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Screening Suitable Ecological Grasses and the Seeding Rate in the Muli Mining Area

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Abstract: To target the lack of suitable grass species in the ecological restoration process of the Muli mining area, nine ecological grass species of Gramineae, Gentianaceae, Scrophulariaceae, and Ranunculaceae were selected as experimental materials to simulate the external alkaline environment for a seed germination test, which could be used to explore the response of seed germination to the environment. At the same time, *Poa pratensis* L. 'Qinghai', *Deschampsia cespitosa*, *Koeleria cristata*, and *Elymus tangutorum* were used as test materials to carry out a variety of comparison and screening tests of suitable seeding rates. The effects of the seeding rate on plant coverage, biomass, forage nutrients, and soil properties were analyzed by a variety of comparison and seeding rate tests. The results showed the following: (1) The relative germination rate of *Koeleria cristata*, *Elymus tangutorum*, *Deschampsia cespitosa*, and *Poa pratensis* L. 'Qinghai' was more than 70%, and the coverage in the returning green period was more than 60%, which was significantly higher than that of other treatments ($p < 0.05$) and can better adapt to the environment of the Muli mining area compared to other grass species. Meanwhile, the adaptability of *Pedicularis kansuensis*, *Gentiana macrophylla*, and *Aconitum pendulum* was weak. (2) It was found that when the seeding rate was 9 $g \cdot m^{-2}$, the biomass of *Poa pratensis* L. 'Qinghai', *Deschampsia cespitos*, and *Koeleria cristata* was the highest, which was 296.45 $g \cdot m^{-2}$, 224.32 $g \cdot m^{-2}$, and 236.35 $g \cdot m^{-2}$, which was significantly higher than that of other treatments ($p < 0.05$); the aboveground biomass was 356.24 $g \cdot m^{-2}$ when the seeding rate of *Elymus tangutorum* was 18 $g \cdot m^{-2}$, which was significantly higher than that of other treatments ($p < 0.05$). The membership function showed that the comprehensive evaluation value was 0.701, 0.576, 0.610, and 0.673 when the seeding rate of *Poa pratensis* L. 'Qinghai', *Deschampsia cespitos*, and *Koeleria cristata* was 9 $g \cdot m^{-2}$ and the seeding rate of *Elymus tangutorum* was 18 $g \cdot m^{-2}$. To sum up, it is recommended that the four ecological grass species of *Poa pratensis* L. 'Qinghai', *Deschampsia cespitosa*, *Koeleria cristata*, and *Elymus tangutorum* can be used as the main grass species for ecological restoration in high-altitude and alpine areas such as the Muli mining area, which is affected by an alpine climate and fragile habitats. The optimum sowing rate of *Poa pratensis* L. 'Qinghai', *Deschampsia cespitosa*, and *Koeleria cristata* is 9 $g \cdot m^{-2}$, and that of *Elymus tangutorum* is 18 $g \cdot m^{-2}$. This cultivation method can effectively promote plant growth and development, improve the physicochemical properties of soil, and is conducive to improving the stability and sustainability of artificial grassland in alpine mining areas.

Keywords: ecological grass species; seeding rate; biomass; soil physicochemical properties; Muli mining area; sustainable artificial grassland

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1. Introduction

The Muli coal mine is located in the southern Qilian Mountains in Qinghai Province. It consists of four mining areas: Jiangcang, Juhugeng, Hushan, and Duosuogongma. The mining area is 159.13 km^2, including 11 open-pit mines and 19 slag mountains. More than 20 million tons of its coal has been mined [1,2]. Due to the simple mining method of 'water fast flow', frequent mining activities, and long-term unreasonable mining and utilization in the past, the original surface vegetation in a large area of the Muli mining area has been seriously damaged, the vegetation coverage rate in the mining area has decreased, and the soil fertility, water conservation capacity, and biodiversity have also been reduced, which has seriously reduced the sustainability of its ecosystem. Especially in the dumps accumulated due to open-pit mining, the surface matrix is extremely unstable and vulnerable to water erosion and wind erosion, thus accelerating the process of soil nutrient loss and soil degradation. In addition, the accumulation of dumps reduces the area of available natural grassland, which is not conducive to the sustainable development of local animal husbandry. Therefore, to protect the ecological security of the Muli area, its governance and restoration cannot be ignored. The ecological restoration of the Muli mining area is the first demonstration of a project of large-scale mine management in alpine and high-altitude areas in China. It is affected by the alpine climate and fragile habitats, and there is no successful experience and mature model to learn from at home or abroad, which has strong exploratory and experimental significance [3].

The ecological restoration of the alpine mining area in the Qinghai–Tibet Plateau is special. Limited by the special environmental conditions of the alpine and high altitudes, the research on its ecological restoration mainly focuses on soil reconstruction and vegetation reconstruction [4]. The key to vegetation restoration in alpine mining areas is the selection of suitable grass species and their seeding rates, and their climatic conditions and soil characteristics determine the selection of suitable plants [5–7]. The selection of suitable grass species for vegetation restoration in alpine mining areas should not only adapt to alpine climate conditions but also aim at soil characteristics and various heavy metal pollution problems in mining areas [8]. A large number of scholars in the United States, Britain, Germany, Australia, and China have found that native plants are more adaptable than exotic species and can better adapt to the environment, so they are the first choice for ecological restoration in mining areas [9–13]. At present, the main grass species selected for ecological restoration in alpine mining areas are Gramineae grass species, which is due to the hardiness, alkali resistance, and metal tolerance of Gramineae grass species adapted to the alpine mining environment. Gramineae species can tolerate alkaline stress through various physiological mechanisms, such as osmotic regulation, ion balance regulation, antioxidant mechanism, pH regulation, and root changes, to maintain normal physiological functions [1,3,10,14]. The ecological restoration of the copper mine area in the southeastern margin of Tibet uses *Elymus nutans*, *Festuca sinensis*, and *Poa crymophila* L. 'Qinghai' to sow, which can significantly increase the average height of the herb layer and reduce the soil heavy metal pollution [15]. *Elymus nutans* and *Poa crymophila* L. 'Qinghai' were selected for the rehabilitation of vegetation in the Deerni copper mine in the Sanjiangyuan area of China. With the increase in years, the community succeeded in achieving a stable state [16].

Due to the poor stability of the ecosystem and the unique geographical location in the Muli mining area, there is a lack of suitable ecological grass species and an unclear seeding rate in the process of ecological restoration. This study aims to improve the vegetation coverage rate, physicochemical properties of the soil, and sustainable development of the ecosystem in the mining area. Ecological grass species resistant to alkali stress such as Gramineae, Gentianaceae, Scrophulariaceae, and Ranunculaceae were selected as experimental materials to carry out the introduction screening and seeding rate screening test. To explore the effects of different community configurations 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 ecological grass species with cold and alkali resistance for alpine mining areas; (2) obtaining the suitable seeding rate of four common ecological restoration types of grass (*Poa pratensis* L. 'Qinghai', *Deschampsia cespitosa*, *Koeleria cristata*, and *Elymus tangutorum*).

2. Materials and Methods

2.1. Study Area

The study area is located in the Juhugeng mining area (38°9′34″ N, 99°9′40″ E) in Muli Town (Figure 1), Tianjun County, Qinghai Province. The average altitude is 4200 m. The annual average temperature is −5.3 °C, the average temperature in the coldest month (January) is −17.2 °C, and the average temperature in the hottest month (July) is 15.6 °C. The annual rainfall is 282~774 mm, mainly concentrated in May and September. The annual evaporation is 1049.9 mm, and the annual sunshine hours are 2551~3332 h. The growth time of forage grass is short, only about 120 days.

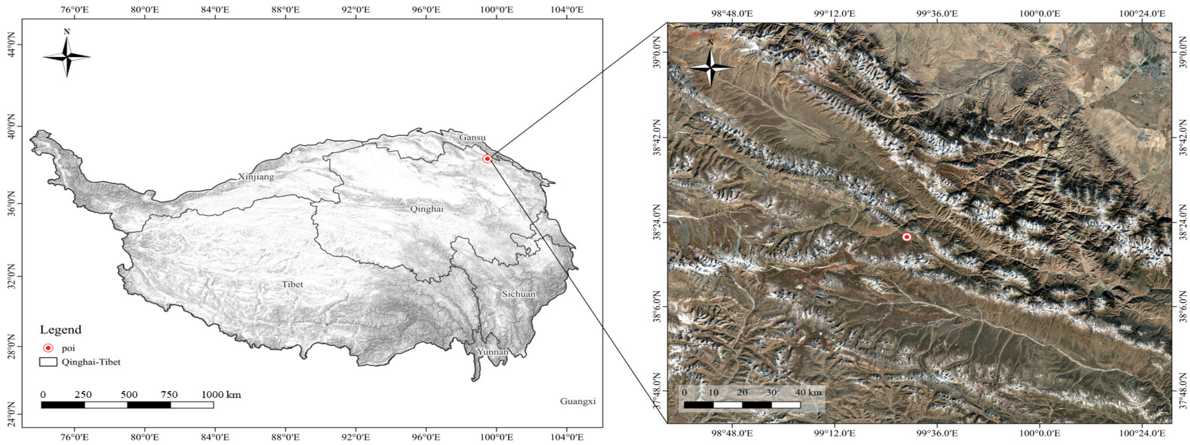

Figure 1. Geographical location of the study area.

