulfuric acid–hydrogen peroxide' method and determined by an AA3 continuous flow analyzer (SEAL AA3, Berlin, Germany). The total phosphorus content of plants was determined by the 'sulfuric acid–hydrogen peroxide' digestion method and spectrophotometer (Shimadzu 2550, Beijing, China) [28,29].

Determination of the plant nutrient content

The plant's crude protein content was converted from the plant's nitrogen content. The content of crude fat was determined by the soxhlet ether extraction method. Soluble sugar content was determined by the anthrone colorimetric method. Soluble protein content was quantified by the BCA protein quantitative method. Acid detergent fiber content and neutral detergent fiber content were determined by the acid detergent and neutral detergent method [28,29].

Determination of soil physicochemical parameters

According to the 5-point mixed sampling method, soil samples of 0–10 cm and 10–20 cm were randomly collected from each plot and divided into sealed bags, which were repeated three times. The soil of each soil layer was divided into two parts: one was air-dried and the other was wet soil frozen [25,29].

Soil moisture content using the drying method. The soil pH was determined by the potentiometric method using a pH meter (PHS-3C, Beijing, China). Soil nutrient content was determined using Soil Agrochemical Analysis (Third Edition) [30]. Soil organic matter content was determined using the potassium dichromate volumetric method. Total nitrogen was determined using the semi-micro Kjeldahl method. The total phosphorus was determined using the sodium hydroxide melting–molybdenum antimony anti-colorimetric method. The total potassium content was determined using sodium hydroxide melting-flame spectrophotometry. Available phosphorus was determined using the sodium bicarbonate extraction-molybdenum antimony colorimetric method. Available potassium was determined using ammonium acetate extraction–flame spectrophotometry. Ammonia nitrogen was determined using the hydrogen chloride extraction–distillation method. Nitrate nitrogen was measured by phenol disulfonic acid colorimetry.

Comprehensive ranking:

Principal component analysis was carried out on the following: the coverage, aboveground biomass, belowground biomass, and four other plant phenotypic indicators; nine forage quality indicators, including plant organic carbon, nitrogen, phosphorus content, crude protein, crude fat, soluble sugar, soluble protein, neutral fiber, and acid fiber; ten soil physicochemical indexes, including soil water content, pH, soil organic matter, total nitrogen, total phosphorus, total potassium, available phosphorus, available potassium, ammonia nitrogen and nitrate nitrogen. The key indexes were screened out.

The membership function value calculation formula is as follows:

$$R(Xj) = (Xj - Xmin)/(Xmax - Xmin), \quad (1)$$

In the formula, Xj, Xmin, and Xmax are the comprehensive index of the index in the jth treatment and the minimum and maximum values of the comprehensive index of the jth treatment.

The weight calculation formula is as follows:

$$Wj = Pj/\sum_{j=1}^{n} Pj, \quad (2)$$

The Wj value in the formula represents the weight of the jth comprehensive index and Pj is the contribution rate of the jth comprehensive index.

Comprehensive Evaluation Values

$$D = \sum_{j=1}^{n} [U(xj) \times Wj], \quad (3)$$

U(xj) in the formula represents the membership function value of the jth comprehensive index value and Wj represents the weight of the jth comprehensive index.

2.4. Data Processing

SPSS 25.0 (IBM, New York, NY, USA) was used for data analysis, and Origin 2022 and Excel 2016 (Microsoft, Washington, DC, USA) were used to draw charts. One-way analysis of variance was used to test the differences between treatments ($p < 0.05$). Multiple comparisons were performed using the LSD method. Principal component analysis was used to screen out the key indicators, and the membership function was used to comprehensively evaluate the ranking.

3. Results

3.1. Analysis of Vegetation Community Characteristics Under Different Mixed Grass Species and Seeding Rates

3.1.1. Vegetation Coverage Under Different Mixed Grass Species and Seeding Rates

The vegetation coverage of each treatment, from high to low, was HF, HB3, HA2, HD, HE, HA1, HA3, HB2, HB1, HC2, HC1, and HC3 (Figure 2). The vegetation coverage of HF was the highest (97.33%), which was not significantly different from that of HD, HE, HA2, and HB3 ($p > 0.05$), but was significantly higher than that of the other seven treatments ($p < 0.05$). The coverage of HC3 was the lowest (58.06%).

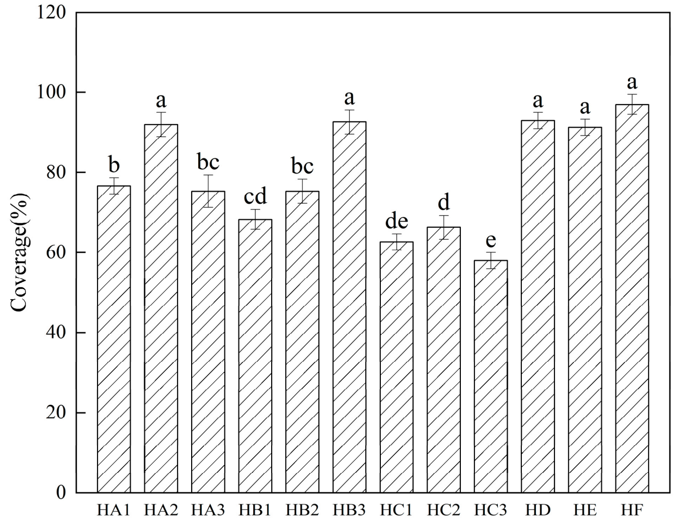


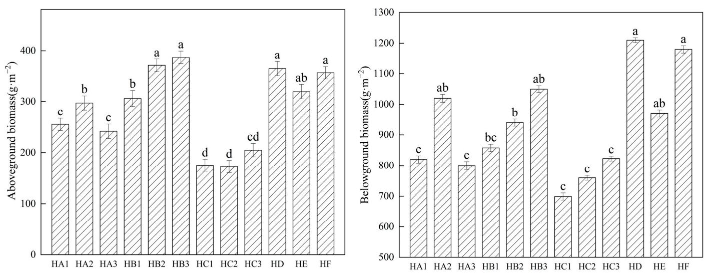
Figure 2. Total coverage of plants with different mixed grass species and seeding rates. Note: Different lowercase letters indicate significant differences between different treatments ($p < 0.05$).

