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Effects of Irrigation Amounts and Fertilizer Types on Seed Yield and Water-Use Efficiency of *Lespedeza potaninii* in Northwest China

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Abstract: *Lespedeza potaninii* is native to the Tengger Desert and exhibits a high degree of adaptation to arid conditions. It develops both chasmogamous (CH) and cleistogamous (CL) flowers with different morphologies and attachment positions. However, the manner in which the amount of irrigation and the fertilizer type affect the reproductive allocation of *L. potaninii* is not well known. Field experiments on *L. potaninii* were performed using a split-plot design in both 2023 and 2024, with three irrigation amounts (I1, 100 mm; I2, 200 mm; I3, 300 mm) for the main plots and three fertilizer types (F1, control; F2, 90 kg/ha of P fertilizer; F3, organic fertilizer) for the sub-plots. The results revealed that irrigation amounts and fertilizer types significantly affected *L. potaninii* yield components, total seed yield, CH seed yield, CL seed yield, and water-use efficiency (WUE). The application of P fertilizer significantly ($p < 0.05$) enhanced CH seed yield by 7–11% compared with control or organic fertilizer. However, the impact of fertilizer type on the seed yield of CL varied under different irrigation amounts. The seed yield of the CL part was higher under a 100 mm of irrigation, while the seed yield of the CH part was higher under the I2 and I3 irrigation amounts. The maximum seed yields in 2023 and 2024 were 974 kg/ha (I2F2) and 1011 kg/ha (I3F2). Irrigation amounts had a positive and direct effect, and fertilizer types had a positive and indirect effect, on CH seed yield by positively affecting the number of racemes and pods and the thousand-seed weight of the CH part and the number of stems. Irrigation amounts and fertilizer types exhibited a positive and indirect effect on CL seed yield by positively affecting the number of stems, racemes, florets, and pods of the CL part. Treatment I2F2 resulted in relatively high WUE, IWUE, and PWUE compared with I1; and the I2 increased the WUE by 62.74% and 42.05%, on average, the IWUE by 31.05% and 27.60%, on average, and the PWUE by 162.00% and 155.21%, on average, in 2023 and 2024, respectively. Our research can further elucidate the relationship between CH or CL seed yield, on the one hand, and amount of irrigation or fertilizer type, on the other, and offer guidelines for conserving agricultural water resources and selecting fertilizer for the *Lespedeza* genus.



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Keywords: *Lespedeza potaninii*; dimorphic plant; yield components; CH and CL seed yield; water-use efficiency

1. Introduction

The global population is anticipated to surge towards nearly 10 billion by the year 2050, resulting in a substantial increase in food demand and placing significant strain on the global food supply chain [1,2]. Therefore, people need to find sustainable and efficient methods to enhance crop yields from available land. Due to the conflict between food security and water scarcity, achieving agricultural sustainability is extremely challenging in the arid and semi-arid regions of northwest China [3,4]. This region has undergone severe reductions in its groundwater levels, resulting in a pressing water shortage, primarily driven by the expansion of farmland [5]. Furthermore, due to the infertile soils prevalent in numerous semi-arid regions worldwide, fertilizer is indispensable for ensuring crop growth and productivity [6]. The overapplication of chemical fertilizers coupled with excessive irrigation, aimed at achieving high crop yields, results in poor fertilizer and water-use efficiency [7]. Therefore, in order to foster sustainable agricultural development in arid and semi-arid regions, it is crucial to understand the mechanisms of plants' response to water and fertilizer.

Lespedeza potaninii, a perennial xerophytic subshrub belonging to the Fabaceae family, is the dominant plant in the desert steppe and exhibits a high degree of adaptation to arid conditions [8]. It is regarded as a promising pioneer species for the restoration of degraded desert ecosystems [9]. *L. potaninii* is an excellent legume forage and plays a crucial role in livestock nutrition, grassland rehabilitation, vegetation restoration, artificial grassland construction, and the conservation of soil and water efforts in China's arid and semi-arid regions [10]. Usually, seeds of *L. potaninii* are harvested for further application. Certain plant species have undergone evolutionary adaptations, resulting in the development of dimorphic flowers to ensure their survival and reproduction in harsh environments [11]. The cleistogamous (CL) flower, distinguished by its robust adaptability to adverse conditions, ensures successful pollination and production of offspring with consistent genetic material. Conversely, the chasmogamous (CH) flower plays a crucial role in maintaining the genetic diversity of the plants [12]. *Dichanthelium clandestinum* possesses dimorphic flowers, with the proportion of CH flowers and CL flowers being regulated by different environmental conditions [13]. Specifically, as soil water content decreases, the number of CH flowers diminishes, while the number of CL flowers significantly increases [14]. This variation in soil water content ultimately affects the production of CH and CL flowers and, consequently, the seeds derived from them [15]. *L. potaninii* also possesses dimorphic flowers, but the precise impact of irrigation amounts and fertilizer types on the reproductive allocation of *L. potaninii* is unknown, which hinders its seed production and application.

In arid regions with little rainfall, irrigation serves as an effective method for meeting the water requirements of crops and thus ensuring high yields [16]. Drip irrigation under plastic is widely employed in the northwest of China and has advantages in maintaining soil humidity and temperature, suppressing weed growth, and enhancing agricultural productivity [17,18]. Drip irrigation under plastic represents a water-conservation technology suitable for arid regions, which precisely and timely administers fertilizer and water [7,19]. This advanced technique not only boosts crop yields but also minimizes water loss, and reduces the application of fertilizer rate [20]. The amount of irrigation is also crucial in irrigation practices. Previous research has demonstrated that a moderate increased amount of irrigation can boost crop yield, optimize irrigation water-use efficiency, and result in high quality [21]. However, excessive irrigation led to reduced water-use efficiency, increased potential for nutrient leaching, and diminished crop yield [22]. Thus, it is challenging to determine the optimal irrigation amounts that prioritize crop yield, quality, and irrigation water efficiency, respectively.

Phosphorus stands out as one of the essential macronutrients for plant growth and reproduction, while it can be adsorbed and fixed by soil, leading to its transport distance

in soil being less than 15 cm and to the rate of its utilization by single-season crops being below 25% [23,24]. This results in the frequent overapplication of phosphorus (P) fertilizers in actual production processes [25]. Decreasing phosphorus fertilizer consumption and enhancing its utilization efficiency are crucial. Organic fertilizers are rich in nutrients and organic materials, which can enhance soil fertility and improve fertilizer use efficiency [26]. Applying organic fertilizer is a traditional practice for enhancing soil organic matter and the nutrient content of agroecosystems [27]. The substitution of organic fertilizer is an effective strategy for boosting crop yields and improving soil structure while reducing reliance on chemical fertilizers input [28,29]. There is a scarcity of reporting on the replacement of chemical fertilizers with organic ones in the production of native grass seeds.

Although there have been reports on research related to *L. potaninii* seed production [30,31], little is known about the effects of irrigation amounts and fertilizer types on the proportions of CH and CL seeds. The theme of this study includes the following three points: (1) determining the influence of irrigation amounts and fertilizer types on the reproductive allocation of CH and CL, (2) determining how seed yield and yield components respond to irrigation amounts and fertilizer types, (3) finding the optimum water-use efficiency with the highest yield in *L. potaninii* seed production in arid and semi-arid regions.

2. Materials and Methods

2.1. Dimorphic Characteristic of *L. potaninii*

The ‘Tenggeli’ cultivars of *L. potaninii* seeds, provided by Lanzhou University breeders, were used. *L. potaninii* develops both CH and CL flowers, as well as corresponding CH and CL seeds, but there are differences in their morphology and attachment positions (Figure 1). Four floral developmental stages were defined based on the flower morphology, including the squaring stage, the early flowering stage, the peak flowering stage, and the late flowering stage. There are visible yellow petals during the CH early flowering stage, white petals during the CH peak flowering stage, and creamy-white petals during the CH late flowering stage, while there are no visible petals during all the flowering stages of CL (Figure 1A,B). In addition, CH flowers have a relatively long flower stalk, while CL flowers are attached at the base of the leaves with a nearly invisible flower stalk. Similarly, CH seeds are attached to a relatively long flower stalks, while CL seeds are attached at the base of the leaves (Figure 1C).