The original vegetation types in the experimental area are mainly alpine meadows and swamp meadows, and the specific geographical location is shown in Figure 1. After soil preparation, the basal physicochemical properties of the soil in the field experiment were as follows: the soil water content was 13.86%; the pH (water–soil ratio 1:2.5) was 8.47; and the soil nutrient content was 261.76 g/kg of organic matter, 6.69 g/kg of total nitrogen, 1.94 g/kg of total phosphorus, 14.11 g/kg of total potassium, 51.17 mg/kg of available phosphorus, 548.51 mg/kg of available potassium, 3.28 g/kg of ammonium nitrogen, and 3.09 g/kg of nitrate nitrogen.

2.2. Methods

2.2.1. Simulating the External Environment for Seed Germination Test

In late May 2022, 30 samples of the 0–20 cm soil layer were collected using the 'S' sampling method in the artificial grassland test area of the Muli mining area, and an acidity meter (PHS-3C, Shanghai, China) was used to determine the soil pH value of all samples. It was found that the soil in the slag mountain and mine test area of the Muli mining area was alkaline. The pH was mainly 8.2–8.8. Therefore, this experiment simulated the alkaline environment and carried out the germination experiment of seeds under alkaline stress with a pH of 8.5.

Using sterile deionized water as the reference solution (pH = 6.8), the pH was adjusted to 8.5 with 1 mol·L^{-1} NaOH and HCl by using the acidity meter (PHS-3C, Shanghai, China), and there were 9 experimental grass species (Table 1). First, the seeds were disinfected with NaClO and rinsed with sterilized deionized water 7–8 times, and the solution with a pH of 8.5 was dropped into a Petri dish until it was saturated with 2 layers of filter paper. Fifty uniform, plump, and consistent seeds were randomly selected and placed in a Petri dish; this was repeated three times. The culture dishes were placed in a thermostatic incubator (GHP-9080, Wuxi, China) at a temperature of (25 ± 1) °C (12 h dark/12 h light). Every 2 days, 5 mL water was added. After the seeds began to germinate, the filter paper was saturated with water every day. The germination of the seeds was observed and recorded daily until the number of germinations did not increase after 5 days [17].

Table 1. Basic information on the grass species.

Grass Seed	Labeled	Thousand Grain Weight (g)	Seeding Rate (g·m^{-2})
Poa pratensis L. 'Qinghai'	Pp	0.23	9.00
Deschampsia cespitosa	Dc	0.34	9.00
Koeleria cristata	Kc	0.36	9.00
Elymus tangutorum	Et	2.64	24.00
Poa crymophila L. 'Qinghai'	Pc	0.21	9.00
Puccinellia tenuiflora cv. 'Tongde'	Pt	0.2	9.00
Gentiana macrophylla	Gm	0.18	6.00
Aconitum pendulum	Ap	1.66	6.00
Pedicularis kansuensis	Pk	0.51	6.00

2.2.2. Comparative Test of Seedling Stage and Green Stage Coverage of 9 Kinds of Ecological Grass

Field experiments were carried out on 9 ecological grass species (Table 1) in July 2022. The seeding rate of the upper grass, *Elymus tangutorum*, was 24 g·m^{-2}, and the seeding rate of the lower grasses, *Poa pratensis* L. 'Qinghai', *Deschampsia cespitosa*, *Koeleria cristata*, *Poa crymophila* L. 'Qinghai', and *Puccinellia tenuiflora* cv. 'Tongde' was 9 g·m^{-2}, and the seeding rate of *Gentiana macrophylla*, *Pedicularis kansuensis*, and *Aconitum pendulum* was 6 g·m^{-2}. The seeding method was artificial sowing, The sowing amount was determined by referring to the previous pre-experiment. After the terrain regulation slag screening and paving of the test site, a base fertilizer was applied with a rotary tiller (1BQD-3.4, Beijing, China) over 10 cm. The fertilization rate was 25 m^3·667 m^{-2} sheep manure + 1.5 t·667 m^{-2} commercial organic fertilizer (mineral-source humic acid bio-organic fertilizer, Henan Lisuo Crop Protection Co., Ltd., Changge City, China); the organic matter was ≥ 45%, and the total nutrient content was N + P_2O_5 + K_2O ≥ 5% [18,19].

A plot was designed with a randomized block design with a plot area of 4 m × 5 m and a plot spacing of 0.5 m. Each grass species had three replicates, and a total of 27 plots were set up. After sowing, 20 ± 2 g·m^{-2} of non-woven fabric was laid to keep water and heat preservation and prevent soil erosion. Harmless treatment was carried out after collecting the seedlings [18,19].

2.2.3. Screening Test of Suitable Sowing Rate for 4 Ecological Grass Species

Three seeding rates (Table 2) were set up for *Poa pratensis* L. 'Qinghai' (Pp), *Deschampsia cespitosa* (Dc), *Koeleria cristata* (Kc), and *Elymus tangutorum* (Et) with good adaptability to carry out the screening test of a suitable seeding rate. A randomized block design was used, with 12 treatments repeated 3 times and a total of 36 plots, and the plot area was 4 m × 5 m. The planting method was consistent with ecological grass cultivation (Section 2.2.2) [18,19].

Table 2. Different seeding rates of ecological grass species.

Treatment		Grass Seed	Seeding Rate (g·m^{-2})
Pp	Pp1	*Poa pratensis* L. 'Qinghai'	6.00
	Pp2	*Poa pratensis* L. 'Qinghai'	9.00
	Pp3	*Poa pratensis* L. 'Qinghai'	12.00
Dc	Dc1	*Deschampsia cespitosa*	6.00
	Dc2	*Deschampsia cespitosa*	9.00
	Dc3	*Deschampsia cespitosa*	12.00
Kc	Kc1	*Koeleria cristata*	6.00
	Kc2	*Koeleria cristata*	9.00
	Kc3	*Koeleria cristata*	12.00
Et	Et1	*Elymus tangutorum*	18.00
	Et2	*Elymus tangutorum*	24.00
	Et3	*Elymus tangutorum*	30.00

2.3. Sample Collection and Determination

2.3.1. Simulating the External Environment for Seed Germination

The number of germinations was recorded every day after seed germination. After 7 days of culture after germination, the seedlings were taken out, the surface water was sucked dry with filter paper, and the root length and bud length of the seedlings were measured with a vernier caliper (DWKC-2012, Beijing, China).

$$\text{Germination rate (GE, \%)} = \text{18 d normal germination seed number/test seed number} \times 100,$$

$$\text{Germination index (GI)} = \sum(\text{Gt/Dt}),$$

In this formula, Gt is the number of germinations at day t, and Dt is the corresponding number of days of the germination test.

$$\text{Vigor index (VI)} = \text{GI} \times \text{S},$$

In this formula, GI is the germination index, and S is the length of the seedling [17,20,21].

$$\text{Relative germination rate (RGR, \%)} = \text{treatment germination rate/control germination rate} \times 100,$$

$$\text{Relative root length (RRL, \%)} = \text{treated root length/control root length} \times 100,$$

$$\text{Relative bud length (RBL, \%)} = \text{treatment bud length/control bud length} \times 100,$$

$$\text{Relative germination index (RGI, \%)} = \text{treatment germination index/control germination index} \times 100\%,$$

$$\text{Relative vigor index (RVI, \%)} = \text{treatment vigor index/control vigor index} \times 100\%$$

2.3.2. Ecological Grass Cultivation Experiment

The coverage of the seedling stage was measured by a visual method in mid-September 2022, and the coverage of the regreening stage was measured in mid-June 2023.

2.3.3. Suitable Seeding Rate Screening Test

At the end of August 2023, three 50 cm × 50 cm quadrats were randomly set up in each experimental plot to collect samples, with a total of 108 quadrats.

Determination of Growth Characteristics

Height: 10 plants were randomly selected from each plot. The natural height from the ground to the leaf tip of the main stem was measured, and the average value was calculated as the plant height. Coverage: a visual method, the ratio of the vertical projection area in the sample, was used. 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. Underground biomass: root samples were collected from the samples using a root drill with a diameter of 7 cm, and 4 drills were used to collect each sample to remove the soil and dry it to a constant weight [18,22].

Determination of Plant Nutrients

The plant crude protein content was estimated from the plant nitrogen content; the content of crude fat was determined by the Soxhlet ether extraction method. The soluble sugar content was by the anthrone colorimetric method; the soluble protein content was quantified by the BCA protein quantitative method; and the acid detergent fiber content and neutral detergent fiber content were determined by the acid detergent and neutral detergent method [18,23,24].