3.1.2. Vegetation Biomass and Root–Shoot Ratio Under Different Mixed Grass Species and Seeding Rates

The aboveground biomass of each treatment, from high to low, was HB3, HB2, HD, HF, HE, HB1, HA2, HA1, HA3, HC3, HC1, and HC2 (Figure 3). Among them, the aboveground biomass of HB3 was the highest (387.06 $g\cdot m^{-2}$), which was not significantly different from that of HB2, HD, HE, and HF ($p > 0.05$), but significantly higher than that of the other seven treatments ($p < 0.05$). The aboveground biomass of HC2 was the lowest, which was significantly lower than that of the other treatments, except for HC1 and HC3 ($p < 0.05$).

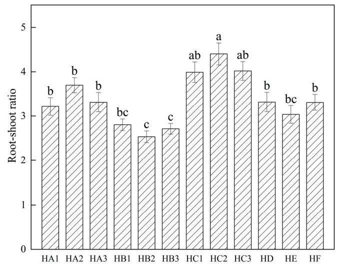
The belowground biomass of each treatment, from high to low, was HD, HF, HA2, HB3, HE, HB2, HB1, HC3, HA1, HA3, HC2, and HC1. Among them, the belowground biomass of HD was the highest (1235.47 $g\cdot m^{-2}$), which was not significantly different from that of HA2, HB3, HE, and HF ($p > 0.05$), but significantly higher than that of the other seven treatments ($p < 0.05$), and the belowground biomass of HC1 was the smallest.

The root–shoot ratios of each treatment from high to low were HC2, HC1, HC3, HA2, HA3, HF, HD, HA1, HE, HB1, HB3, and HB2. Among them, the root–shoot ratio of HC2 was the highest (4.35), which was not significantly different from that of HC1 and HC3 ($p > 0.05$) but was significantly higher than that of the other nine treatments ($p < 0.05$). The root–shoot ratio was the lowest in HB2 and HB3.



(**A**) (**B**)

Figure 3. *Cont*.



(**C**)

Figure 3. Aboveground biomass, belowground biomass, and root–shoot ratio of different mixed grass species and seeding rates. Note: Different lowercase letters indicate significant differences between different treatments ($p < 0.05$), the same below. (**A**–**C**) are Aboveground biomass, Belowground biomass, and Root–shoot ratio, respectively.

3.2. Analysis of Plant Stoichiometry Under Different Mixed Grass Species and Seeding Rates

The order of plant carbon content from highest to lowest was HF, HD, HB3, HB2, HE, HC2, HA2, HA1, HB1, HC3, HC1, and HA3 (Figure 4). The plant carbon content of HF was the highest, which was significantly higher than that of other treatments, except HB2, HB3, HD, and HE ($p < 0.05$), and HA3 had the lowest carbon content. The plant nitrogen content of HF reached the maximum value of 27.79 g·kg^{-1}, which was not significantly different from HB3, HD, and HE ($p > 0.05$), significantly higher than other treatments ($p < 0.05$), and HA3 had the lowest plant nitrogen content. The plant phosphorus content of HB3 was the highest (3.05 g·kg^{-1}), which was not significantly different from that of HC2, HC3, HD, HE, and HF ($p > 0.05$), but significantly higher than that of the other six treatments ($p < 0.05$).

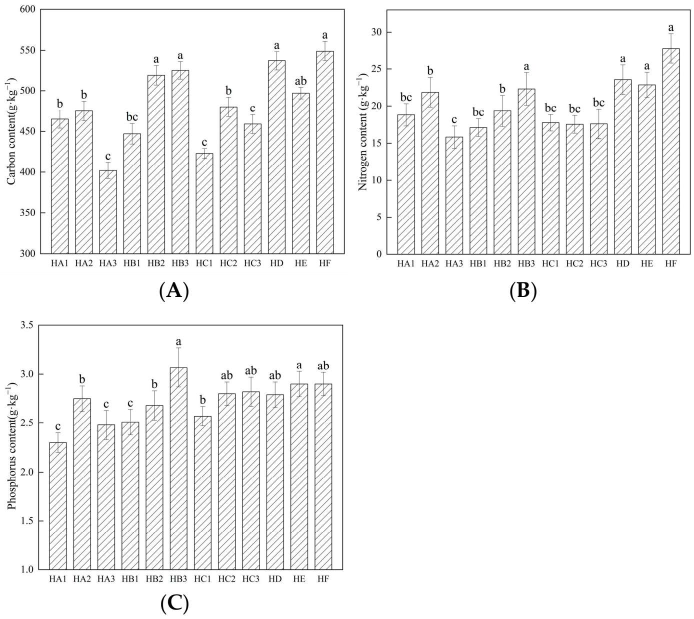


Figure 4. The stoichiometric ratio of plants with different mixed grass species and seeding rate. Note: Different lowercase letters indicate significant differences between different treatments ($p < 0.05$), the same below. (**A**–**C**) are Aboveground biomass, Belowground biomass, and Root–shoot ratio, respectively.

3.3. Nutrient Composition Analysis of Vegetation Under Different Mixed Grass Species and Seeding Rates

The nutrient contents of plants under different mixed sowing treatments were significantly different (Table 2). Among the 12 mixed sowing treatments, the crude protein content of HE was the highest (146.03 g·kg^{-1}), which was significantly higher than that of other mixed sowing treatments except HB2, HD, and HF ($p < 0.05$). The crude protein content of HB3 was the lowest (108.02 g·kg^{-1}). Among the 12 mixed sowing treatments, the crude fat content of HD, HE, and HF reached more than 25%, which were 27.39%, 28.14%, and 25.66%. The crude fat content of HC1 was the lowest, only 19.67%. The variation range of soluble sugar was 35.53~63.65 mg·g^{-1}, among which HC2 ranked first, HE ranked second, and there was no significant difference between the two ($p > 0.05$). The variation range of soluble protein was 45.97–60.62 mg·g^{-1}, among which HD was the highest, followed by HB3, which was not significantly different from HB2, HE, and HF ($p > 0.05$), significantly higher than other treatments ($p < 0.05$). The contents of neutral fiber and acid fiber were the lowest in HD, which were 52.27% and 30.81%. Among them, the neutral fiber was the highest in HF (64.54%), and the acid fiber was the highest in HE (36.41%).