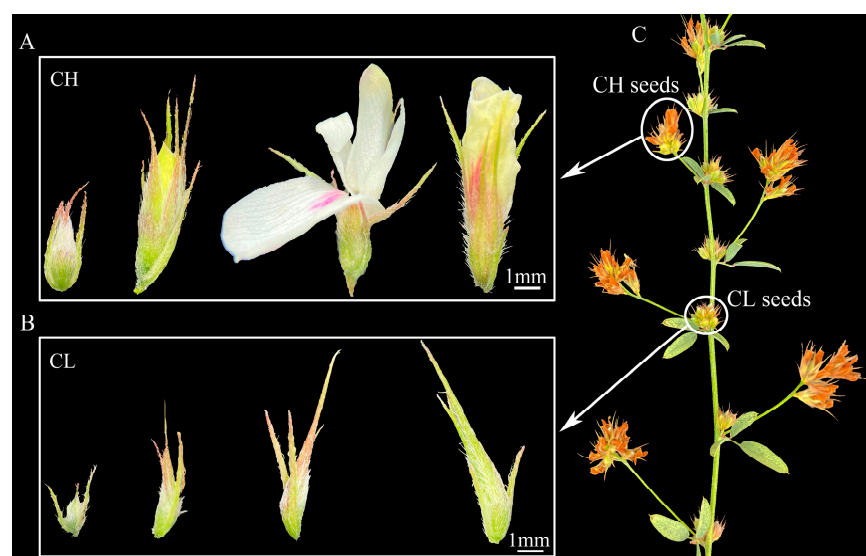


Figure 1. *L. potaninii* flower morphology and branch characters. CH (A) and CL (B) squaring stage, early flowering stage, peak flowering stage, and late flowering stage. (C) Branch characters, which include CH seeds and CL seeds.

2.2. Experimental Site

In this study, the field experiment was performed during two continuous *L. potaninii* growing seasons in 2023 and 2024 at the Herbage Improvement Experimental Station of Lanzhou University (elevation: 1470 m, latitude: 38°76' N, longitude: 100°50' E), Gansu Province, China, located in a typical area of the temperate continental climate. Figure S1 presents the average temperature, minimum temperature, maximum temperature, and precipitation during the *L. potaninii* growth period in both 2023 and 2024. According to the USDA soil texture classification, the soil in the experimental site is classified as Mot-Cal-Orthic Aridisol, which falls under the Xeric Haplocalcid category [32]. Before the present study, corn was cultivated on this land. Soil samples were obtained before this study to analyze soil nutrients. The soil at a depth of 0–30 cm had a pH of 8.63, a total nitrogen content of 0.33 g/kg, available nitrogen of 19.34 mg/kg, total phosphorus of 0.65 g/kg, available phosphorus of 5.80 mg/kg, and available potassium of 84 mg/kg.

2.3. Experimental Design and Treatments

In this study, the field experiment was conducted in a split-split-plot design with four replicates, where the main plots were composed of three irrigation amounts, and the subplots comprised three fertilizer types. Irrigation was conducted using a drip irrigation system under plastic mulching with the installation of water meters in each plot to control the amount of irrigation. The drip lines were arranged at a distance of 60 cm from one another along the rows of *L. potaninii*, while maintaining a 30 cm spacing between each emitter. *L. potaninii* thrives in regions with an annual rainfall of 100–400 mm, therefore, the experiment set up three irrigation amounts: 100 mm (I1), 200 mm (I2), and 300 mm (I3) based on the annual rainfall characteristics of the experimental area. For the I1 treatment, 25 mm was irrigated at each of the regreening stage, branching stage, squaring stage, and pod periods. For the I2 and I3 treatments, 50 mm and 75 mm were irrigated at each of the four periods, respectively (Table S1). Since the experimental station is newly established with poor soil quality, nitrogen (450 kg/ha) and potassium (270 kg/ha) fertilizers were uniformly applied to the experimental fields before the experiments to ensure plant normal growth, which were defined as the base fertilizer. Our previous study showed that 90 kg/ha P₂O₅ treatment resulted in higher seed yield of *L. potaninii* [31]. Therefore, 90 kg/ha P₂O₅ was selected as a treatment in this study. The 3000 kg/ha organic fertilizer application rate, commonly used by local farmers for seed production, was selected as another treatment in this study. Therefore, the fertilizer types designed for this experiment were as follows: control, P fertilizer, and organic fertilizer. For the control treatment, only the base fertilizer was applied. For the P fertilizer treatment, base fertilizer + 90 kg/ha of P₂O₅ was applied. The P₂O₅ is derived from calcium superphosphate (Yunnan Yuntianhua Co., Ltd., Kunming, China), with a composition including available phosphorus ≥ 16.0% and water-soluble phosphorus ≥ 11.0% (calculated as P₂O₅). For the organic fertilizer treatment, base fertilizer + 3000 kg/ha of organic fertilizers was applied. The organic fertilizer (Qianjin Biotechnology Co., Ltd., Zhangye, China) sourced from cattle manure. Its composition includes: organic matter content: ≥30%, N + P₂O₅ + K₂O > 4%, moisture: ≤30%, pH: 5.5–8.5, mechanical impurities ≤ 0.5%. During the planting period in 2023 and the regreening stage in 2024, fertilizers were plowed into the soil layer below 5 cm. The experiment comprised 9 treatments with a total of 36 plots and each plot measuring 8 m × 8 m. To ensure the integrity of the treatment, each plot was isolated by 1-m-wide walkways, and within each plot, the rows were spaced at 1-m by 1-m intervals. One week before sowing, the corn stubs were removed (The preceding crop was corn). Before sowing, the experimental land was leveled, and the seeds of *L. potaninii* were treated to break their hardness [33]. *L. potaninii* seeds' germination rate, measured using the double-layer filter

paper method, was 87%. On 26 April 2023 (Spring), the seeds were manually sown using the hill-drop method, with the depth ranging from 1 to 2 cm and each hole containing 5–10 seeds. After the seeds germinated, we removed the extra seedlings to ensure that only one seedling remained in each hole. The planting density was set at 5.56×10^4 plants per hectare, with a plant spacing of 60×30 cm [30]. During the growth seasons, weed control measures were implemented as required.

2.4. Data Collection and Measurements

2.4.1. CH, CL, and Total Seed Yield; Yield Components; And Agronomic Characters

During the seed maturity period, ten plants from the central region of each plot were randomly selected to measure the basal stem diameter and plant height of each plant, and their chasmogamous (CH) and cleistogamous (CL) seeds were separately harvested to assess CH seed yield, CL seed yield, and total seed yield. The seeds' water content was determined using the oven-drying method, and the seeds were harvested once their water content reached about 10%. After undergoing drying, threshing, and cleaning, the harvested seeds were placed into bags in preparation for the measurement of the 1000-seed weight, as well as other relevant indicators.

The CH and CL seed yield components encompassed the number of stems per square meter, raceme number per stem, floret number per raceme, pod number per raceme, and 1000-seed weight. Before harvesting, we randomly selected 10 individual plants from each plot to determine the number of stems of each plant. Subsequently, the recorded values were converted to stems per square meter. Additionally, 30 intact stems and racemes from each plot were used to determine the number of racemes per stem, number of florets per raceme, and number of pods per raceme, respectively. Additionally, ten more plants were randomly selected from each plot, and their aboveground parts were harvested. The samples were dried at a constant temperature of 65°C until they reached a constant weight. Subsequently, they were weighed and then converted to calculate the aboveground biomass (kg/ha) and the harvest index was used, which represents the ratio between the seed yield and the aboveground biomass at maturity (%).