Determination of Soil Physical and Chemical Indicators

According to the 5-point mixed sampling method, soil samples from 0–10 cm and 10–20 cm were randomly collected from each plot and divided into sealed bags; this was repeated three times. The soil in each soil layer was divided into two parts: one was air-dried and the other was wet soil-frozen [18,25].

The soil moisture content was determined by the drying method. The soil pH value was determined by the potentiometric method with the acidity meter (PHS-3C, Shanghai, China). The soil nutrient content was determined using 'Soil Agrochemical Analysis' [26]. The soil organic matter was determined by the potassium dichromate trick method. The total nitrogen was determined by the semi-micro-Kjeldahl method. The total phosphorus was determined by the sodium hydroxide melting–molybdenum antimony anti-colorimetric method. The total potassium was determined by sodium hydroxide melting–flame spectrophotometry. The available phosphorus was determined by the sodium bicarbonate extraction–molybdenum antimony colorimetric method. The available potassium was determined by ammonium acetate extraction–flame spectrophotometry. The ammonia nitrogen was determined by the hydrogen chloride extraction–distillation method. The nitrate nitrogen was measured by phenol–disulfonic acid colorimetry [25,26].

Comprehensive Ranking

The calculation formula of the membership function value is R (Xj) = (Xj − Xmin)/(Xmax − Xmin)

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 in the jth treatment [20].

The weight calculation formula is

$$\mathrm{Wj} = \mathrm{Pj} / \sum_{j=1}^{n} \mathrm{Pj}$$

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

The comprehensive evaluation value is

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

In the formula, U (Xj) represents the membership function value of the jth comprehensive index value, and Wj represents the weight of the jth comprehensive index [20].

2.4. Data Analysis

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. The germination rate, root length, bud length, germination index, and vigor index of the grass seeds were evaluated by the TOPSIS method [27,28]. The membership function ranking method was used for comprehensive analysis [29,30].

3. Results

3.1. Screening of Ecological Grass Species

3.1.1. Effect of Alkaline Environment on Relative Germination Rate, Root Length, Bud Length, Germination Index, and Viability Index of Ecological Grass Seeds

After treatment with a pH = 8.5 solution, the relative germination rates of different ecological grass seeds were significantly different (Figure 2a). The relative germination rate of Dc was the highest (130.73%), which was significantly higher than that of the other eight ecological grass species. The relative germination rates of Dc, Kc, Et, Pt, Pp, and Pc were significantly higher than those of Gm, Ap, and Pk ($p < 0.05$). It can be seen that the relative germination rate of Gramineae species in an alkaline environment is higher than that of other families, and the difference is significant.

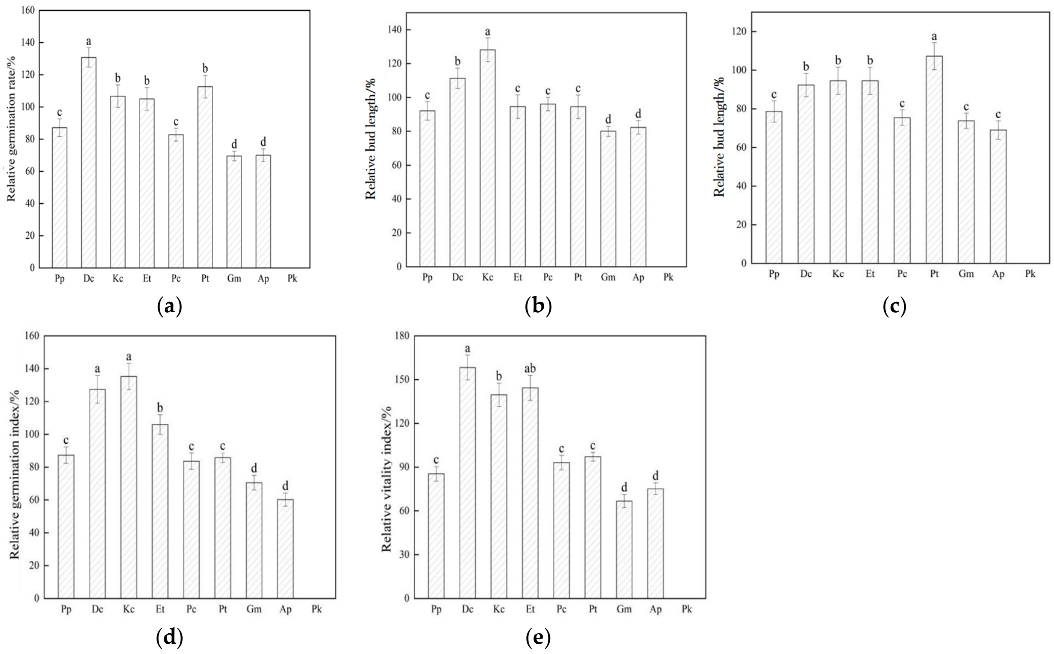

Figure 2. Relative germination rate, root length, bud length, germination index, and viability index of test grass species. Note: different lowercase letters indicate significant differences among different grass species ($p < 0.05$). (**a**–**e**) are Relative Germination Rate, Root Length, Bud Length, Germination Index, and Viability Index, respectively.

Under an alkaline environment, the relative bud length of the Kc seedlings was the highest (128.08%), which was significantly higher than those of Pp, Dc, Et, Pc, Pt, Gm, and Ap, which were 39.17%, 15.07%, 35.45%, 33.34%, 35.55%, 60.04% and 55.74% ($p < 0.05$). The relative shoot length of some grasses was significantly higher than that of other grasses (Figure 2b).

Under alkaline stress, the relative root length of the different ecological grass seedlings was Pt > Kc > Et > Dc > PP > Pc > Gm > AP > Pk (Figure 2c). The relative root length of Pt was the longest, up to 112.58%, which was significantly higher than that of the other grass species ($p < 0.05$). The relative root length of Dc, Kc, and Et was longer, which was significantly higher than that of Pp, Pc, Gm, Ap, and Pk ($p < 0.05$). The higher the relative root length, the stronger the alkali resistance of the root system is.

The relative germination index and relative vigor index are the comprehensive reflection of the seed germination rate and growth increment and are indexes to evaluate seed vigor. The higher the value, the stronger the vigor of the tested grass species under alkaline stress is and the faster the growth and development speed is. The relative germination index of Kc was the highest (135.28%), followed by Dc, which was significantly higher than Pp, Et, Pc, Pt, Gm, Ap, and Pk ($p < 0.05$). The relative germination index of Et was significantly higher than those of Pp, Pc, Pt, Gm, and Ap, which were 21.33%, 26.73%, 23.47%, 50.23%, and 76.03%. The relative germination index of Gramineae in an alkaline solution of a pH of 8.5 was high, indicating that the germination rate of seeds was still fast under alkaline stress (Figure 2d).

The top four relative vigor indexes of the ecological grass species were those of Dc, Et, Kc, and Pt (Figure 2e). The relative vigor index of Dc was the highest, which was not significantly different from that of Et ($p > 0.05$) but was significantly higher than that of other treatments ($p < 0.05$). The vigor index of the grasses was significantly higher than that of Gm, Ap, and Pk ($p < 0.05$). It can be seen that in the alkaline environment, there were significant differences in the relative germination index and relative vigor index among different ecological grass species. Among them, Dc, Kc, and Et had the highest relative germination index and relative vigor index.

3.1.2. Comprehensive Evaluation of Alkali Resistance of Nine Ecological Grasses

The TOPSIS method was selected because it is based on the comprehensive evaluation of the positive ideal solution and the far away from the ideal solution. It can comprehensively compare multiple indicators of the research object and has been widely used in the evaluation of alkali tolerance at the germination stage and seedling stage. Using this method to compare the germination characteristics of different forage seeds under alkaline stress can overall analyze their comprehensive quality differences and avoid the defects of few-indexes evaluation.

The relative germination rate, relative bud length, relative root length, relative germination index, and relative vigor index were selected to comprehensively evaluate the alkali resistance of the tested ecological grasses (Table 3). The comprehensive ranking of the alkali resistance of the nine tested grass species showed that the four ecological grass species of *Elymus tangutorum*, *Deschampsia cespitosa*, *Koeleria cristata*, and *Poa pratensis* L. 'Qinghai' had good alkali resistance, and the alkali resistance of *Gentiana macrophylla*, *Aconitum pendulum*, and *Pedicularis kansuensis* was poor. The species with good alkali resistance are more adaptable to alkaline soil, and the above four grass species with good alkali resistance can be preferred for sowing.

Table 3. The alkaline resistance of the tested grass seeds was comprehensively evaluated by the TOPSIS method.