Table 2. Nutritional composition of vegetation with mixed grass species and seeding rates.

Treatment	Crude Protein (g·kg^{-1})	Crude Fat (%)	Soluble Sugar (mg·g^{-1})	Soluble Protein (mg·g^{-1})	Neutral Fiber (%)	Acidic Fiber (%)
HA1	117.52 ± 10.02 ^{c}	22.67 ± 2.13 ^{b}	43.64 ± 2.35 ^{b}	49.26 ± 2.43 ^{b}	55.73 ± 2.47 ^{b}	35.16 ± 2.37 ^{a}
HA2	129.14 ± 12.43 ^{b}	23.23 ± 1.54 ^{b}	42.38 ± 3.03 ^{b}	49.80 ± 3.31 ^{b}	55.94 ± 4.72 ^{b}	35.42 ± 2.32 ^{a}
HA3	130.09 ± 9.32 ^{b}	20.72 ± 1.54 ^{c}	43.23 ± 3.45 ^{b}	45.97 ± 2.64 ^{c}	54.02 ± 2.35 ^{bc}	33.78 ± 2.47 ^{ab}
HB1	120.84 ± 10.02 ^{c}	24.42 ± 2.32 ^{ab}	35.53 ± 2.43 ^{c}	48.56 ± 2.53 ^{b}	56.98 ± 3.84 ^{b}	35.87 ± 1.58 ^{a}
HB2	134.27 ± 10.32 ^{ab}	22.86 ± 1.68 ^{b}	39.76 ± 2.37 ^{c}	50.75 ± 3.38 ^{ab}	54.88 ± 3.26 ^{bc}	34.38 ± 1.32 ^{ab}
HB3	108.02 ± 8.48 ^{c}	24.02 ± 1.68 ^{ab}	39.94 ± 1.34 ^{c}	55.38 ± 4.32 ^{a}	56.81 ± 2.65 ^{b}	35.47 ± 2.37 ^{a}
HC1	110.87 ± 10.32 ^{c}	19.67 ± 12.05 ^{c}	53.96 ± 2.04 ^{ab}	49.09 ± 3.36 ^{b}	58.66 ± 3.25 ^{ab}	33.09 ± 1.66 ^{ab}
HC2	109.56 ± 8.63 ^{c}	20.59 ± 1.68 ^{c}	63.65 ± 3.24 ^{a}	48.53 ± 4.52 ^{b}	63.12 ± 4.15 ^{a}	32.92 ± 2.36 ^{b}
HC3	109.95 ± 9.56 ^{c}	22.55 ± 2.47 ^{b}	49.14 ± 2.23 ^{b}	46.69 ± 2.43 ^{c}	60.25 ± 4.25 ^{a}	33.16 ± 1.37 ^{ab}
HD	143.52 ± 11.02 ^{a}	27.39 ± 1.64 ^{a}	55.49 ± 3.42 ^{ab}	60.62 ± 3.54 ^{a}	52.27 ± 3.23 ^{c}	30.81 ± 1.82 ^{c}
HE	146.03 ± 10.52 ^{a}	28.14 ± 2.13 ^{a}	58.78 ± 2.43 ^{a}	55.21 ± 3.26 ^{a}	63.61 ± 4.24 ^{a}	36.41 ± 2.35 ^{a}
HF	136.23 ± 11.24 ^{ab}	25.66 ± 2.14 ^{ab}	57.72 ± 3.47 ^{a}	53.42 ± 3.48 ^{ab}	64.54 ± 3.53 ^{a}	34.12 ± 1.84 ^{a}

Note: Different lowercase letters indicate significant differences between different treatments ($p < 0.05$), the same below.

3.4. Analysis of Soil Physicochemical Indexes Under Different Mixed Grass Species and Seeding Rates

3.4.1. Soil Water Content Changes Under Different Mixed Grass Species and Seeding Rates

The soil water content of different mixed grass species and the seeding rates were different (Figure 5). The soil water content of each mixed sowing treatment was significantly higher than that of CK ($p < 0.05$). In the 0~10 cm soil layer, the soil water content of HD was the highest (25.75%), which was 47.33% higher than that of CK, and the difference was significant ($p < 0.05$), followed by HB2. In the 10~20 cm soil layer, the soil moisture content of each mixed sowing treatment was between 21.34% and 25.53%. The soil moisture content of HD was the highest (25.53%), followed by HB2 (25.41%), which was significantly higher than that of CK ($p < 0.05$).

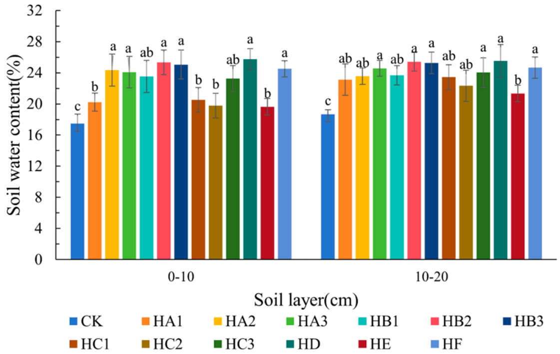


Figure 5. Soil moisture content of different mixed grass species and seeding rates. Note: Different lowercase letters represent the significant difference between different treatments in the same soil layer ($p < 0.05$), the same as below.