2.4.2. Water-Use Efficiency

The soil water balance method was used to calculate plant evapotranspiration during the *L. potaninii* growth season [34] as follows:

$$ET = I + P - R - D \pm \Delta SWS$$

Here, D represents the deep drainage (mm), ET represents evapotranspiration, I represents the irrigation amount (mm), P represents the precipitation amount (mm), R represents the surface runoff (mm), and ΔSWS represents the difference in soil water storage within the 0–60 cm soil layer before and after the experiment (mm). Due to the ridging implemented in each plot which prevents runoff within the experimental plots surface runoff wasn't included. Additionally, because of low precipitation amounts, there was little drainage below the soil depth of 60 cm. The soil moisture content within the 0–60 cm soil layer was measured at the sowing and harvesting stages. Using a soil auger, soil samples were collected from the same borehole at depths of 0–20 cm, 20–40 cm, and 40–60 cm, and the soil moisture content of each layer was measured separately. To further investigate the seed yield per unit of applied irrigation water, we utilized the following equations to compute water-use efficiency (WUE), irrigation water-use efficiency (IWUE), and precipitation water-use efficiency (PWUE) [35,36] as follows:

$$WUE = Y/ET$$

$$IWUE = Y/I$$

$$PWUE = Y/P$$

Here, Y represents the actual harvestable seed yield (kg/ha), I represents the irrigation water amount (mm), and P represents the precipitation amount.

2.5. Statistical Analysis

The data were documented in Excel 2019 (Microsoft., NM, Redmond, WA, USA). R version 4.0.3 (R Core Team, 2020, Auckland, New Zealand) and SPSS 19.0 (SPSS Inc., Chicago, IL, USA) were used for data analysis. An analysis of Variance (ANOVA) was performed on the data regarding seed yield, yield components, and agronomic traits. Duncan's multiple range test was used to compare the treatment means of four replicates, with a significance threshold set at $p < 0.05$. Correlation analysis was employed to assess the relationships between seed yield and its components in 2023 and 2024. The contribution of each component to seed yield was determined as the product of the correlation coefficient between the seed yield and the yield components, on the one hand, and the corresponding direct path coefficient [37]. Furthermore, a structural equation model (SEM), developed in R (the piecewiseSEM package), was employed to investigate the effects of irrigation amounts and fertilizer types on CH and CL seed yield and on yield components of *L. potaninii* in 2023 and 2024.

3. Results

3.1. Irrigation Amounts and Fertilizer Types Affect Seed Yield

It can be seen in Table S2 that the application of fertilizer and irrigation significantly influenced *L. potaninii* seed yield ($p < 0.001$). In addition, the year also significantly ($p < 0.001$) affected *L. potaninii* seed yield (Table S2). In 2023, the I2F2 and I3F2 treatment produced the maximum seed yield of 974 and 969 kg/ha, respectively (Figure 2). Under the same irrigation conditions, the application of P₂O₅ significantly increased seed yield. Compared with the control, the application of P₂O₅ significantly increased seed yield by 33%, and the application of organic fertilizer significantly increased seed yield by 11% under the I1 irrigation (Figure 2A). Under the I2 and I3 irrigation conditions, the seed yield under the P fertilizer treatment was significantly larger than the control and organic fertilizer treatments; furthermore, increase in seed produced by the control and organic fertilizer was the same (Figure 2A). In 2024, the I2F2 and I3F2 treatments produced a maximum seed yield of 1001 and 1011 kg/ha, respectively. Under the I1 and I3 irrigation conditions, the seed yield under the control and organic fertilizer treatments was similar and significantly reduced compared with the P fertilizer treatment (Figure 2B). Under the I2 irrigation conditions, the seed yield of the P fertilizer treatment was significantly larger than that of organic fertilizer, and the seed yield of organic fertilizer was significantly larger than that of the control (Figure 2B).

At the maturity stage during both *L. potaninii* growing seasons (2023–2024), the seed yields of the CH and CL parts were also measured, respectively (Figure 2C–F). The results indicated that the CH and CL seed yields were significantly influenced by irrigation amounts, fertilizer, and year ($p < 0.001$), while the interaction between or among them had no significant effect on the CH and CL seed yields (Table S2). Under the same irrigation amount, the CH seed yield was significantly ($p < 0.05$) affected by fertilizer (P₂O₅ and organic fertilizer) in 2023 and 2024 (Figure 2C,E). The application of P fertilizer was effective in increasing the CH seed yield. In comparison with the control and organic fertilizer treatment, CH seed yield was increased by 8–11% in 2023 and by 7–10% in 2024 with treatment by P fertilizer under different irrigation amounts, respectively. However, the

fertilizer had significant ($p < 0.05$) effects on the CL seed yield under the I1 irrigation condition in 2023 and 2024 (Figure 2D,F), and the CL seed yield was increased by 22% in 2023 and by 16% in 2024. Under the I2 irrigation, the CL seed yield was significantly increased under the P fertilizer treatment compared with the control condition, while there was no significant difference between organic fertilizer and P fertilizer. Under the I3 irrigation, there was no significant difference among the control, organic fertilizer, and P fertilizer conditions. In addition, under the I1 irrigation, the seed yield of the CL part was higher, while under I2 and I3 irrigation amounts, the seed yield of the CH part was more than that of CL in 2023 and 2024 (Figure 2C–F).

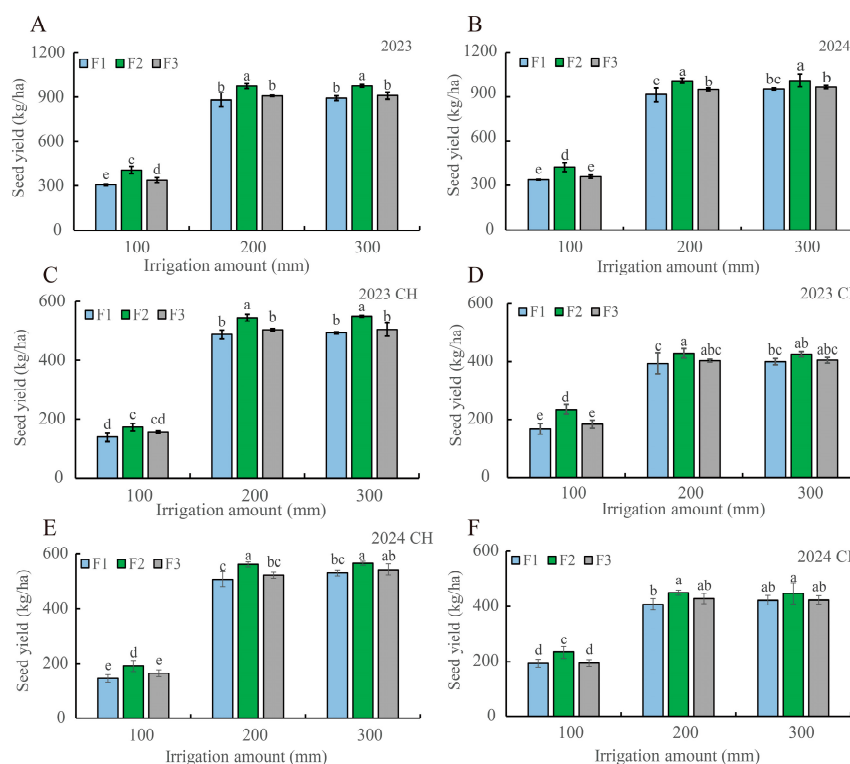


Figure 2. Irrigation amounts and fertilizer types affect *L. potaninii* total seed yield (A,B), seed yield of the CH part (C,E), and seed yield of the CL part (D,F) in 2023 and 2024. F1, control; F2, P fertilizer; F3, organic fertilizer. Different lowercase letters present significance at the 0.05 level.