Numbered	Treatment	Closeness Degree (Ci)	Scheduling
Et	*Elymus tangutorum*	0.73	1
Dc	*Deschampsia cespitosa*	0.72	2
Kc	*Koeleria cristata*	0.63	3
Pp	*Poa pratensis* L. 'Qinghai'	0.54	4
Pt	*Puccinellia tenuiflora* cv. 'Tongde'	0.52	5
Pc	*Poa crymophila* L. 'Qinghai'	0.40	6
Gm	*Gentiana macrophylla*	0.31	7
Ap	*Aconitum pendulum*	0.32	8
Pk	*Pedicularis kansuensis*	0.00	9

3.1.3. Vegetation Coverage of Ecological Grasses at Seedling Stage and Regreening Stage

The coverage of each grass species at the seedling stage was Et > Kc > Dc > PP > Pt > Pc > Pk > Ap = Gm (Figure 3). The coverage of Et at the seedling stage was the highest (73.86%), which was significantly higher than that of the other grass species, except Kc ($p < 0.05$). The coverage of Gramineae was high, and only a small number of seeds of *Pedicularis kansuensis* emerged, while *Gentiana macrophylla* and *Aconitum pendulum* did not germinate.

The coverage of the regreening period of Dc was 88.63%, which was significantly higher than that of Pc, Pt, Pk, Gm, and Ap (Figure 3). That of Dc was significantly higher than Pc and Pt by 47.66 and 23.05% ($p < 0.05$). The vegetation coverage of Pp, Dc, Pc, and Pt in the seedling stage and regreening stage was significantly different ($p < 0.05$). The test results show that the coverage of *Poa pratensis* L. 'Qinghai', *Deschampsia cespitosa*, *Poa crymophila* L. 'Qinghai', and *Puccinellia tenuiflora* cv. 'Tongde' in the regreening stage was high.

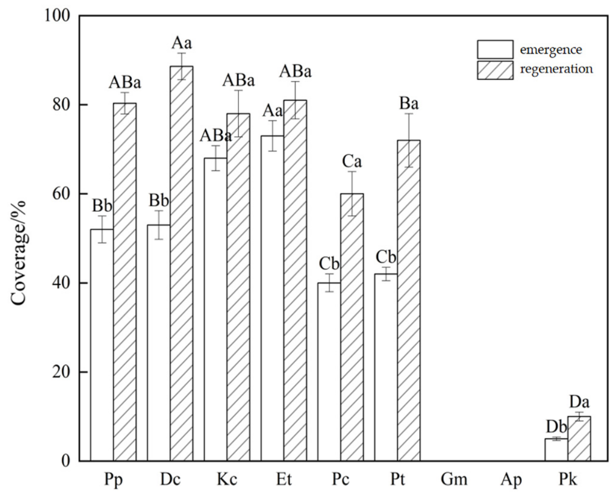

Figure 3. Vegetation cover during the seedling emergence and regreening periods. Note: different capital letters represent significant differences between different grass species in the same period, and different lower-case letters indicate significant differences between the same grass species in different periods ($p < 0.05$).

3.2. Suitable Seeding Rate Screening

3.2.1. Analysis of Growth Traits of Ecological Grasses Under Different Seeding Rates

Under different seeding rates, the plant height of the ecological grass species was significantly different (Figure 4a). Among the three seeding rates of the Pp varieties, the plant height of Pp2 was the highest (40.58 cm), which was significantly higher, by 19.12%, than that of Pp1 and 31.99% higher than that of Pp3 ($p < 0.05$). In the Dc varieties, the plant height of Dc1 was 18.58 cm, which was significantly higher than that of Dc2 and Dc3 ($p < 0.05$). Under different seeding rates, the plant height of Kc3 was the highest (25.53 cm), which was not significantly different from other treatments ($p > 0.05$). Among the three seeding treatments of the Et varieties, the plant height of Et1 was the highest, which was significantly higher than that of Et2 and Et3 by 11.46% and 16.99% ($p < 0.05$). The results showed that a suitable seeding rate could significantly increase the plant height of the tested grass species, and the optimum seeding rate was different for different grass species.

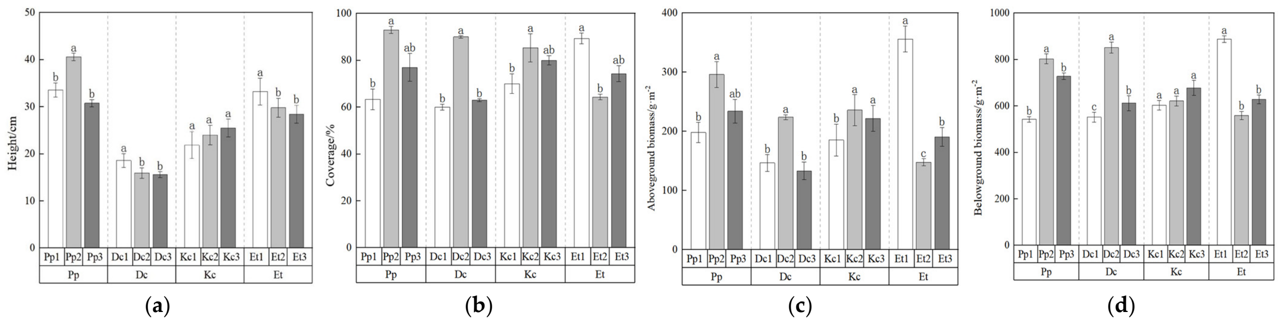

Figure 4. Comparison of ecological grass growth traits at different seeding rates. Note: different lowercase letters indicate significant differences between the different seeding rates of the same grass species ($p < 0.05$). (**a**–**d**) are Height, Coverage, Aboveground biomass and Belowground biomass, respectively.

The coverage of ecological grass species varied with different seeding rates (Figure 4b). In the three seeding rates of the Pp varieties, the coverage was ranked as Pp2 > Pp3 > Pp1, and Pp2 was significantly higher, by 47.62%, than Pp1 ($p < 0.05$). Among the Dc varieties, the coverage of Dc2 was the highest, up to 90.04%, which was significantly higher than that of other treatments ($p < 0.05$). The coverage of Kc2 and Kc3 reached 80%, and the coverage of Kc2 was significantly higher than that of Kc1 ($p < 0.05$). Under the three seeding rates of the Et varieties, the coverage of Et1 was the highest (89.33%), which was significantly higher than that of Et2 ($p < 0.05$). The results showed that a suitable seeding rate could significantly increase the coverage of the ecological grass seeds, and the coverage increased first and then decreased with the increase in the seeding rate.

Under different seeding rates, the aboveground biomass of the ecological grass species was significantly different (Figure 4c). Among the three seeding rates of the Pp varieties, the biomass of Pp2 was the highest, up to 296.45 $g \cdot m^{-2}$, which was significantly increased by 31.22% compared to Pp1 ($p < 0.05$). Among the Dc varieties, only the biomass of Dc2 reached more than 200 $g \cdot m^{-2}$, which was 224.32 $g \cdot m^{-2}$, which was significantly higher than that of other seeding rates ($p < 0.05$). Among the three seeding treatments of the Kc varieties, Kc2 and Kc3 were significantly higher than Kc1 ($p < 0.05$). The aboveground biomass of the Et varieties was significantly different under different seeding rates ($p < 0.05$). Among them, the aboveground biomass of the Et1 treatment was the highest, which was 356.45 $g \cdot m^{-2}$, followed by Et3 and Et2.

Under different seeding rates, the underground biomass of the ecological grass species was different (Figure 4d). In the three seeding rates treatments of the Pp varieties, the underground biomass was ranked as Pp2 > Pp3 > Pp1. Among them, Pp2 was as high as 803.35 $g \cdot m^{-2}$, which was significantly higher than other treatments ($p < 0.05$). In the Dc varieties, the underground biomass of Dc2 was 852.08 $g \cdot m^{-2}$, which was significantly increased by 54.35% compared to Dc1 ($p < 0.05$). The underground biomass of the Kc varieties reached 600 $g \cdot m^{-2}$, which was 603.45 $g \cdot m^{-2}$, 621.33 $g \cdot m^{-2}$, and 678.07 $g \cdot m^{-2}$. Among the Et varieties, the underground biomass of Et1 was as high as 888.42 $g \cdot m^{-2}$, which was significantly higher than that of other seeding rates treatments ($p < 0.05$).

3.2.2. Analysis of Nutritional Components of Ecological Grass Species Under Different Seeding Rates

In different seeding treatments, the nutrient content of the ecological grass species was different (Table 4). Among the three seeding rates of the Pp varieties, the contents of crude protein, crude fat, soluble sugar, and soluble protein in the Pp2 treatment were the highest, which were 176.71 $g \cdot kg^{-1}$, 2.83%, 50.19 $mg \cdot g^{-1}$, and 81.47 $mg \cdot g^{-1}$, which were significantly higher than those of the other two seeding rates ($p < 0.05$). The neutral fiber content of each treatment was between 52.22% and 52.88%, and the acidic fiber content of each treatment was between 26.40% and 28.54%, and there was no significant difference among different seeding rates ($p > 0.05$).