3.4.2. Soil pH Changes Under Different Mixed Grass Species and Seeding Rates

The soil pH of different treatments was different, and the soil pH of each mixed treatment was significantly lower than that of CK ($p < 0.05$) (Figure 6). In the 0~10 cm soil layer, the soil pH of HB3, HD and HE decreased by 10.48%, 10.47%, and 10.83% compared with CK, and the difference was significant ($p < 0.05$). In the 10~20 cm soil layer, the soil pH of different mixed grass species and seeding rates was lower than that of CK. The soil pH of HD, HE, and HF was the smallest, which was 6.90%, 9.25%, and 8.16% lower than that of CK, and the difference was significant ($p < 0.05$).

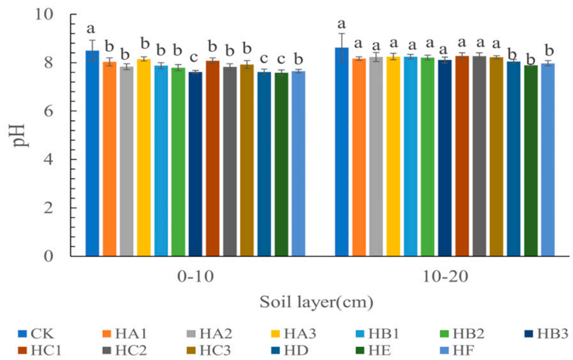


Figure 6. Soil pH of different mixed grass species and seeding rates. Note: Different lowercase letters indicate significant differences between different treatments ($p < 0.05$), the same below.

3.4.3. Changes in Soil Nutrients Under Different Mixed Grass Species and Seeding Rates

The contents of soil organic matter, total nitrogen, total phosphorus, total potassium, available phosphorus, available potassium, ammonia nitrogen, and nitrate nitrogen under different mixed grass species and seeding rates were significantly higher than those of CK. At the same time, the improvement effect of soil nutrient content in different mixed grass species and seeding rates was different (Tables 4 and 5).

In the 0~10 cm soil layer (Table 4), the contents of soil organic matter and total phosphorus were the highest in HB3, which were 290.66 g·kg^{-1} and 2.52 g·kg^{-1}, which were 41.47% and 55.56% higher than CK, and the difference was significant ($p < 0.05$). The contents of total nitrogen and available potassium in soil reached the maximum in HA2, which were 8.28 g·kg^{-1} and 855.36 mg·kg^{-1}, which increased by 42.02% and 76.84% compared with CK, and the difference was significant ($p < 0.05$). The total potassium content of the soil was the highest in HB2, which was 16.89 g·kg^{-1}. The mixed sowing treatments were significantly higher than CK, and the increment was between 0.79 and 2.09 compared with CK ($p < 0.05$). The contents of soil available phosphorus and nitrate nitrogen were the highest in HF, which were 73.25 mg·kg^{-1} and 4.25 mg·kg^{-1}. The soil ammonia nitrogen content of each mixed sowing treatment was 2.88~3.84 mg·kg^{-1}, and the HD was the highest (3.84 mg·kg^{-1}), which was significantly increased by 46.01% compared with CK, and the difference was significant ($p < 0.05$).

In the 10–20 cm soil layer (Table 5), the contents of soil organic matter and total phosphorus were the highest in HB3, which were 260.66 g·kg^{-1} and 2.52 g·kg^{-1}, which were 28.23% and 50.90% higher than CK, and the difference was significant ($p < 0.05$). The contents of soil total nitrogen and available phosphorus reached the maximum in HF, which were 5.97 g·kg^{-1} and 56.25 mg·kg^{-1}. They increased by 38.84% and 20.71% compared with CK, and the difference was significant ($p < 0.05$). The total potassium content of the soil was the highest in HE, which was 18.97 g·kg^{-1}. The total potassium content of each mixed sowing treatment was significantly higher than that of CK, and the increment was between 5.82% and 28.44% compared with CK. The content of soil-available potassium was the highest in HC3, which was 427.54 mg·kg^{-1}. The soil ammonia nitrogen content of each mixed sowing treatment was approximately between 2.88 and 3.84 mg·kg^{-1}, the HA2 was the highest (3.15 mg·kg^{-1}), which was significantly increased by 55.94% compared with

CK, and the difference was significant ($p < 0.05$). The soil nitrate nitrogen content of each mixed sowing treatment was approximately between 3.01 and 3.71 mg·kg^{-1}, the HD was the highest (3.71 mg·kg^{-1}), which was significantly increased by 32.97% compared with CK ($p < 0.05$).

3.4.4. Comprehensive Evaluation of Different Mixed Grass Species and Seeding Rates

Principal Component Analysis of Each Index Under Different Mixed Grass Species and Seeding Rates

Principal component analysis can use the linear combination of the original variables to form several comprehensive indicators (principal components), which not only reduces the analysis indicators but also does not lose the original index information and comprehensively analyzes the processing of multiple indicators. The adaptability of each treatment was comprehensively evaluated by three community characteristic indexes, nine plant quality indexes, and ten soil physicochemical indexes. It is found that the eigenvalues of the first five principal components are greater than 1, and the cumulative contribution rate is more than 80%, indicating that these five principal components can comprehensively evaluate each treatment (Table 3).

Table 3. Results of the principal component analysis.

Principal Component	Eigenvalues	Contribution Rate (%)	Cumulative Contribution Rate (%)
Principal component1	9.066	39.416	39.416
Principal component2	3.532	15.357	54.773
Principal component3	3.047	13.248	68.02
Principal component4	1.989	8.646	76.667
Principal component5	1.657	7.205	83.872

The principal component matrix of the index factor shows the weight coefficients of each main index in the principal component matrix (Table 6). The characteristic value of the first principal component was 9.066, and the contribution rate was 39.416%. Among the principal components, the coverage (0.915), aboveground biomass (0.935), belowground biomass (0.947), plant carbon content (0.792), plant nitrogen content (0.865), soil pH (−0.811), soil organic matter (0.808), soil total nitrogen (0.799), soil total phosphorus (0.794), soil ammonia nitrogen (0.706), and soil nitrate nitrogen (0.675) had the highest absolute value of the eigenvector. The characteristic value of the second principal component was 3.532, and the contribution rate was 15.357%. The absolute value of the eigenvector of plant phosphorus content (0.636), plant soluble sugar (0.868), plant neutral fiber (−0.603), and plant acid fiber (−0.605) was the highest. The eigenvalue of the third principal component is 3.047, and the contribution rate is 13.248%. In this principal component, only the absolute value of the eigenvector of soil water content (0.607) is high. The characteristic value of the fourth principal component was 1.989, and the contribution rate was 8.646%. In this principal component, the absolute value of the eigenvector of soil total potassium (0.640) and soil available potassium (0.640) was high. The characteristic value of the fifth principal component is 1.657, and the contribution rate is 7.205%.