3.2. Yield Components Were Influenced by Irrigation Amounts and Fertilizer Types

Basal stem diameter, plant height, and aboveground biomass of *L. potaninii* under different irrigation amounts and fertilizer treatments in 2023 and 2024 were measured at the maturity stage, and an analysis of Variance (ANOVA) was conducted. The results indicated that basal stem diameter, plant height, and aboveground biomass were significantly influenced by irrigation amount, fertilizer type, and year ($p < 0.01$); harvest index was significantly influenced by irrigation amount ($p < 0.001$) and by the interaction between irrigation amount and fertilizer type ($p < 0.05$); and plant height was significantly affected by the interaction of year and irrigation amount ($p < 0.01$) (Table S3).

In general, the values of basal stem diameter, plant height, and aboveground biomass in 2024 were larger than those in 2023 (Table 1). The largest basal stem diameter was 2.75 mm at I3F2, the largest plant height was 92.20 cm at I3F2, the most aboveground biomass was 4048.19 kg/ha at I3F2, and the largest harvest index was 27.51% at I3F1 (Table 1). Plant height showed a significant increase with increasing irrigation amounts. Under the I2 and I3 irrigation conditions, the application of P fertilizer and organic fertilizer significantly increased plant height compared with the control in 2023 and 2024. As the amount of irrigation increased, the basal stem diameter first increased and then remained

stable. In addition, aboveground biomass and the harvest index exhibited the same trend. Under the I2 and I3 irrigation conditions, the application of fertilizer was effective in increasing basal stem diameter and aboveground biomass. However, the application of fertilizer had no effect on the harvest index.

Table 1. *L. potaninii* aboveground biomass, basal stem diameter, harvest index, and plant height under different treatments during the growing seasons of 2023 and 2024.

Treatments	Plant Height (cm)		Basal Stem Diameter (mm)		Aboveground Biomass (kg/ha)		Harvest Index (%)	
	2023	2024	2023	2024	2023	2024	2023	2024
I1F1	54.18 ± 1.39 ^e	56.35 ± 3.32 ^f	1.80 ± 0.06 ^{de}	2.18 ± 0.07 ^b	1967 ± 85 ^c	1963 ± 132 ^d	15.61 ± 0.53 ^c	17.54 ± 1.05 ^b
I1F2	56.93 ± 2.05 ^e	65.85 ± 1.89 ^e	2.02 ± 0.02 ^{bc}	2.20 ± 0.18 ^b	2226 ± 64 ^c	2377 ± 64 ^d	18.41 ± 1.09 ^b	17.97 ± 0.90 ^b
I1F3	54.00 ± 1.89 ^e	59.30 ± 3.44 ^{ef}	1.75 ± 0.06 ^e	2.15 ± 0.18 ^b	2036 ± 112 ^c	2186 ± 113 ^d	16.81 ± 0.99 ^{bc}	16.64 ± 0.94 ^b
I2F1	71.08 ± 0.80 ^d	73.00 ± 2.82 ^d	1.95 ± 0.03 ^{cd}	2.25 ± 0.09 ^b	3330 ± 122 ^b	3519 ± 123 ^c	26.49 ± 0.42 ^a	26.03 ± 0.37 ^a
I2F2	78.53 ± 1.99 ^c	81.75 ± 1.95 ^{bc}	2.42 ± 0.05 ^a	2.47 ± 0.12 ^{ab}	3823 ± 137 ^a	3975 ± 258 ^{ab}	25.54 ± 0.88 ^a	25.77 ± 1.84 ^a
I2F3	77.08 ± 1.99 ^c	77.55 ± 1.93 ^{cd}	2.10 ± 0.06 ^{bc}	2.32 ± 0.07 ^{ab}	3372 ± 105 ^b	3561 ± 106 ^{bc}	26.96 ± 0.79 ^a	26.76 ± 0.80 ^a
I3F1	83.93 ± 0.84 ^b	79.80 ± 0.73 ^{bcd}	2.14 ± 0.05 ^b	2.37 ± 0.18 ^{ab}	3302 ± 118 ^b	3478 ± 119 ^c	27.10 ± 0.78 ^a	27.51 ± 1.00 ^a
I3F2	90.80 ± 1.19 ^a	92.20 ± 1.15 ^a	2.47 ± 0.02 ^a	2.75 ± 0.09 ^a	3867 ± 104 ^a	4048 ± 105 ^a	25.26 ± 0.65 ^a	25.02 ± 0.64 ^a
I3F3	87.40 ± 0.70 ^{ab}	86.40 ± 1.95 ^{ab}	2.33 ± 0.07 ^a	2.51 ± 0.19 ^{ab}	3558 ± 138 ^{ab}	3736 ± 139 ^{abc}	25.67 ± 1.07 ^a	25.96 ± 0.91 ^a

Different lowercase letters within a column represent significant difference at $p < 0.05$ level. I1, 100 mm irrigation amount; I2, 200 mm irrigation amount; I3, 300 mm irrigation amount; F1, control; F2, P fertilizer; F3, organic fertilizer.

The amount of irrigation and fertilizer had a significant impact on seed yield components. The ANOVA results showed that the number of stems and the number of racemes and florets of both the CH and CL parts were significantly affected by irrigation amounts, fertilizer, and years ($p < 0.001$; Table S4). The thousand-seed weight and seed yield per plant of both the CH and CL parts were significantly influenced by irrigation amounts, fertilizer, and years ($p < 0.01$; Table S5). The number of CH Pods was significantly affected by irrigation amounts ($p < 0.001$) and years ($p < 0.01$). The number of CL pods was significantly influenced by irrigation amounts ($p < 0.001$), fertilizer ($p < 0.01$), and years ($p < 0.05$).

The number of stems per square meter significantly increased with increasing irrigation in 2023 and 2024. Under the same irrigation amount, the application of P fertilizer significantly increased the number of stems compared to the application of organic fertilizer and control (Table 2). The highest number of stems was observed under the I2F2 and I3F2 treatments in both *L. potaninii* growing seasons. I2 and I3 irrigation amounts significantly increased the number of CH and CL racemes compared with the I1 irrigation amount (Table 2). Under the same irrigation conditions, the number of CH racemes after the application of P fertilizer was greater than their number both without fertilizer and with organic fertilizer in 2023, while the fertilizer types had little effect on the number of CL racemes in 2023 and 2024. The impact of irrigation amounts and fertilizer types on the number of florets of CH and CL was relatively small, with no significant differences between treatments in 2023 and 2024 (Table 2). Overall, the number of CH florets was more than that of CL. The highest number of CH pods was obtained under I3F2 (11 in 2023), while the highest number of CL pods was obtained under I3 irrigation (Table 3). The I3 irrigation amount significantly increased the number of CH pods by 22–25% compared with the I1 irrigation amount in both growth seasons, while different fertilizer treatments had no effect on the number of CH and CL pods under the same irrigation condition. In addition, a greater number of CH pods were observed compared to the number of CL pods. In 2023 and 2024, the highest CH and CL 1000-seed weights under the I2F2 and I3F2 treatments were 2.4 g and 2.5 g and 2.4 g and 2.4 g, respectively (Table 3). Irrigation treatments significantly improved seed yield; compared with the I1 irrigation treatment, the I2 treatment increased CH seed yield per plant by 2.15–2.50 times and 1.92–2.54 times and increased CL seed yield per plant by 0.81–1.36 times and 1.00–1.19 times in 2023 and 2024, respectively (Table 3). Under same irrigation amounts, the application of P fertilizer significantly increased the CH and CH seed yield per plant compared to their yield without

fertilizer or with the application of organic fertilizer, while there was no significant difference between the seed yield of CH and CL without fertilizer and with the application of organic fertilizer. Overall, the seed yield in 2024 was higher than that in 2023. Interestingly, under the I1 irrigation amount, the seed yield per plant of CH was less than that of CL, while under I2 and I3 irrigation amounts, the seed yield per plant of CH was larger than that of CL in both years (Table 3).