Table 4. Comparison of nutrient composition of ecological grass species with different seeding rates.

Treatment		Crude Protein ($g \cdot kg^{-1}$)	Crude Fat (%)	Soluble Sugar ($mg \cdot g^{-1}$)	Soluble Protein ($mg \cdot g^{-1}$)	Neutral Fiber (%)	Acidic Fiber (%)
Pp	Pp1	113.36 ± 15.62 c	2.51 ± 0.18 b	42.25 ± 2.43 b	71.87 ± 4.56 b	52.22 ± 5.39 a	28.24 ± 3.46 a
	Pp2	176.71 ± 16.33 a	2.83 ± 0.15 a	50.19 ± 4.35 a	81.47 ± 6.46 a	52.88 ± 2.40 a	26.40 ± 3.58 a
	Pp3	139.48 ± 16.75 b	2.17 ± 0.20 c	48.77 ± 3.52 a	74.74 ± 3.57 b	52.44 ± 3.89 a	28.54 ± 4.26 a
Dc	Dc1	171.85 ± 12.32 a	2.62 ± 0.28 a	41.07 ± 4.52 c	57.74 ± 2.65 c	53.01 ± 5.83 a	30.59 ± 2.68 a
	Dc2	158.52 ± 13.62 b	2.67 ± 0.22 a	57.70 ± 5.47 a	73.77 ± 6.46 a	55.12 ± 7.54 a	31.07 ± 3.48 a
	Dc3	171.31 ± 18.32 a	2.41 ± 0.17 b	51.54 ± 4.35 b	62.92 ± 6.34 b	52.54 ± 6.54 a	30.97 ± 4.35 a
Kc	Kc1	98.60 ± 9.63 b	2.81 ± 0.23 b	50.74 ± 3.58 b	84.54 ± 7.52 a	55.01 ± 7.53 a	30.93 ± 2.76 a
	Kc2	117.88 ± 16.36 a	3.14 ± 0.25 a	55.72 ± 5.36 a	81.72 ± 4.28 a	50.01 ± 4.30 b	28.05 ± 1.68 b
	Kc3	105.81 ± 12.85 b	2.83 ± 0.18 b	51.06 ± 6.42 b	82.53 ± 6.43 a	50.12 ± 5.39 b	28.01 ± 2.35 b
Et	Et1	136.23 ± 12.68 a	2.56 ± 0.26 a	57.72 ± 2.74 a	73.41 ± 3.48 a	60.54 ± 4.36 a	34.12 ± 5.30 a
	Et2	99.87 ± 12.13 c	2.58 ± 0.34 a	49.65 ± 3.46 b	68.06 ± 7.42 ab	59.01 ± 5.76 a	32.02 ± 4.34 a
	Et3	114.93 ± 14.50 b	2.32 ± 0.14 b	56.09 ± 5.32 a	65.18 ± 7.43 b	58.61 ± 5.43 a	33.52 ± 2.45 a

Note: different lowercase letters indicate significant differences between the different seeding rates of the same grass species ($p < 0.05$).

Among the three seeding rates of the Dc varieties, the crude protein content of Dc1 was the highest (171.85 g·kg^{-1}), which was 8.42% higher than that of Dc2 ($p < 0.05$). The contents of crude fat, soluble sugar, and soluble protein in Dc2 were the highest, which were 2.67%, 57.70 mg·g^{-1}, and 73.77 mg·g^{-1}, which were significantly higher than those in the other two seeding rates ($p < 0.05$). There was no significant difference in the neutral fiber content and acidic fiber content among different seeding rates, and both show that Dc2 had the highest contents ($p > 0.05$).

Among the three seeding rates of the Kc varieties, the contents of crude protein, crude fat, and soluble sugar in Kc2 were the highest, which were 117.88 g·kg^{-1}, 3.14%, and 55.72 mg·g^{-1}, which were significantly higher than those of the other two seeding rates ($p < 0.05$). The contents of soluble protein in each treatment ranged from 81.72 mg·g^{-1} to 84.54 mg·g^{-1}, and there was no significant difference among different seeding rates ($p > 0.05$). The neutral fiber content and acidic fiber content show that Kc1 had the highest contents, which were 55.01% and 30.93%, which were significantly higher than those in other treatments ($p < 0.05$).

In the three seeding treatments of the Et varieties, the crude protein content of Et1 was significantly higher than that of Et2 and Et3, being 36.41% and 18.53% higher ($p < 0.05$). The crude fat content ranged from 2.32% to 2.58%, and the crude fat content of Et2 was the highest, which was significantly higher than that of Et3 (11.21%) ($p < 0.05$). The soluble sugar and soluble protein of Et1 were the highest, which were 136.23 g·kg^{-1} and 73.41 mg·g^{-1}. There was no significant difference in the content of acid fiber and neutral fiber among different seeding rates ($p > 0.05$). From the perspective of forage nutrients, the nutrient content of each ecological grass species increased significantly under a suitable sowing rate. The contents of crude protein, crude fat, soluble sugar, and soluble protein in Pp, Dc, and Kc were the highest under a medium sowing rate, and the contents of crude protein, crude fat, soluble sugar, and soluble protein in Et were the highest under a low sowing rate.

3.2.3. Analysis of Physical and Chemical Properties in Soil of Ecological Grass Species Under Different Seeding Rates

Soil Water Content Under Different Seeding Rates

There were significant differences in the soil water content among different seeding rates and different soil depths (Figure 5). Under different seeding rates, the water content of the 0~10 cm and 10~20 cm soil layers of the Pp varieties were significantly higher than that of CK ($p < 0.05$). Among them, in the 0~10 cm soil layer, the water content of Pp2 was the highest, up to 24.93%, which was significantly higher than that of CK by 42.73%. In the 10~20 cm soil layer, the water content of Pp3 was the highest (22.63%), which was significantly higher than that of CK ($p < 0.05$).

The soil water content of the Dc varieties was significantly different under different seeding rates and soil depths (Figure 5). In the 0~10 cm soil depth, the soil water content of Dc2 and Dc3 was significantly higher than that of CK by 33.36% and 35.52% ($p < 0.05$). In the 10~20 cm soil layer, that of Dc2 was significantly higher, by 30.46%, than that of CK.

The soil water content of the Kc varieties was significantly affected by different seeding rates and different soil depths (Figure 5). In the 0~10 cm and 10~20 cm soil depths, the soil water content of Kc2 was the highest, which was significantly higher than that of CK by 29.12% and 22.38% ($p < 0.05$). In the soil layer with a depth of 0~10 cm, the soil water content of Kc3 was the lowest, and there was no significant difference between Kc3 and CK ($p > 0.05$).

Under different seeding rates, the soil water content of Et1 was the highest in the 0~10 cm soil depth (19.98%), which was significantly different from other treatments ($p < 0.05$). The Et3 processing was second, and Et2 was the lowest at 16.68%. In the soil layer with a depth of 10~20 cm, the water content of each treatment was ranked as Et1 > Et2 > Et3 > CK, and the difference was not significant ($p < 0.05$).

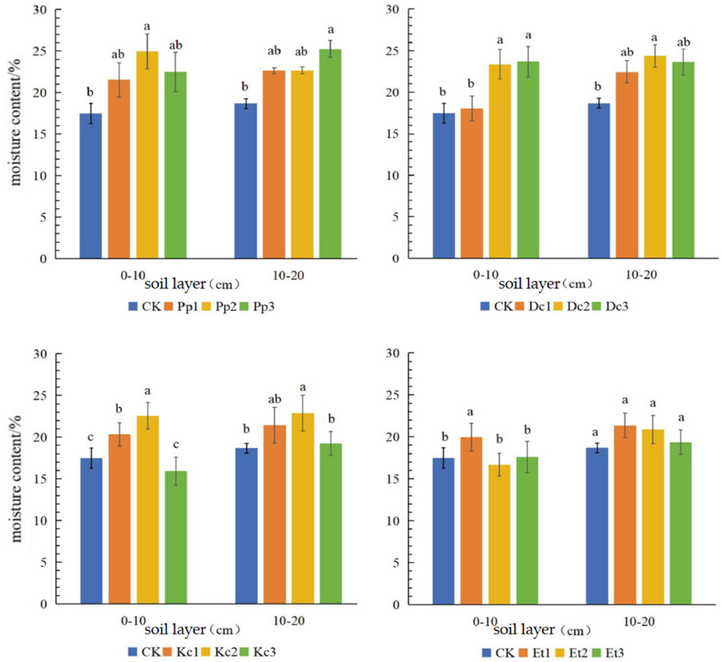

Figure 5. Comparison of the soil moisture content under different seeding rates. Note: different lowercase letters represent significant differences between different treatments in the same soil layer ($p < 0.05$).