Membership Function Ranking of Different Mixed Grass Species and Seeding Rates

According to the weight of each index, the comprehensive evaluation value of each treatment was calculated. The comprehensive ranking of each treatment was as follows: HF > HE > HB3 > HD > HA2 > HB2 > HA1 > HA3 > HB1 > HC2 > HC3 > HC1 (Table 7). Among them, the comprehensive evaluation values (D) of HF, HE, and HB3 in each mixed method were 0.848, 0.750, and 0.655, which were the top three treatments in the comprehensive ranking.

Table 4. Soil nutrients of different mixed grass species and seeding rates (0~10 cm).

Treatment	Organic Matter ($g \cdot kg^{-1}$)	Total Nitrogen ($g \cdot kg^{-1}$)	Total Phosphorus ($g \cdot kg^{-1}$)	Total Potassium ($g \cdot kg^{-1}$)	Available Phosphorus ($mg \cdot kg^{-1}$)	Rapidly Available Potassium ($mg \cdot kg^{-1}$)	Ammoniacal Nitrogen ($mg \cdot kg^{-1}$)	Nitrate Nitrogen ($mg \cdot kg^{-1}$)
HA1	261.68 ± 14.25^{b}	7.52 ± 0.46^{b}	2.28 ± 0.15^{b}	16.51 ± 1.25^{ab}	67.03 ± 4.25^{ab}	743.07 ± 12.34^{ab}	3.41 ± 0.21^{ab}	3.85 ± 0.21^{a}
HA2	268.53 ± 16.35^{b}	8.28 ± 0.42^{a}	2.48 ± 0.07^{ab}	16.84 ± 1.24^{a}	57.12 ± 2.39^{b}	855.36 ± 12.04^{a}	3.07 ± 0.18^{ab}	3.95 ± 0.25^{a}
HA3	254.68 ± 14.36^{bc}	7.96 ± 0.54^{b}	2.35 ± 0.05^{b}	16.66 ± 1.18^{a}	68.25 ± 4.22^{ab}	820.32 ± 24.21^{a}	2.92 ± 0.02^{b}	3.99 ± 0.19^{a}
HB1	261.57 ± 16.33^{b}	7.72 ± 0.52^{b}	2.32 ± 0.13^{b}	15.59 ± 1.42^{c}	57.15 ± 2.32^{b}	565.45 ± 16.43^{b}	3.79 ± 0.08^{a}	3.51 ± 0.11^{b}
HB2	288.55 ± 16.75^{ab}	8.09 ± 0.52^{ab}	2.33 ± 0.15^{b}	16.89 ± 1.20^{a}	66.85 ± 2.34^{ab}	540.55 ± 11.32^{b}	2.88 ± 0.14^{b}	3.95 ± 0.15^{a}
HB3	290.66 ± 15.22^{a}	8.24 ± 0.41^{a}	2.52 ± 0.18^{a}	15.63 ± 1.16^{c}	64.25 ± 4.32^{b}	715.36 ± 22.31^{ab}	3.83 ± 0.22^{a}	3.73 ± 0.07^{ab}
HC1	244.82 ± 17.36^{c}	7.38 ± 0.38^{bc}	2.47 ± 0.20^{ab}	15.91 ± 1.22^{c}	57.75 ± 5.32^{b}	585.21 ± 17.36^{b}	2.99 ± 0.15^{b}	3.63 ± 0.20^{ab}
HC2	224.86 ± 11.36^{c}	5.95 ± 0.38^{c}	2.12 ± 0.11^{b}	16.87 ± 1.24^{a}	67.75 ± 5.21^{ab}	590.37 ± 16.33^{b}	2.98 ± 0.15^{b}	3.47 ± 0.15^{b}
HC3	234.48 ± 15.27^{c}	7.31 ± 0.54^{bc}	2.31 ± 0.15^{b}	16.01 ± 1.16^{c}	68.25 ± 3.21^{ab}	680.29 ± 15.43^{a}	2.85 ± 0.05^{b}	3.25 ± 0.26^{b}
HD	290.25 ± 14.65^{a}	8.15 ± 0.46^{a}	2.50 ± 0.13^{a}	16.63 ± 1.07^{a}	58.15 ± 2.56^{b}	715.45 ± 16.43^{ab}	3.84 ± 0.19^{a}	3.86 ± 0.17^{a}
HE	273.36 ± 11.43^{ab}	7.93 ± 0.37^{b}	2.46 ± 0.20^{ab}	16.11 ± 0.47^{c}	62.24 ± 3.28^{ab}	775.32 ± 20.31^{ab}	3.48 ± 0.22^{a}	3.91 ± 0.22^{a}
HF	281.57 ± 24.36^{ab}	8.11 ± 0.64^{a}	2.48 ± 0.17^{ab}	16.47 ± 0.86^{ab}	73.25 ± 4.23^{a}	735.22 ± 16.32^{ab}	3.65 ± 0.18^{a}	4.25 ± 0.16^{a}
CK	205.45 ± 12.14^{d}	5.83 ± 0.03^{d}	1.62 ± 0.12^{c}	14.80 ± 1.51^{d}	47.20 ± 2.34^{c}	383.68 ± 11.25^{e}	2.63 ± 0.01^{c}	3.06 ± 0.02^{b}

Note: Different lowercase letters indicate significant differences between different treatments ($p < 0.05$), the same below.