3.3. Correlation Analysis of Seed Yield and Yield Components

Spearman correlation is a method used to assess correlations between indicators. The results indicated that the *L. potaninii* seed yield of the CH part was significantly positively correlated with aboveground biomass, basal stem diameter, plant height, number of stems, number of racemes, number of florets, number of pods, and 1000-seed weight of the CH part (Figure 3A). Similarly, the CL seed yield was also significantly positively correlated with all yield components (Figure 3B). The number of racemes, number of florets, and number of pods of CH and CL were significantly positively correlated with plant height, number of stems, basal stem diameter, and aboveground biomass. In addition, there was a significant correlation between yield components (Figure 3).

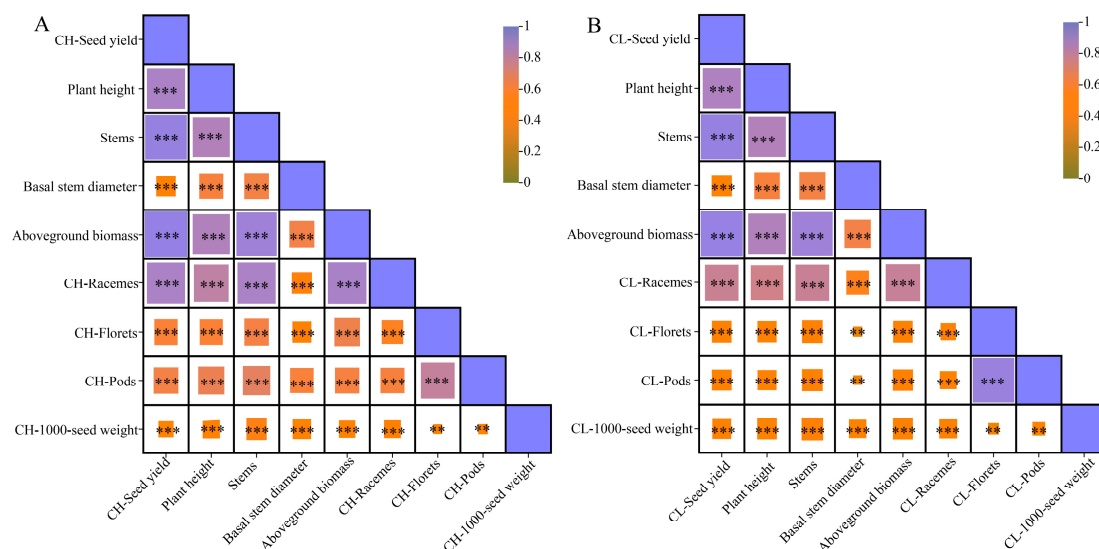


Figure 3. Correlation analysis of *L. potaninii* seed yield of CH (A) and CL (B) and yield components in 2023 and 2024. ** and *** present the significance level at $p < 0.01$ and $p < 0.001$.

3.4. Irrigation Amount and Fertilizer Types Influence Seed Yield by Impacting Yield Components

The structural equation model (SEM) was strategically utilized to describe the influence of irrigation amounts, fertilizer types, and yield components on the seed yield of CH and CL. The SEM analysis indicated that irrigation amounts, fertilizer types, and yield components account for 93% of the variation in CH seed yield. In addition, all variables explained 78%, 50%, 34%, and 63% of variations in the number of racemes per stem, the number of flowers per raceme, the number of pods per raceme, 1000-seed weight of CH, and the number of stems, respectively (Figure 4A). Irrigation treatments had a positive and direct effect on CH seed yield ($p < 0.001$) by positively affecting the number of stems ($p < 0.001$), the number of CH racemes per stem, the number of CH pods per raceme, and CH 1000-seed weight. Fertilizer types had a positive and indirect effect on CH seed yield by positively affecting seed yield components. Additionally, the number of stems had a positive and direct effect on the number of racemes per stem in CH ($p < 0.001$), the number of pods per raceme in CH ($p < 0.001$), CH 1000-seed weight ($p < 0.001$), and CH seed yield ($p < 0.001$).

Table 2. *L. potaninii* stems, racemes per stem, and florets per raceme of CH and CL under different irrigation amounts and fertilizer types in 2023 and 2024.

Treatments	Stems (m ⁻²)		CH Racemes/Stem		CL Racemes/Stem		CH Florets/Raceme		CL Florets/Raceme	
	2023	2024	2023	2024	2023	2024	2023	2024	2023	2024
I1F1	113 ± 2 ^d	135 ± 10 ^d	24.50 ± 1.10 ^e	27.00 ± 3.33 ^d	26.66 ± 1.14 ^d	29.25 ± 0.48 ^d	9.00 ± 0.58 ^c	9.50 ± 0.50 ^b	7.00 ± 0.58 ^b	7.50 ± 0.50 ^b
I1F2	131 ± 8 ^c	165 ± 15 ^c	29.21 ± 0.80 ^d	31.16 ± 1.41 ^{cd}	30.01 ± 0.53 ^{cd}	32.40 ± 1.26 ^{bcd}	9.75 ± 0.25 ^{abc}	10.00 ± 0.00 ^{ab}	7.50 ± 0.50 ^{ab}	8.00 ± 0.00 ^{ab}
I1F3	117 ± 4 ^d	139 ± 3 ^d	26.34 ± 1.46 ^e	28.33 ± 1.46 ^d	29.35 ± 0.50 ^{cd}	30.00 ± 1.07 ^{cd}	9.50 ± 0.65 ^{bc}	9.75 ± 0.63 ^b	7.00 ± 0.58 ^b	8.00 ± 0.82 ^{ab}
I2F1	212 ± 3 ^b	227 ± 9 ^b	37.40 ± 0.23 ^c	39.04 ± 1.23 ^{ab}	32.78 ± 2.01 ^{bc}	33.54 ± 1.92 ^{bc}	10.25 ± 0.25 ^{abc}	11.00 ± 0.58 ^{ab}	7.50 ± 0.50 ^{ab}	8.50 ± 0.50 ^{ab}
I2F2	231 ± 1 ^a	257 ± 9 ^a	41.90 ± 0.89 ^{ab}	43.91 ± 2.93 ^{ab}	36.64 ± 1.84 ^{ab}	37.84 ± 1.70 ^a	11.50 ± 0.95 ^{ab}	12.00 ± 0.82 ^a	9.00 ± 0.58 ^a	9.50 ± 0.50 ^a
I2F3	214 ± 4 ^b	234 ± 13 ^{ab}	37.90 ± 0.92 ^c	39.86 ± 1.87 ^{ab}	34.73 ± 1.53 ^{ab}	36.20 ± 1.39 ^{ab}	11.00 ± 0.58 ^{ab}	11.50 ± 0.96 ^{ab}	8.00 ± 0.00 ^{ab}	9.00 ± 0.58 ^{ab}
I3F1	208 ± 4 ^b	228 ± 3 ^b	39.40 ± 1.28 ^{bc}	37.56 ± 1.22 ^{bc}	34.40 ± 0.50 ^{ab}	36.15 ± 1.30 ^{ab}	10.75 ± 0.48 ^{abc}	11.50 ± 0.50 ^{ab}	8.50 ± 0.95 ^{ab}	9.00 ± 0.58 ^{ab}
I3F2	237 ± 5 ^a	261 ± 5 ^a	42.90 ± 0.32 ^a	45.03 ± 3.67 ^a	38.19 ± 0.91 ^a	39.25 ± 0.48 ^a	11.75 ± 0.85 ^a	12.00 ± 0.82 ^a	9.00 ± 0.58 ^a	9.50 ± 0.50 ^a
I3F3	214 ± 5 ^b	234 ± 5 ^{ab}	39.35 ± 0.57 ^{bc}	41.79 ± 1.54 ^{ab}	35.20 ± 1.16 ^{ab}	36.55 ± 0.92 ^{ab}	11.25 ± 0.48 ^{ab}	12.00 ± 0.00 ^a	8.50 ± 0.50 ^{ab}	9.50 ± 0.50 ^a

Different lowercase letters within a column represent significant difference at $p < 0.05$ level. I1, 100 mm irrigation amount; I2, 200 mm irrigation amount; I3, 300 mm irrigation amount; F1, control; F2, P fertilizer; F3, organic fertilizer.