Analysis of Soil pH Under Different Seeding Rates

The effects of the different varieties and seeding rates of ecological grasses on the rhizosphere soil pH at different soil depths were not significant ($p > 0.05$) (Figure 6). For the Pp, Dc, Kc, and Et varieties under three different seeding rates, in the 0~10 cm and 10~20 cm soil depths, there was no significant difference between CK and other treatments, but the soil pH in the 0~10 cm soil layer was lower than that in the 10~20 cm layer, and the surface soil pH decreased. In the 0~10 cm soil layer, the soil pH of Et1 and Et3 was 6.65% and 5.35% lower than that of CK. In summary, different treatments can reduce the soil pH value of the slag mountain, but there was no significant difference between the treatments.

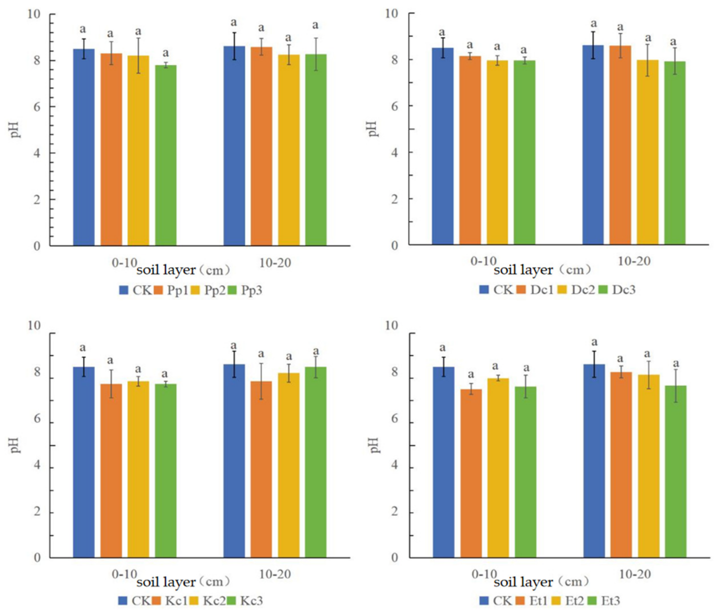

Figure 6. Comparison of the soil pH at different seeding rates. Note: different lowercase letters represent significant differences between different treatments in the same soil layer ($p < 0.05$).

Analysis of Soil Nutrients Under Different Seeding Rates

Research shows that after reseeding four ecological grass species in the Muli mining area, the contents of organic matter, total nitrogen, total phosphorus, total potassium, ammonia nitrogen, nitrate nitrogen, available phosphorus, and available potassium in the soil of the mining area were significantly higher than those of CK (Tables 5 and 6). In the 0~10 cm soil layer, the soil improvement effect of Pp2 was the best under the three seeding rates of the Pp varieties, and the organic matter content increased by 33.60% compared to CK. The total nitrogen, total phosphorus, and total potassium of Pp2 was improved by 39.62%, 54.32%, and 20.47% compared to CK, in which available phosphorus and available potassium in soil increased by 64.70% and 53.26% compared to CK ($p < 0.05$). Under the three seeding rates of the Dc varieties, the soil improvement effect of Dc2 was the best. The contents of organic matter, total nitrogen, total phosphorus, total potassium, ammonia nitrogen, nitrate nitrogen, and available phosphorus in the soil of Dc2 were 14.37%, 32.93%, 37.65%, 17.64%, 12.93%, 28.43%, and 21.29% higher than those of CK, and the difference was significant ($p < 0.05$). Under the three seeding rates of the Kc varieties, the soil improvement effect of Kc2 was the best. The contents of organic matter, total nitrogen, total phosphorus, total potassium, ammonia nitrogen, nitrate nitrogen, available phosphorus, and available potassium in the soil of Kc2 were 298.95 $g \cdot kg^{-1}$, 7.86 $g \cdot kg^{-1}$, 2.30 $g \cdot kg^{-1}$, 16.71 $g \cdot kg^{-1}$, 3.45 $g \cdot kg^{-1}$, 4.51 $g \cdot kg^{-1}$, 64.14 $mg \cdot kg^{-1}$, and 750.57 $mg \cdot kg^{-1}$, which were 45.51%, 34.82%, 41.98%, 12.91%, 31.18%, 47.39%, 35.89%, and 55.40% higher than those of CK; the difference was significant ($p < 0.05$). Under the three seeding rates of the Et varieties, the soil improvement effect of Et1 was the best. The contents of organic matter, total nitrogen, total phosphorus, ammonia nitrogen, nitrate nitrogen, available phosphorus, and available potassium in the soil of Et1 were 56.28%, 42.54%, 61.73%, 45.63%, 44.44%, 54.87%, and 49.80% higher than those of CK ($p < 0.05$).

Table 5. Soil nutrients at different seeding rates (0~10 cm).

Soil Layer	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 ($mg \cdot kg^{-1}$)	Available Potassium ($mg \cdot kg^{-1}$)	Ammonia Nitrogen ($g \cdot kg^{-1}$)	Nitrate Nitrogen ($g \cdot kg^{-1}$)
0~10	Pp1	278.59 ± 9.45 a	7.35 ± 0.65 b	2.47 ± 0.13 a	17.07 ± 1.03 b	67.12 ± 8.23 b	695.33 ± 15.46 b	2.94 ± 0.24 b	3.14 ± 0.54 a
	Pp2	274.49 ± 16.87 a	8.14 ± 0.14 a	2.50 ± 0.01 a	17.83 ± 1.30 a	77.74 ± 10.50 a	740.24 ± 22.47 a	2.69 ± 0.23 c	3.09 ± 0.32 a
	Pp3	259.51 ± 16.46 b	7.31 ± 0.26 b	2.18 ± 0.13 b	17.20 ± 2.03 b	59.20 ± 1.31 c	600.56 ± 28.90 c	3.25 ± 0.36 a	3.10 ± 0.44 a
	CK	205.45 ± 12.14 c	5.83 ± 0.03 c	1.62 ± 0.12 c	14.80 ± 1.51 c	47.20 ± 2.34 d	483.68 ± 11.25 d	2.63 ± 0.01 c	3.06 ± 0.02 a
	Dc1	255.88 ± 14.47 b	6.71 ± 0.21 b	2.40 ± 0.12 a	17.73 ± 1.04 a	53.78 ± 2.54 a	640.75 ± 29.50 b	2.69 ± 0.25 c	3.51 ± 0.20 b
	Dc2	234.98 ± 14.30 c	7.75 ± 0.46 a	2.23 ± 0.01 c	17.41 ± 1.02 a	57.25 ± 3.11 a	570.63 ± 34.20 c	2.97 ± 0.16 a	3.93 ± 0.19 a
	Dc3	296.76 ± 24.60 a	6.54 ± 0.40 c	2.31 ± 0.01 b	15.21 ± 0.49 b	54.74 ± 4.80 a	720.86 ± 36.27 a	2.85 ± 0.18 b	3.89 ± 0.30 a
	CK	205.45 ± 12.14 d	5.83 ± 0.03 d	1.62 ± 0.12 d	14.80 ± 1.51 c	47.20 ± 2.34 b	483.68 ± 11.25 d	2.63 ± 0.01 c	3.06 ± 0.02 c
	Kc1	228.28 ± 20.05 c	6.73 ± 0.48 bc	2.29 ± 0.12 a	17.91 ± 1.76 a	47.23 ± 2.61 c	575.46 ± 32.55 c	2.78 ± 0.20 b	4.49 ± 0.65 a
	Kc2	298.95 ± 23.53 a	7.86 ± 0.30 a	2.30 ± 0.02 a	16.71 ± 1.08 b	64.14 ± 5.44 a	750.57 ± 25.80 a	3.45 ± 0.42 a	4.51 ± 0.87 a
	Kc3	278.13 ± 15.43 b	6.79 ± 0.24 b	2.38 ± 0.01 a	18.12 ± 1.54 a	57.56 ± 3.92 b	675.22 ± 30.27 b	3.67 ± 0.38 a	3.42 ± 0.24 b
	CK	205.45 ± 12.14 d	5.83 ± 0.03 c	1.62 ± 0.12 b	14.80 ± 1.51 c	47.20 ± 2.34 c	483.68 ± 11.25 d	2.63 ± 0.01 c	3.06 ± 0.02 c
	Et1	321.07 ± 16.39 a	8.31 ± 0.16 a	2.62 ± 0.15 a	15.47 ± 0.98 b	73.10 ± 3.74 a	723.54 ± 35.60 a	3.83 ± 0.36 a	4.42 ± 0.63 a
	Et2	260.23 ± 21.25 c	7.19 ± 0.47 b	2.36 ± 0.12 b	16.60 ± 1.03 a	42.07 ± 2.10 c	640.89 ± 31.05 b	2.68 ± 0.17 c	3.08 ± 0.14 c
	Et3	294.54 ± 15.36 b	7.23 ± 0.54 b	2.61 ± 0.03 a	16.95 ± 1.20 a	61.80 ± 1.30 b	540.00 ± 22.60 c	3.01 ± 0.26 b	4.06 ± 0.37 b
	CK	205.45 ± 12.14 d	5.83 ± 0.03 c	1.62 ± 0.12 c	14.80 ± 1.51 b	47.20 ± 2.34 c	483.68 ± 11.25 d	2.63 ± 0.01 c	3.06 ± 0.02 c

Note: different lowercase letters indicate significant differences between the different seeding rates of the same grass species ($p < 0.05$).