Table 5. Soil nutrients of different mixed grass species and seeding rates (10~20 cm).

Treatment	Organic Matter ($g \cdot kg^{-1}$)	Total Nitrogen ($g \cdot kg^{-1}$)	Total Phosphorus ($g \cdot kg^{-1}$)	Total Potassium ($g \cdot kg^{-1}$)	Available Phosphorus ($g \cdot kg^{-1}$)	Rapidly Available Potassium ($mg \cdot kg^{-1}$)	Ammoniacal Nitrogen ($mg \cdot kg^{-1}$)	Nitrate Nitrogen ($mg \cdot kg^{-1}$)
HA1	212.84 ± 10.02^{c}	3.95 ± 0.17^{c}	2.41 ± 0.13^{a}	17.13 ± 1.02^{b}	44.25 ± 6.14^{c}	362.84 ± 11.31^{b}	3.05 ± 0.25^{a}	3.01 ± 0.22^{bc}
HA2	230.15 ± 8.03^{b}	4.22 ± 0.26^{c}	2.49 ± 0.11^{a}	17.60 ± 1.32^{b}	42.25 ± 3.25^{c}	396.36 ± 10.34^{b}	3.15 ± 0.14^{a}	3.02 ± 0.14^{bc}
HA3	224.68 ± 14.36^{bc}	5.96 ± 0.25^{a}	2.05 ± 0.05^{b}	16.56 ± 1.28^{bc}	48.25 ± 4.26^{bc}	352.32 ± 24.21^{b}	2.92 ± 0.02^{b}	3.59 ± 0.19^{a}
HB1	211.01 ± 7.24^{c}	5.09 ± 0.35^{bc}	1.83 ± 0.03^{bc}	17.09 ± 1.36^{b}	45.00 ± 3.55^{c}	361.46 ± 10.32^{b}	2.11 ± 0.01^{c}	3.09 ± 0.01^{bc}
HB2	207.12 ± 8.03^{c}	3.40 ± 0.14^{c}	1.61 ± 0.07^{c}	16.53 ± 1.34^{bc}	41.75 ± 2.16^{c}	390.08 ± 11.04^{b}	2.87 ± 0.12^{b}	3.40 ± 0.11^{b}
HB3	260.66 ± 5.12^{a}	5.24 ± 0.41^{b}	2.52 ± 0.18^{a}	15.63 ± 1.16^{c}	54.25 ± 2.02^{a}	415.36 ± 22.31^{ab}	3.03 ± 0.22^{a}	3.24 ± 0.17^{bc}
HC1	207.73 ± 8.10^{c}	4.31 ± 0.15^{c}	1.62 ± 0.12^{c}	16.23 ± 1.26^{bc}	46.50 ± 3.03^{c}	355.43 ± 16.32^{b}	2.07 ± 0.73^{c}	3.31 ± 0.22^{bc}
HC2	228.60 ± 6.16^{bc}	5.57 ± 0.26^{b}	1.95 ± 0.04^{bc}	17.93 ± 1.32^{ab}	42.25 ± 5.03^{c}	415.06 ± 13.44^{ab}	2.28 ± 0.11^{c}	3.57 ± 0.21^{a}
HC3	226.56 ± 10.44^{bc}	5.15 ± 0.26^{b}	1.58 ± 0.05^{c}	15.97 ± 1.34^{bc}	45.50 ± 3.16^{c}	427.54 ± 17.52^{a}	2.26 ± 0.16^{c}	3.05 ± 0.24^{bc}
HD	238.68 ± 6.27^{b}	4.96 ± 0.14^{bc}	1.68 ± 0.07^{c}	18.08 ± 1.05^{a}	52.50 ± 0.26^{b}	409.16 ± 15.33^{ab}	2.70 ± 0.11^{bc}	3.71 ± 0.23^{a}
HE	201.95 ± 12.16^{c}	3.89 ± 0.11^{c}	1.57 ± 0.03^{c}	18.97 ± 1.20^{a}	44.75 ± 3.16^{c}	369.36 ± 18.44^{b}	2.39 ± 0.12^{c}	3.12 ± 0.20^{bc}
HF	224.86 ± 10.32^{bc}	5.97 ± 0.32^{a}	2.33 ± 0.13^{ab}	13.91 ± 0.64^{c}	56.25 ± 2.16^{a}	415.57 ± 10.04^{ab}	3.04 ± 0.15^{a}	3.27 ± 0.12^{bc}
CK	203.28 ± 11.48^{c}	4.30 ± 0.09^{c}	1.67 ± 0.02^{c}	14.77 ± 0.80^{c}	46.60 ± 2.65^{c}	370.60 ± 10.28^{b}	2.02 ± 0.01^{c}	2.79 ± 0.16^{c}

Note: Different lowercase letters indicate significant differences between different treatments ($p < 0.05$), the same below.

Table 6. Load matrix of each index factor.

Observable Indicator	1	2	3	4	5
Coverage	0.915	0.146	0.086	0.245	0.076
Aboveground biomass	0.935	−0.137	−0.016	−0.127	0.119
Belowground biomass	0.947	0.179	0.02	0.044	−0.109
Plant carbon content	0.792	0.416	0.131	−0.157	−0.033
Plant nitrogen content	0.865	0.393	0.216	−0.012	−0.064
Plant phosphorus contents	0.343	0.636	0.246	−0.528	0.361
Plant crude protein	0.555	−0.181	0.177	0.331	−0.349
Plant crude fat	0.54	−0.441	0.228	0.112	0.514
Plant soluble sugar	−0.091	0.868	0.192	0.094	−0.346
Plant soluble protein	0.35	0.164	−0.432	−0.144	−0.322
Plant neutral fiber	−0.162	−0.603	0.415	−0.044	0.111
Acidic plant fiber	0.156	−0.605	0.533	−0.011	0.363
Soil water content	0.582	−0.123	0.607	−0.262	0.101
Soil pH	−0.811	−0.371	−0.373	0.102	0.078
Soil organic matter	0.808	−0.337	0.767	−0.08	0.062
Soil total nitrogen	0.799	−0.373	−0.125	0.094	0.303
Soil total phosphorus	0.794	−0.058	−0.293	−0.264	0.219
Soil total potassium	0.008	0.405	−0.433	0.64	0.011
Soil available phosphorus	−0.085	0.47	0.078	0.273	0.288
Soil available potassium	0.356	−0.028	0.075	0.64	0.22
Soil ammonia nitrogen	0.706	−0.212	0.32	−0.213	0.441
Soil nitrate nitrogen	0.675	0.117	−0.17	0.559	0.21

Table 7. A comprehensive ranking of the membership functions of each treatment.