Table 3. *L. potaninii* pods per raceme, 1000-seed weight, and seed yield per plant of CH and CL under different irrigation amounts and fertilizer types in 2023 and 2024.

Treatments	CH Pods/Raceme		CL Pods/Raceme		CH 1000-Seed Weight (g)		CL 1000-Seed Weight (g)		CH Seed Yield Per Plant (g)		CL Seed Yield Per Plant (g)	
	2023	2024	2023	2024	2023	2024	2023	2024	2023	2024	2023	2024
I1F1	8.75 ± 0.48 ^d	9.25 ± 0.48 ^b	7.00 ± 0.58 ^a	7.50 ± 0.50 ^b	2.18 ± 0.04 ^b	2.26 ± 0.02 ^e	2.09 ± 0.02 ^b	2.19 ± 0.03 ^d	2.50 ± 0.13 ^d	2.63 ± 0.12 ^e	3.00 ± 0.17 ^f	3.49 ± 0.13 ^d
I1F2	9.25 ± 0.25 ^{cd}	9.50 ± 0.50 ^b	7.25 ± 0.48 ^a	7.75 ± 0.28 ^{ab}	2.25 ± 0.09 ^{ab}	2.37 ± 0.05 ^{bcd}	2.20 ± 0.06 ^{ab}	2.32 ± 0.06 ^{bc}	3.11 ± 0.11 ^c	3.46 ± 0.18 ^d	4.23 ± 0.15 ^e	4.20 ± 0.19 ^c
I1F3	9.00 ± 0.41 ^{bcd}	9.25 ± 0.48 ^b	7.00 ± 0.58 ^a	7.75 ± 0.68 ^{ab}	2.21 ± 0.06 ^{ab}	2.30 ± 0.06 ^{de}	2.14 ± 0.04 ^b	2.25 ± 0.04 ^{cd}	2.80 ± 0.04 ^{cd}	2.98 ± 0.11 ^e	3.30 ± 0.13 ^f	3.51 ± 0.11 ^d
I2F1	9.75 ± 0.25 ^{abcd}	10.50 ± 0.50 ^{ab}	7.25 ± 0.48 ^a	8.25 ± 0.28 ^{ab}	2.24 ± 0.06 ^{ab}	2.35 ± 0.02 ^{cde}	2.24 ± 0.06 ^b	2.26 ± 0.03 ^{cd}	8.76 ± 0.13 ^b	9.13 ± 0.26 ^c	7.08 ± 0.33 ^d	7.33 ± 0.18 ^b
I2F2	10.00 ± 0.00 ^{abcd}	11.50 ± 0.50 ^a	8.75 ± 0.48 ^a	9.25 ± 0.48 ^a	2.44 ± 0.04 ^a	2.50 ± 0.06 ^{ab}	2.37 ± 0.10 ^a	2.40 ± 0.02 ^a	9.79 ± 0.10 ^a	10.11 ± 0.08 ^a	7.67 ± 0.13 ^a	8.06 ± 0.08 ^a
I2F3	10.50 ± 0.65 ^{abc}	10.50 ± 0.28 ^{ab}	7.75 ± 0.25 ^a	8.75 ± 0.48 ^{ab}	2.30 ± 0.03 ^{ab}	2.43 ± 0.06 ^{abc}	2.30 ± 0.05 ^b	2.29 ± 0.03 ^{bc}	9.05 ± 0.03 ^b	9.40 ± 0.10 ^{bc}	7.25 ± 0.04 ^{abc}	7.69 ± 0.16 ^{ab}
I3F1	10.50 ± 0.29 ^{abc}	11.25 ± 0.48 ^a	8.25 ± 0.85 ^a	8.75 ± 0.48 ^{ab}	2.31 ± 0.06 ^{ab}	2.43 ± 0.06 ^{abc}	2.28 ± 0.04 ^b	2.25 ± 0.03 ^{cd}	8.86 ± 0.04 ^b	9.56 ± 0.10 ^{bc}	7.19 ± 0.10 ^{cd}	7.59 ± 0.15 ^{ab}
I3F2	11.25 ± 0.95 ^a	11.75 ± 0.68 ^a	8.75 ± 0.48 ^a	9.25 ± 0.48 ^a	2.42 ± 0.13 ^a	2.52 ± 0.03 ^a	2.37 ± 0.11 ^a	2.38 ± 0.02 ^{ab}	9.88 ± 0.02 ^a	10.17 ± 0.06 ^a	7.65 ± 0.08 ^{ab}	8.02 ± 0.33 ^a
I3F3	10.75 ± 0.48 ^{ab}	11.25 ± 0.48 ^a	8.50 ± 0.29 ^a	9.00 ± 0.58 ^{ab}	2.25 ± 0.09 ^{ab}	2.46 ± 0.06 ^{abc}	2.28 ± 0.05 ^b	2.38 ± 0.01 ^{ab}	9.07 ± 0.21 ^b	9.77 ± 0.18 ^{ab}	7.28 ± 0.09 ^{abc}	7.61 ± 0.13 ^{ab}

Different lowercase letters within a column represent significant difference at $p < 0.05$ level. I1, 100 mm irrigation amount; I2, 200 mm irrigation amount; I3, 300 mm irrigation amount; F1, control; F2, P fertilizer; F3, organic fertilizer.

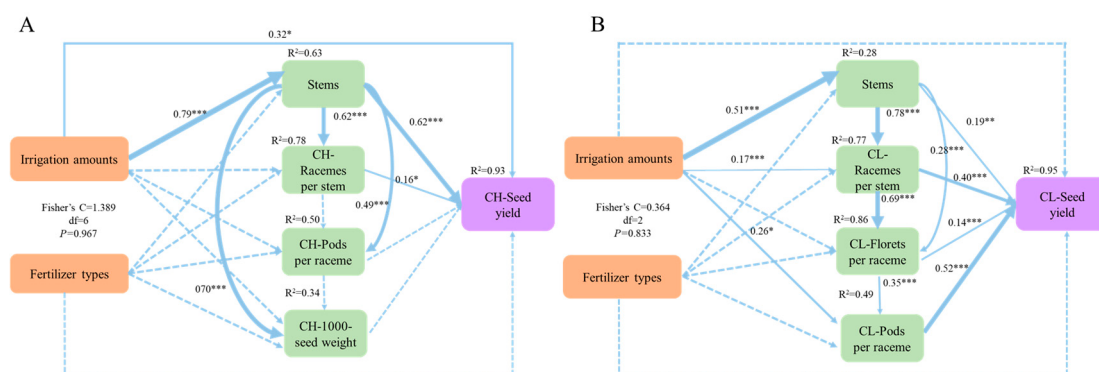


Figure 4. Structural equation modeling (SEM) revealed direct and indirect effects of irrigation amounts, fertilizer types, and yield components on the seed yield of CH (A) and CL (B). The numbers next to the arrows represent the standardized path coefficient. Solid arrows represent a direct effect, dashed arrows represent an indirect effect, and line width indicates intensity proportion. R^2 represents the proportion of variance in each dependent variable that is explained by the model. *, **, and *** represent significance at $p < 0.05$, $p < 0.01$, and $p < 0.001$.