In the 10~20 cm soil layer, under the three seeding rates of the Pp varieties, the soil improvement effect of Pp2 was the best, and its organic matter content increased by 24.74% compared to CK. Its total nitrogen and total potassium increased by 31.86% and 15.30% compared to CK. The ammonia nitrogen, nitrate nitrogen, available phosphorus, and available potassium in the soil of Pp2 increased by 22.77%, 11.83%, 12.60%, and 57.97% compared to CK. Except for the total phosphorus, there were significant differences between Pp2 and CK ($p < 0.05$). Under the three seeding rates of the Dc varieties, the soil improvement effect of Dc2 was the best. The contents of organic matter, total phosphorus, total potassium, ammonia nitrogen, nitrate nitrogen, available phosphorus, and available potassium in the soil of Dc2 were 9.04%, 19.16%,18.42%, 12.93%, 27.60%, 16.42%, and 53.63% higher than those of CK. Except for the total nitrogen, the differences were significant ($p < 0.05$). Under the three seeding rates of the Kc varieties, the soil improvement effect of Kc2 was the best. The organic matter, total nitrogen, ammonia nitrogen, nitrate nitrogen, available phosphorus, and available potassium of Kc2 was 268.46 g·kg^{-1}, 6.48 g·kg^{-1}, 3.43 g·kg^{-1}, 4.43 g·kg^{-1}, 62.43 mg·kg^{-1}, and 430.54 mg·kg^{-1}, which were 32.06%, 50.70%, 69.80%, 58.78%, 33.97%, and 16.17% higher than those of CK. Except for the total phosphorus and total potassium, there were significant differences ($p < 0.05$). Under the three seeding rates of the Et varieties, the soil improvement effect of Et1 was the best. The contents of organic matter, total nitrogen, total phosphorus, total potassium, ammonia nitrogen, nitrate nitrogen, available phosphorus, and available potassium of Et1 were 57.06%, 48.37%, 12.58%, 4.27%, 49.50%, 38.71%, 51.46%, and 39.05% higher than those of CK ($p < 0.05$). It can be seen that the artificial grassland established by reseeding four ecological grass species in the Muli mining area could not only reduce soil conductivity but also increase the soil nutrient content. The soil improvement effect of different soil layers was the best in low and medium seeding rates.

Table 6. Soil nutrients at different seeding rates (10~20 cm).

Soil Layer	Treatment	Organic Matter (g·kg^{-1})	Total Nitrogen (g·kg^{-1})	Total Phosphorus (g·kg^{-1})	Total Potassium (g·kg^{-1})	Available Phosphorus (mg·kg^{-1})	Available Potassium (mg·kg^{-1})	Ammonia Nitrogen (g·kg^{-1})	Nitrate Nitrogen (g·kg^{-1})
10~20	Pp1	278.59 ± 9.45 a	7.35 ± 0.65 b	2.47 ± 0.13 a	17.07 ± 1.03 b	67.12 ± 8.23 b	695.33 ± 15.46 b	2.94 ± 0.24 b	3.14 ± 0.54 a
	Pp2	274.49 ± 16.87 a	8.14 ± 0.14 a	2.50 ± 0.01 a	17.83 ± 1.30 a	77.74 ± 10.50 a	740.24 ± 22.47 a	2.69 ± 0.23 c	3.09 ± 0.32 a
	Pp3	259.51 ± 16.46 b	7.31 ± 0.26 b	2.18 ± 0.13 b	17.20 ± 2.03 b	59.20 ± 1.31 c	600.56 ± 28.90 c	3.25 ± 0.36 a	3.10 ± 0.44 a
	CK	205.45 ± 12.14 c	5.83 ± 0.03 c	1.62 ± 0.12 c	14.80 ± 1.51 c	47.20 ± 2.34 d	483.68 ± 11.25 d	2.63 ± 0.01 c	3.06 ± 0.02 a
	Dc1	255.88 ± 14.47 b	6.71 ± 0.21 b	2.40 ± 0.12 a	17.73 ± 1.04 a	53.78 ± 2.54 a	640.75 ± 29.50 b	2.69 ± 0.25 c	3.51 ± 0.20 b
	Dc2	234.98 ± 14.30 c	7.75 ± 0.46 a	2.23 ± 0.01 c	17.41 ± 1.02 a	57.25 ± 3.11 a	570.63 ± 34.20 c	2.97 ± 0.16 a	3.93 ± 0.19 a
	Dc3	296.76 ± 24.60 a	6.54 ± 0.40 c	2.31 ± 0.01 b	15.21 ± 0.49 b	54.74 ± 4.80 a	720.86 ± 36.27 a	2.85 ± 0.18 b	3.89 ± 0.30 a
	CK	205.45 ± 12.14 d	5.83 ± 0.03 d	1.62 ± 0.12 d	14.80 ± 1.51 c	47.20 ± 2.34 b	483.68 ± 11.25 d	2.63 ± 0.01 c	3.06 ± 0.02 c
	Kc1	228.28 ± 20.05 c	6.73 ± 0.48 bc	2.29 ± 0.12 a	17.91 ± 1.76 a	47.23 ± 2.61 c	575.46 ± 32.55 c	2.78 ± 0.20 b	4.49 ± 0.65 a
	Kc2	298.95 ± 23.53 a	7.86 ± 0.30 a	2.30 ± 0.02 a	16.71 ± 1.08 b	64.14 ± 5.44 a	750.57 ± 25.80 a	3.45 ± 0.42 a	4.51 ± 0.87 a
	Kc3	278.13 ± 15.43 b	6.79 ± 0.24 b	2.38 ± 0.01 a	18.12 ± 1.54 a	57.56 ± 3.92 b	675.22 ± 30.27 b	3.67 ± 0.38 a	3.42 ± 0.24 b
	CK	205.45 ± 12.14 d	5.83 ± 0.03 c	1.62 ± 0.12 b	14.80 ± 1.51 c	47.20 ± 2.34 c	483.68 ± 11.25 d	2.63 ± 0.01 c	3.06 ± 0.02 c
	Et1	321.07 ± 16.39 a	8.31 ± 0.16 a	2.62 ± 0.15 a	15.47 ± 0.98 b	73.10 ± 3.74 a	723.54 ± 35.60 a	3.83 ± 0.36 a	4.42 ± 0.63 a
	Et2	260.23 ± 21.25 c	7.19 ± 0.47 b	2.36 ± 0.12 b	16.60 ± 1.03 a	42.07 ± 2.10 c	640.89 ± 31.05 b	2.68 ± 0.17 c	3.08 ± 0.14 c
	Et3	294.54 ± 15.36 b	7.23 ± 0.54 b	2.61 ± 0.03 a	16.95 ± 1.20 a	61.80 ± 1.30 b	540.00 ± 22.60 c	3.01 ± 0.26 b	4.06 ± 0.37 b
	CK	205.45 ± 12.14 d	5.83 ± 0.03 c	1.62 ± 0.12 c	14.80 ± 1.51 b	47.20 ± 2.34 c	483.68 ± 11.25 d	2.63 ± 0.01 c	3.06 ± 0.02 c

Note: different lowercase letters indicate significant differences between the different seeding rates of the same grass species ($p < 0.05$).

3.2.4. Comprehensive Evaluation of Ecological Grass Species Under Different Seeding Rates

Under the density of Pp2, Dc2, Kc2, and Et1, the comprehensive evaluation value (D) was 0.701, 0.576, 0.610, and 0.673, indicating that the seeding rate of *Poa pratensis* L. 'Qinghai', *Deschampsia cespitosa*, and *Koeleria cristata* was 9 g·m^{-2}, and the seeding rate of *Elymus tangutorum* was 18 g·m^{-2}, which was more suitable for the environment of the Muli mining area (Table 7).

Table 7. The integrated membership functional ranking of each grass species at different seeding rates.