Treatment	U (x1)	U (x2)	U (x3)	U (x4)	U (x5)	D	Scheduling
HA1	0.371	0.245	0.612	1	0.453	0.458	7
HA2	0.669	0.392	0.404	0.869	0.931	0.62	5
HA3	0.317	0.425	0	0.989	0.864	0.403	8
HB1	0.455	0	0.715	0.289	0.346	0.386	9
HB2	0.624	0.533	0.077	0.416	1	0.532	6
HB3	0.877	0.453	0.476	0	0.99	0.655	3
HC1	0.129	0.563	0.225	0.241	0.618	0.277	12
HC2	0	1	0.523	0.514	0.449	0.357	10
HC3	0.123	0.581	0.573	0.324	0.747	0.352	11
HD	1	0.626	0.029	0.476	0	0.638	4
HE	0.71	0.673	1	0.673	0.764	0.75	2
HF	0.965	0.876	0.635	0.741	0.664	0.848	1

4. Discussion

The climate of the Muli mining area is cold, the ecosystem is fragile, and the soil is alkaline. Due to the long-term unplanned mining and lack of awareness of ecological protection, the ecological environment problems and hidden dangers of geological disasters in this area have increased. The specific manifestations are as follows: the exposed area of soil is expanded, the physicochemical properties of soil are changed, the community coverage and biomass are reduced, and the biodiversity is reduced [31]. Early ecological management in mining areas mainly focused on vegetation restoration, which is an important way of ecological management. A large number of studies have shown that it is very important to select native grass seeds and their mixed grass species and seeding rates in mining restoration. Plants with strong adaptability, good stress resistance, soil improvement, developed roots, fast growth rates, and high survival rates can be naturally settled and planted in abandoned mining areas [32–34]. Different mixed grass species and seeding rates of artificial grassland can impact the soil, accelerate the recovery rate of vegetation, soil, and microorganisms in the Muli mining area, improve the ecological environment, and promote the harmonious development of man and nature.

4.1. Effects of Different Mixed Grass Species and Seeding Rates on Plant Community Characteristics

The suitable mixed grass species and seeding rates can give full play to the complementary advantages of forage grass, which makes full use of environmental resources, promotes plant growth and development, increases the biomass and coverage of plant community, and improves the stability of artificial grassland community [4,20,21]. Liu et al. [35] found that the mixed sowing of multiple grass species can significantly improve the height, coverage, density, and biomass of grassland vegetation in the study of the vegetation restoration effect in the Muli mining area. The effect is significantly better than the mixed sowing of two grass species, which is consistent with the results that plant community coverage, aboveground biomass, and belowground biomass of HE and HF mixing methods were significantly higher than those of other mixing treatments in this study. Li Sida [36] conducted a mixed planting artificial grassland experiment of *Poa pratensis* cv. Qinghai, *Festuca sinensis*, *Elymus sibiricus*, and *Puccinellia tenuiflora* cv. Tongde on the Qinghai–Tibet Plateau. It was found that with the increase in mixed sowing seed, community coverage, biomass, and community stability were significantly improved. In this study, the coverage, biomass, growth status and soil improvement effects of four mixed sowing grass seeds were significantly higher than those of two grass species. This is mainly attributed to the fact that mixed sowing of different grass species can provide habitat factors such as full use of light, water, and soil nutrients, improve soil physical properties, chemical properties, and biological activity, improve soil water, soil fertilizer retention capacity, and soil structure, to promote crop growth and increase yield.

4.2. Effects of Different Mixed Grass Species and Seeding Rates on Plant Stoichiometry and Nutritional Components

Zheng et al. [37] showed that the content of crude protein and crude fat in artificial grassland mixed with four and five grass species was significantly higher than that of artificial grassland monoculture mixed. Shi et al. [38] established mixed grasslands on the Qinghai–Tibet Plateau and found that the production performance and community stability of methods of four grass species were significantly higher than those of methods of two or three grass species. In this study, the content of crude protein, crude fat, and soluble sugar in HE was the highest, the content of soluble protein in HD was the highest, and the content of acid fiber and neutral fiber in HD was the lowest, that is, the forage varieties of four mixed artificial gramineae grasslands were significantly better than that of two gramineae mixed artificial gramineae grasslands, which was consistent with the above research results. In this study, the contents of crude protein and crude fat in the mixed methods of *Poa pratensis* cv. Qinghai and *Pedicularis kansuensis* were significantly lower than those in other treatments. The possible reason is that *Pedicularis kansuensis* is a root-parasitic plant. During its growth and development, it will obtain water, carbohydrates, and other substances from the host *Poa pratensis* cv. Qinghai to accelerate its own growth and reproduction process. As a host, the quality of *Poa pratensis* cv. Qinghai will be significantly reduced [39].