The irrigation amount, fertilizer types, and yield components accounted for 95% of the variations in the seed yield of CL (Figure 4B). The variations of 77%, 86%, 49%, and 28% were explained by the number of racemes per stem, the number of florets per raceme and the number of pods per raceme of CL, and the number of stems, respectively (Figure 4B). The SEM result indicated that irrigation amount exhibited a positive and indirect effect on CL seed yield by directly positively affecting the number of stems and the number of pods per raceme in CL and by indirectly affecting the number of racemes per stem and the number of florets raceme in CL. Fertilizer type exhibited a positive and indirect effect on CL seed yield by affecting seed yield components. The number of racemes per stem ($p < 0.001$), the number of florets per raceme ($p < 0.001$) and the number of pods per raceme ($p < 0.001$) of CL, and the number of stems ($p < 0.01$) significantly and directly influenced CL seed yield.

3.5. Water-Use Efficiency

Water-use efficiency (WUE) was significantly influenced by irrigation amount ($p < 0.001$) and fertilizer ($p < 0.001$); irrigation water-use efficiency (IWUE) was significantly ($p < 0.001$) influenced by irrigation amount, fertilizer, year, and fertilizer $\times$ year; the precipitation water-use efficiency (PWUE) was significantly influenced by irrigation amount, fertilizer, and year ($p < 0.001$); and the interaction effects of irrigation amount and fertilizer and of irrigation amount and year on PWUE were significant ($p < 0.01$; Table S6).

Compared with I1, on average, the I2 increased WUE by 62.74%, IWUE by 31.05%, and PWUE by 162.00%; the I3, on average, increased WUE by 14.67%, IWUE by 36.23%, and PWUE by 69.90% in 2023 (Table 4). The I2, on average, increased WUE by 42.05%, IWUE by 27.60%, and PWUE by 155.21%. The I3, on average, increased WUE by 30.87% and PWUE by 160.17%. On average, the I3 reduced IWUE by 13.31% compared with I1 in 2024 (Table 4). In the two growing seasons of *L. potaninii*, under the same irrigation amount, the WUE, IWUE, and PWUE first showed increasing and then decreasing trends following the control, application of P fertilizer, or organic fertilizer (Table 4). Treatment I2F2 showed the highest WUE (3.63 and 3.18 kg ha⁻¹ mm⁻¹), IWUE (4.87 and 5.05 kg ha⁻¹ mm⁻¹), and PWUE (6.27 and 18.07 kg ha⁻¹ mm⁻¹), and treatment I1F1 showed relatively low WUE, IWUE, and PWUE in both growth seasons.

Table 4. Effects of irrigation amounts and fertilizer types on water-use efficiency, irrigation water-use efficiency, and precipitation water-use efficiency of *L. potaninii* in 2023 and 2024.

Treatment	WUE (kg ha ^{−1} mm ^{−1})		IWUE (kg ha ^{−1} mm ^{−1})		PWUE (kg ha ^{−1} mm ^{−1})	
	2023	2024	2023	2024	2023	2024
I1F1	1.59 ± 0.27 ^d	1.64 ± 0.43 ^b	3.06 ± 0.03 ^{ef}	3.40 ± 0.01 ^{de}	1.97 ± 0.02 ^e	6.09 ± 0.02 ^e
I1F2	2.88 ± 0.27 ^{ab}	2.53 ± 0.16 ^{ab}	4.08 ± 0.12 ^c	4.26 ± 0.15 ^c	2.63 ± 0.08 ^c	7.62 ± 0.27 ^d
I1F3	1.73 ± 0.21 ^{cd}	2.18 ± 0.55 ^{ab}	3.39 ± 0.08 ^d	3.61 ± 0.05 ^d	2.19 ± 0.05 ^d	6.45 ± 0.10 ^e
I2F1	3.27 ± 0.14 ^a	2.94 ± 0.18 ^a	4.40 ± 0.11 ^b	4.58 ± 0.11 ^b	5.68 ± 0.15 ^b	16.37 ± 0.41 ^c
I2F2	3.63 ± 0.15 ^a	3.18 ± 0.46 ^a	4.87 ± 0.04 ^a	5.05 ± 0.04 ^a	6.27 ± 0.05 ^a	18.07 ± 0.16 ^a
I2F3	3.19 ± 0.44 ^{ab}	2.90 ± 0.41 ^a	4.53 ± 0.01 ^b	4.75 ± 0.02 ^b	5.84 ± 0.01 ^b	17.01 ± 0.08 ^{bc}
I3F1	2.21 ± 0.02 ^{bcd}	2.93 ± 0.31 ^a	2.97 ± 0.02 ^f	3.18 ± 0.01 ^e	5.75 ± 0.05 ^b	17.06 ± 0.06 ^b
I3F2	2.71 ± 0.60 ^{abc}	3.02 ± 0.17 ^a	3.25 ± 0.02 ^{de}	3.37 ± 0.07 ^e	6.28 ± 0.03 ^a	18.10 ± 0.39 ^a
I3F3	2.19 ± 0.36 ^{cd}	2.36 ± 0.34 ^{ab}	3.03 ± 0.04 ^f	3.22 ± 0.02 ^e	5.86 ± 0.08 ^b	17.29 ± 0.10 ^b

Different lowercase letters within a column represent significant difference at $p < 0.05$ level. I1, 100 mm irrigation amount; I2, 200 mm irrigation amount; I3, 300 mm irrigation amount; F1, control; F2, P fertilizer; F3, organic fertilizer.

4. Discussion

4.1. Irrigation Amount and Fertilizer Type Influencing Seed Yield of Total, CH Part, and CL Part

Improving water productivity and crop yield remains a paramount objective in agriculture, especially in arid and semi-arid regions [38]. In these areas, irrigation and rainfall are vital water sources for crop productivity. Optimizing the frequency and amount of irrigation during the growth season can substantially boost the seed yield of *Hedysarum fruticosum* and *Cleistogenes songorica* [39,40]. Similarly, *L. potaninii*, another desert plant, has been shown in previous studies to achieve its highest seed yield after being irrigated five times [31]. Ma et al. (2024) found that the highest seed yield of *L. potaninii* was obtained after irrigating twice, with 350 m³/hm² each time [41]. In this study, we found that the highest seed yields were obtained under 200 mm and 300 mm of irrigation. The timing and quantity of irrigation were key factors that determined yield components and the seed yield of *Medicago sativa* [42]. Therefore, the optimal irrigation amount was 200 mm for *L. potaninii* seed production.

The response of plants to nutrients depends on the source of organic or inorganic fertilizers. Farmers usually use traditional sources of P such as single super phosphate and diammonium phosphate. The main reason for this is that phosphorus serves as an effective fertilizer for improving crop growth and enhancing seed yield [43]. The application of organic fertilizer is a traditional approach that is used to improve soil organic matter and nutrient content within agroecosystems [27]; and it may alter the physicochemical and biological attributes of soil, influence root morphology, and foster plant growth [44]. However, organic fertilizer is a kind of slow-release fertilizer with low fertility, and it is generally used in combination with chemical fertilizer. Previous studies have indicated that replacing chemical fertilizer with organic fertilizer reduces reliance on chemical fertilizers, mitigates environmental degradation, enhances soil fertility, and maintains or even improves crop yields [28,45]. In our study, the seed-yield-increasing effect of P fertilizer application was significantly higher than that of organic fertilizer. This may have occurred because organic fertilizer has the characteristics of low nutrient content and slow nutrient release [46,47]. Therefore, combining organic and inorganic fertilizers is beneficial for increasing *L. potaninii* seed yield.

The study on *Lespedeza davurica* indicated that a six plants/m² planting density coupled with a P rate of 50 kg/hm², or a twelve plants/m² planting density coupled with a P rate of 22 kg/hm², results in maximum seed yield [48]. We conducted previous research on the seed production of *L. potaninii*. The results showed that the maximum seed yield was

obtained at a plant density of 44,444 plants/ha and 90 kg/ha of P fertilizer [30]. In addition, *L. potaninii* seed yield was highest when irrigated five times and fertilized with 90 kg/ha of P fertilizer [31]. Therefore, the application of 90 kg/ha of P fertilizer was the most suitable for seed production of *L. potaninii*. In this study, over a two-year experimental period, we found that 90 kg/ha of P fertilizer along with a 200 mm of irrigation amount, produced the highest yield of *L. potaninii* seed production.