Treatment	Degree of Affiliation (Math.) U (x_1)	Degree of Affiliation (Math.) U (x_2)	Degree of Affiliation (Math.) U (x_3)	Degree of Affiliation (Math.) U (x_4)	Degree of Affiliation (Math.) U (x_5)	Value of the Affiliation Function D	Scheduling
Pp1	0.563	0.556	0.013	0.039	0.282	0.361	3
Pp2	0.974	1.000	0.232	0.054	0.815	0.701	1
Pp3	0.507	0.688	0.088	0.023	0.584	0.415	2
Dc1	0.000	0.719	0.385	0.179	0.469	0.330	3
Dc2	0.279	0.721	0.604	0.981	1.000	0.576	1
Dc3	0.034	0.780	0.706	0.269	0.000	0.396	2
Kc1	0.393	0.229	0.062	1.000	0.677	0.383	2
Kc2	0.790	0.554	0.275	0.886	0.021	0.610	1
Kc3	0.569	0.384	0.000	0.627	0.170	0.382	3
Et1	1.000	0.285	1.000	0.333	0.369	0.673	1
Et2	0.336	0.000	0.202	0.030	0.559	0.197	3
Et3	0.421	0.037	0.534	0.000	0.687	0.307	2

4. Discussion

The climate of the Muli mining area in Qinghai 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 environmental problems and hidden dangers of geological disasters in this area are increasing [31]. Early ecological management in the mining areas mainly focused on vegetation restoration, which is an important way of conducting ecological management. A large number of studies have shown that species selection is very important in mining restoration. Plants with strong adaptability, good stress resistance, improved soil, developed roots, a fast growth rate, and a high survival rate should be selected, which can be naturally settled and planted on abandoned mining land [32–34]. Through the establishment of artificial grasslands of different grass species, we can explore their impact on soil, accelerate the recovery of vegetation, soil, and microorganisms in the Muli mining area, improve the ecological environment, and promote the harmonious development of humanity and nature [35].

4.1. Analysis of Germination Characteristics and Regreening Status of Ecological Grass Species

Seed germination is the premise of plant growth and development. Grass seeds can be screened by measuring seed germination. Environmental factors such as temperature, altitude, and soil in different regions are the key to determining the adaptability of grass seeds [36]. When the soil pH $\geq$ 8.5, many trace elements will form insoluble compounds and cannot be fixed, which will lead to a lack of trace elements and affect the normal growth of plants [37]. In this experiment, nine kinds of ecological grass species with better growth and development in the native vegetation of the Muli mining area were selected as experimental materials for seed germination and artificial grassland establishment tests. In this experiment, the relative germination rate of hairy grass and wheat grass in the alkaline environment was high, which may be due to the accumulation of acid metabolites such as proline with a buffering effect to adapt to a higher pH so that it can promote the low concentration of alkali stress in metabolic regulation [38]. Tian et al. [39] showed that *Poa pratensis* L. 'Qinghai' had a strong germination ability in alkaline environments and that its CIPK24 gene had the function of being suitable for adverse environments, but the expression of this gene was the weakest in the root. In this experiment, the germination rate of *Poa pratensis* L. 'Qinghai' in our alkaline environment was higher, but the root length was lower, which was consistent with its research results. The germination rate of *Pedicularis kansuensis* in the alkaline environment was 0, but it had a certain emergence in the field. A possible reason is that the germination rate of Pedicularis kansuensis can be greatly improved under variable temperature conditions [40]. The temperature was constant during the indoor germination test, and the field test met the conditions of variable temperature required for germination. The germination rate of *Gentiana macrophylla* and *Aconitum pendulum* in the indoor alkaline germination test was low, and no seedlings appeared in the field, indicating that *Gentiana macrophylla* and *Aconitum pendulum* are not suitable for planting artificial grassland as pioneer grass species in the Muli mining area. After the artificial grassland is planted in the mining area, the soil environment is improved, and then sowing *Gentiana macrophylla* and *Aconitum pendulum* is possible to improve the species diversity and species richness of the artificial grassland and promote the sustainable development of the ecosystem in the mining area.

A large number of scholars have evaluated the germination ability of species using the TOPSIS method [41–43]. In this study, the germination ability of nine grass species was compared using the Topsis method. By combining the indoor and outdoor test results, it was found that *Poa pratensis* L. 'Qinghai', *Deschampsia cespitosa*, *Koeleria cristata*, and *Elymus tangutorum* can better adapt to the habitat of the Muli mining area, and the adaptability of *Gentiana macrophylla*, *Pedicularis kansuensis*, and *Aconitum pendulum* is poor.

4.2. Analysis of Seeding Quantity Characteristics of Ecological Grass Seeds

A large number of studies have shown that seeding rate has a certain effect on plant growth characteristics, quality, and soil properties [44–46]. In this study, when the seeding rate of *Poa pratensis* L. 'Qinghai', *Deschampsia cespitosa*, and *Koeleria cristata* was 9 $g \cdot m^{-2}$, that is, when the seeding rate was medium, the aboveground biomass was the largest. The aboveground biomass increased first and then decreased with the increase in the seeding rate, which was consistent with the results obtained for Medicago falcata and *Avena sativa* L. [47–49]. In this study, the plant height and coverage were the highest when the seeding rate was 9 $g \cdot m^{-2}$ (medium density), which was consistent with the results of Chen et al. [50] for Bromus inermis. The main reason is that a suitable seeding rate can make plants obtain sufficient nutrients. However, with the increase in the seeding rate, the available resources of individuals in the population decrease and competition intensifies, thus inhibiting plant growth and development [51]. In this study, the plant growth characteristics of the treatments with the highest seeding rate were inhibited.

Under different seeding rates, the feeding quality of ecological grass species is different. In this study, when the seeding rate of *Elymus tangutorum* was 18 $g \cdot m^{-2}$ (low density), the contents of crude protein, crude fat, and soluble protein were the highest, which was similar to the results of Feng Peng [52]. Fu Dongqing [53] also obtained the same results when exploring the effects of different seeding rates on oat quality. Jing Fang [54] showed that the content of crude protein and crude fat in oats decreased with an increase in the seeding rate. Some scholars also found that with the increase in seeding rate the content of crude protein and crude fat increased first and then decreased [55]. In this study, the crude fat content of *Poa pratensis* L. 'Qinghai' increased first and then decreased with the increase in the seeding rate, which was consistent with the results of that study.

Under different seeding rates, the soil's physical and chemical properties were different. In all treatments, Pp2, Dc2, and Kc2 had a higher soil water content and lower soil bulk density, which was consistent with the result that the soil water content under a medium density was higher than that under a high density in caragana woodland [56]. In the grassland ecosystem, plants and soil interact with each other. Soil provides nutrients for plants. On the contrary, the growth and development of plants also affect the physicochemical properties and nutrients of soil. In this study, Pp2 and Dc2 had better plant growth conditions, and their soil nutrient content was also higher. Some scholars have shown that the better the plant growth, the more litter there is, and the higher the soil's organic carbon content is, which is consistent with our results [57].

Through membership function sorting, the problem that many indicators cannot be analyzed for all indicators can be solved. In this study, two methods were used to obtain that the seeding rate of *Poa pratensis* L. 'Qinghai' and *Koeleria cristata* in 9 $g \cdot m^{-2}$, and the seeding rate of *Elymus tangutorum* in 18 $g \cdot m^{-2}$ had a high level of plant aboveground biomass and coverage, fast growth forage quality, and good soil improvement effect.

Since 2022, the Muli mining area has been greenly restored through a series of technical measures such as soil reconstruction and vegetation restoration, and the ecological environment of the mining area has been significantly controlled. However, how to rationally manage (via mixed sowing, nutrient addition, disease prevention, and control) and utilize (via grazing, mowing, and green manure) artificial grassland in the restoration area to achieve sustainable restoration remains an important issue. At the same time, trace amounts of heavy metals and other substances have accumulated during the growth of forage. When livestock eat grass, they can remove a small part of the local heavy metals and other substances. If the livestock do not eat grass, the grass will return to the soil after death. Therefore, it is of great significance to continue to carry out related research on grazing and the utilization of artificial grassland in the Muli mining area to realize the continuous restoration of vegetation in the Muli mining area.

5. Conclusions and Prospect

5.1. Conclusions

In summary, the four ecological grasses of *Poa pratensis* L. 'Qinghai', *Deschampsia cespitosa*, *Koeleria cristata*, and *Elymus tangutorum* can adapt to the ecological environment of the Muli mining area. After the establishment of artificial grassland, the vegetation had a high grass yield, good quality, large coverage, and good soil condition. The recommended seeding rate of *Poa pratensis* L. 'Qinghai', *Deschampsia cespitosa*, and *Koeleria cristata* is 9 $g \cdot m^{-2}$, and the recommended seeding rate of *Elymus tangutorum* is 18 $g \cdot m^{-2}$.

5.2. Prospect

In this study, there were few ecological grass species in families other than Gramineae. Only the *Pedicularis kansuensis* of Scrophulariaceae could survive in the extremely harsh environment of the Muli mining area. The seeds of *Pedicularis kansuensis*, *Gentiana macrophylla*, and *Aconitum pendulum* were inconsistent in the indoor germination and field cultivation experiments. It may be that the seeds have low-temperature and variable-temperature dormancy, which need further research.

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