4.3. Effects of Different Mixed Grass Species and Seeding Rates on Soil Physicochemical Properties

A large number of studies have shown that mixed planting of multiple grass species can increase plant community coverage, aboveground biomass, and belowground biomass, thereby increasing soil porosity and water content, reducing soil pH, and improving soil physicochemical properties [5,20,38–40]. Hadehaze et al. [41] found that mixed sowing of gramineae can significantly reduce soil bulk density and increase water content. Wang et al. [42] found that the mixed sowing of grass and grass can significantly reduce the soil pH value and change the soil EC value, bulk density, and water content. Chen et al. [43] found that different mixed grass species seeding rates and mixed sowing ratios could reduce soil pH and increase soil nutrient content. This study found that the soil water content of different mixed grass species and the seeding rates were significantly higher than that of CK, while the soil pH value was significantly lower than that of CK ($p < 0.05$) in the alpine mining area. The soil pH values of HD, HE, and HF were 10.99%, 11.35%, and 10.53% lower than that of CK ($p < 0.05$). The results showed that the mixed sowing of grass species could significantly improve the soil physicochemical properties of artificial grassland in the alpine mining area, which was consistent with the results of the above scholars. This phenomenon may be due to the mixed sowing of grass species, the community structure and function being more perfect, the growth rate of the aboveground and underground parts of the plant being accelerated, the roots being more developed, the degree of soil agglomeration being changed, and the surface infiltration capacity and soil's water-holding capacity being improved to maintain the high water content of the soil [20,40].

In the process of planting artificial grassland in alpine pastoral areas, mixed sowing can also increase soil nutrient content [20,21]. Liu et al. [35] found that mixed sowing of multiple grass species could increase soil nutrient content and promote the increase in forage yield by evaluating the restoration effect of mixed sowing grassland in alpine mining areas. Wang et al. [34] found that the contents of soil organic matter, alkali-hydrolyzable nitrogen, available phosphorus, and available potassium in coal mine dump were significantly increased after the mixed planting of one-year-old herbs and perennial herbs in the study of vegetation restoration in open-pit coal mine dump, and the content of organic matter was increased by about 20% compared with CK. In this study, the nutrient content of the soil under different mixed grass species and seeding rates was higher than that of CK, but the improvement of soil was different. The soil nutrients of HF were high, and the soil improvement effect was good. The contents of soil organic matter, total nitrogen, total phosphorus, and total potassium (0–10 cm soil layer) increased by 41.28%, 39.79%, 54.32%, and 12.36% compared with CK, and the contents of ammonia nitrogen and nitrate nitrogen increased by 46.01% and 26.14% compared with CK ($p < 0.05$). The increase in soil nutrients was significantly higher than that of Liu et al. [35] and Wang et al. [44]. The possible reason was that the sheep manure organic fertilizer as the base fertilizer had a high degree of maturity, and the granular organic fertilizer contained a large number of microorganisms to add sheep manure decomposition [45].

4.4. Comprehensive Evaluation of Plant Community Adaptability and High Yield of Different Mixed Grass Species and Seeding Rates

The effects of different mixed grass species and seeding rates on plant community characteristics, forage nutritional quality, and mining soil were different [46,47]. To evaluate the adaptability, yield, and soil improvement effect of each mixed planting combination, multiple factors need to be considered, including community characteristics, nutritional quality, and soil physicochemical properties. The membership function is an effective method. Through quantitative analysis and a comprehensive comparison of relevant indicators, the limitations of a single indicator are eliminated [48]. In this study, the principal component analysis of different mixed grass species and seeding rates was carried out, and it was found that the cumulative contribution rates of the first five principal components reached 83.872%. Then, the membership function ranking was used for comprehensive evaluation. It was found that the mixed grass species and the seeding rates of multiple grass species were significantly better than the mixed grass species and seeding rates of two grass species: *Poa pratensis* cv. Qinghai + *Poa crymophila* cv. Qinghai + *Puccinellia tenuiflora* cv. Tongde + *Pedicularis kansuensis* had the highest comprehensive ranking, the best plant community growth, the best forage quality, and the best soil improvement effect, which was consistent with the research results of Shi et al. [38]. The coverage, biomass and soil characteristics of multi-grass mixed sowing were significantly better than those of single sowing and two-grass mixed sowing.

Since 2022, the Muli mining area has been restored to green through a series of technical measures such as soil reconstruction and vegetation restoration, and the ecological environment of the mining area has been controlled. However, how to rationally manage and utilize the artificial grassland in the restoration area to achieve sustainable restoration is still an important issue. During the growth of forage grass, trace amounts of heavy metals and other substances are accumulated. When livestock consume forage grass, they can remove a small part of local heavy metals and other substances. If the forage grass is not eaten by livestock, it will return to the soil after death. Therefore, it is of great practical significance to continue to carry out relevant research on the grazing and utilization of artificial grassland in the Muli mining area to realize the continuous restoration of vegetation and reduce soil heavy metal pollution in the Muli mining area.

5. Conclusions and Prospects

5.1. Conclusions

The mixed grass species and seeding rates of *Poa pratensis* cv. Qinghai + *Poa crymophila* cv. Qinghai + *Puccinellia tenuiflora* cv. Tongde + *Pedicularis kansuensis* (HF) had the highest vegetation coverage (97.33%), followed by the mixed grass species and seeding rates of *Poa pratensis* cv. Qinghai + *Poa crymophila* cv. Qinghai + *Pedicularis kansuensis* (HE), which was 95.26%. The aboveground biomass of HF was the largest (356.27 $g \cdot m^{-2}$), and the aboveground biomass of HE was 319.42 $g \cdot m^{-2}$. Principal component analysis showed that the cumulative contribution rate of the first five principal components reached 83.872%. The ranking results of the membership function showed that the comprehensive score of HF mixed grass species and seeding rates was high (0.848), followed by HE mixed grass species and seeding rates (0.750). In summary, HF and HE had high vegetation biomass, large coverage, and good soil restoration effect, which was suitable for mixed grass species and seeding rates in the Muli mining area.

5.2. Prospects

(1) In this study, there are few grass species of other families except Gramineae. Only *Pedicularis kansuensis* of Scrophulariaceae can survive in the extremely harsh environment of the Muli mining area. The collection of native grass seeds should be continuously strengthened to enrich the screening of suitable native grass seeds in the Muli mining area.

(2) Grass species adaptability and community stability are the results of a long-term evaluation. Limited by the project implementation time and epidemic situation, this study only discussed the plant growth and soil remediation effect in the second year, and the relevant conclusions were only preliminary results. Because of the adaptability of grass species and the stability of mixed grass communities, long-term continuous observation and research should be carried out in the future.

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