L. potaninii is a dimorphic plant; it produces CH and CL flowers, and its total seed yield is derived from both CH seeds and CL seeds. A previous research showed that the number of times that the plant is irrigated influences the proportion of *L. potaninii* CH and CL seeds [31]. With decreasing soil water content, the CL seed yield of *Dichanthelium clandestinum* increased and, finally, became higher than the yield of CH seeds [13]. We obtained similar results in this study, showing that the seed yield of CL was higher than that of CH under an irrigation amount of 100 mm, while the seed yield of CL was lower than that of CH under 200 mm and 300 mm irrigation amounts. Previous research showed that in hermaphroditic dimorphic plants, the female function is generally associated with a greater demand for energy, compared to the male, in order to produce flowers, fruits, and seeds. Female plants are usually assumed to perform worse than males under stress [5,49–51]. Therefore, for plants with dimorphic flowers, CH flowers need to consume more energy, which results in a decrease in the proportion of CH flowers under conditions of low soil water content. In our study, the CH flowers of *L. potaninii* have relatively large petals, while the CL flowers do not have visible petals. Additionally, we found that the impact of fertilizer types on the seed yield of CH and CL was different. Under 200 mm or 300 mm of irrigation, the CH seed yield with the application of P fertilizer was significantly higher than that with organic fertilizer, while the application of P or organic fertilizer had no significant effect on CL seed yield. In *Populus cathayana*, females had a higher resource uptake under sufficient supplies of P and nitrogen [52,53]. Conversely, males generally exhibit higher resource use efficiency and a more conservative nutrient requirement to maximize stress tolerance [53,54]. It is possible that the CL seeds' production of *L. potaninii* has a low nutrient demand to gain opportunities to survive in low-resource habitats.

4.2. Yield Components Were Affected by Irrigation and Fertilizer

The effect of irrigation amounts and fertilizer types on the components of seed yield varied among different species. An increase in irrigation significantly boosted the number of fertile shoots, racemes, and pods in alfalfa plants, ultimately contributing to a higher seed yield [55,56]. An increase in the application of P fertilizer improved the number of racemes per stem in alfalfa, whereas excessive P had a detrimental effect [57]. Irrigation during each growth period of *L. potaninii* significantly affected yield components, and seed yield significantly increased [31]. P fertilizer amounts affected the number of stems, racemes, and florets. The optimum yield was obtained under 90 kg/ha of P fertilizer treatment in terms of *L. potaninii* seed production [31]. In addition, another study showed that irrigation time and amount significantly affected plant height, branch number, reproductive branch number, inflorescence number, pod number, pod seed number, and thousand-seed weight in *L. potaninii* [41]. In the present study, the raceme number, floret number, 1000-seed weight, and seed yield per plant, in terms of the CH and CL parts, and stem number were significantly influenced by irrigation amounts and fertilizer types. The maximum values were obtained under P fertilizer treatment (90 kg/ha) and when using 200 mm or 300 mm irrigation amounts. Our findings supported previous research indicating that application of 90 kg/ha of P fertilizer combined with an appropriate irrigation amount positively affected yield components and further increased seed yield.

4.3. Irrigation Amounts and Fertilization Types Affect Water-Use Efficiency

Water-use efficiency (WUE) is crucial for water management in arid and semi-arid regions. Basin irrigation, sprinkler irrigation, and flood irrigation have been applied in the northwest of China; however, these methods suffer from the disadvantages of low irrigation water-use efficiency (IWUE) [7]. Mulched drip irrigation represents an effective water-saving technology that can deliver water and fertilizers to plants in a timely and precise manner [19]. In this study, mulched drip irrigation was applied, and our results indicated that with an increase in the amount of irrigation, the IWUE showed a trend of first increasing and then decreasing. Under the same drip-line layout, the IWUE of tomato exhibited a decreasing trend as the amount of irrigation increased [58]. This is because the water demand of *L. potaninii*, as a type of drought-tolerant plant, is different from that of tomatoes. It was found that moderate irrigation increases WUE, IWUE, and PWUE, while the gain effect was different in 2023 and 2024. This may be due to the fact that the amount of precipitation during the growing season of *L. potaninii* in 2023 and 2024 was different. The impact on WUE tended to decrease with an increase in seasonal precipitation [59]. We observed that fertilization can increase WUE, and the WUE with the application of P fertilizer was higher than with organic fertilizer or control. Fertilization affected root structure, and P fertilizer promoted root growth [60,61], which may benefit the water absorption and utilization of *L. potaninii*. However, organic fertilizer is a slow-release fertilizer and has a relatively minor promoting effect on root growth, resulting in lower WUE. Previous study showed that fertilizer significantly affect WUE in cotton [62]. Plants have varying absorption rates for different fertilizers, thus resulting in differing promotion effects on root growth, which may consequently affect water use efficiency.

5. Conclusions

This study assessed the effect of various water and fertilizer management strategies on *L. potaninii* growth; the total seed yield and seed yield of the CH and CL parts; and water-use efficiency. Irrigation amounts and fertilizer types significantly influenced *L. potaninii* seed yield, and the maximum seed yield was obtained under 200 mm of irrigation along with 90 kg/ha of P fertilizer. Under 100 mm irrigation amount, the seed yield of CL was higher than that of CH, while under 200 mm and 300 mm irrigation, the seed yield of CH and CL was converse. The response of CH and CL seed yields to fertilizer types was also different. Under 200 mm or 300 mm of irrigation, the CH seed yield with 90 kg/ha of P fertilizer was significantly more than the yield with organic fertilizer in both growing seasons; however, there was no difference in the effect of P fertilizer or organic fertilizer on CL seed yield. Irrigation amounts and fertilizer types had a positive effect on seed yield of the CH and CL parts by affecting yield components. Treatment I2F2 had the highest WUE (3.63 and 3.18 kg ha⁻¹ mm⁻¹), IWUE (4.87 and 5.05 kg ha⁻¹ mm⁻¹), and PWUE (6.27 and 8.07 kg ha⁻¹ mm⁻¹) in 2023 and 2024, respectively. This study provides guidance for the selection of fertilizer and irrigation amounts for *L. potaninii* seed production, and contributes to seed production and ecological restoration in arid regions.

Supplementary Materials: The following are available online at <https://www.mdpi.com/article/10.3390/agronomy15051175/s1>, Figure S1: Precipitation (A), monthly mean maximum temperature (B), monthly mean temperature (C), and monthly mean minimum temperature (D) at the experimental station from 2023 to 2024 and the long-term (30 years) average values. Table S1: Growing period date and irrigation time of *Lespedeza potaninii* for the years 2023 and 2024. Table S2: ANOVA for years, irrigation amount, fertilizers, and their interaction with total seed yield, CH seed yield, and CL seed yield of *L. potaninii* for the years 2023 and 2024. Table S3: ANOVA for years, irrigation amount, fertilizers, and their interaction with plant height, basal stem diameter, aboveground biomass, and harvest index of *L. potaninii* for the years 2023 and 2024. Table S4: ANOVA for years, irrigation

amount, fertilizers, and their interaction on stems, CH racemes, CL racemes, CH florets, and CL florets of *L. potaninii* for the years 2023 and 2024. Table S5: ANOVA for years, irrigation amount, fertilizers, and their interaction on CH pods, CL pods, CH 1000-seed weight, CL 1000-seed weight, CH seed yield per plant, and CL seed yield per plant of *L. potaninii* for the years 2023 and 2024. Table S6: ANOVA for water-use efficiency, irrigation water-use efficiency, and precipitation water-use efficiency of *L. potaninii* in 2023 and 2024.

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Data Availability Statement: The original contributions presented in this study are included in the article/Supplementary Materials. Further inquiries can be directed to the corresponding author.

Conflicts of Interest: The authors declare no conflicts of interest.

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