Response of Xinjiang Wild Apple Seedling Growth and Biomass Allocation to Precipitation Amount and Precipitation Interval Postprint

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Abstract

To investigate the effects of different precipitation amounts and precipitation interval times on the growth of Xinjiang wild apple seedlings, a field control experiment was conducted based on the multi-year average annual precipitation and precipitation interval times at the experimental site, with three precipitation gradients [W (monthly average precipitation), W- (15% reduction in monthly average precipitation), and W+ (15% increase in monthly average precipitation)] and two precipitation interval times [T (precipitation interval of 4 d) and T+ (precipitation interval of 8 d)]. The results showed that: (1) Under the same precipitation interval treatment, seedling base diameter, leaf number, aboveground biomass, and belowground biomass increased with increasing precipitation; (2) Under the same precipitation treatment, the T+ treatment promoted main root growth and increased the root-shoot ratio; (3) Compared with the W treatment, the relative growth rates of aboveground biomass, belowground biomass, and total biomass under the W+ treatment increased by 55.42%, 20.75%, and 34.43% on average, respectively. Extending the precipitation interval time promoted root growth and belowground biomass accumulation in Xinjiang wild apple seedlings, and increasing precipitation within a certain range promoted seedling growth and biomass accumulation.

Full Text

Abstract

To reveal the effects of different precipitation amounts and precipitation intervals on the growth of *Malus sieversii* seedlings, we conducted a field control experiment based on multi-year average annual precipitation and precipitation intervals at the experimental site. The experiment included three precipitation gradients: W (monthly average precipitation), W^- (15% decrease in monthly average precipitation), and W^+ (15% increase in monthly average precipitation), and two precipitation intervals: T (4-day interval) and T^+ (8-day interval). Results showed that: (1) Under the same precipitation interval, seedling basal diameter, leaf number, and above- and below-ground biomass increased with increasing precipitation amount; (2) Under the same precipitation amount, the T^+ treatment promoted main root elongation and increased the root/shoot ratio; and (3) Compared with the W treatment, the W^+ treatment increased the relative growth rates of above-ground, below-ground, and total biomass by 55.42%, 20.75%, and 34.43%, respectively. Extending the precipitation interval promoted root growth and below-ground biomass accumulation in *M. sieversii* seedlings, while increasing precipitation amount within a certain range enhanced seedling growth and biomass accumulation.

Keywords: *Malus sieversii*; precipitation amount; precipitation interval; seedling growth

Introduction

Global climate change is altering interannual precipitation patterns and precipitation frequency worldwide. Precipitation represents the primary water source for seed germination and seedling growth, with soil moisture serving as a critical factor for plant development. Future changes in precipitation amount and interval will affect soil water availability, subsequently influencing plant physiological and ecological characteristics and ultimately impacting plant population regeneration and persistence.

Numerous studies have examined how precipitation variability affects terrestrial ecosystem structure and function, including plant growth, species composition, and community structure. During plant regeneration, seedlings are most sensitive to water conditions during early developmental stages, making them vulnerable to precipitation changes. Research demonstrates that global climate change-driven precipitation alterations can either enhance or inhibit seedling recruitment. Increased precipitation promotes seedling biomass accumulation and reduces root/shoot ratios in species such as *Stipa grandis* in Inner Mongolian grasslands, *Agriophyllum squarrosum* in desert ecosystems, *Reaumuria soongorica*, *Nitraria tangutorum*, and *Quercus mongolica* in warm temperate regions. Conversely, altered precipitation intervals affect biomass allocation, as observed in *R. soongorica* and *N. tangutorum*. These findings indicate that plants adopt specific growth strategies to adapt to changing precipitation patterns, adjusting seedling growth to cope with environmental variability. Consequently, seedling responses to precipitation changes and their adaptive characteristics directly influence recruitment success and population dynamics.

The Ili River Valley, a humid island within Central Asia’ s arid region, is highly sensitive to climate change. Recent decades have shown an increasing precipitation trend in this area, which may affect local forest dynamics. *Malus sieversii*, a perennial tree species in the Rosaceae family and the genus *Malus*, dominates the Ili River Valley forests and represents the ancestor of cultivated apples. This nationally protected, endangered species exhibits remarkable stress resistance, including cold and drought tolerance. While previous research has focused on population survival, disease status, core germplasm resources, and genetic characteristics, the specific effects of precipitation amount and interval on *M. sieversii* seedling growth remain poorly understood. Reports indicate that over half of the *M. sieversii* seedlings in Xinyuan County fail to survive until autumn due to drought stress. Therefore, this study investigates how *M. sieversii* seedlings respond to variations in precipitation amount and interval, examining biomass allocation patterns and growth dynamics to theoretically elucidate precipitation change impacts on population regeneration and provide practical guidance for forest nursery management and seedling recruitment in the Ili River Valley.

1.1 Study Site

The experiment was conducted at the Ili Botanical Garden in Xinyuan County, Ili Kazakh Autonomous Prefecture, Xinjiang (43°38 N, 83°61 E). This region features a temperate continental climate with an average annual temperature of 10.0 °C, annual precipitation of 580 mm, and elevation of approximately 1380 m. *Malus sieversii* is the dominant tree species, accompanied by *Crataegus cuneata*, *Armeniaca vulgaris*, and *Juglans regia*. Herbaceous species include *Urtica fissa*, *Arctium lappa*, and *Dactylis glomerata*.

1.3.1 Simulated Precipitation and Interval Settings

Based on multi-year data (2010-2020) from a Davis automatic weather station in Xinyuan County' s wild fruit forest, the average annual precipitation was 580 mm, with maximum and minimum annual precipitation of 660 mm and 500 mm, respectively—representing a 15% deviation from the mean. We established three precipitation treatments: W (monthly average precipitation), W^- (15% reduction), and W^+ (15% increase). Meteorological data indicated an average precipitation interval of 4 days, leading us to set T (4-day interval) to simulate natural frequency and T^+ (8-day interval) to represent extended intervals. This created six precipitation treatments: W+T, W+T^+, W^-+T, W^-+T^+, W^++T, and W^++T^+.

1.3.2 Experimental Setup

We selected a relatively flat 4 m × 5 m plot, divided into six 0.5 m × 0.5 m subplots. Each subplot contained 16 plastic pots (15 cm height, 16 cm diameter) filled with local mountain dark brown soil. Mature *M. sieversii* fruits were collected in October 2020, with seeds extracted and stored at 4 °C for cold stratification to break dormancy. After stratification, seeds were tested for viability using 0.5% TTC (2,3,5-triphenyltetrazolium chloride) solution. Viable seeds were sown on May 15, 2021, at 2 cm depth, with daily watering to maintain soil moisture until germination. On June 1, 2021, we selected 180 uniformly sized seedlings (30 per treatment) and initiated precipitation treatments. Rain shelters (0.5 m height) were installed to prevent natural precipitation interference while ensuring ventilation. Simulated precipitation was applied uniformly to pots using graduated cylinders and beakers between 20:00–22:00 to minimize evaporation.

1.3.3 Seedling Growth Measurements

During the growing season (June–September 2021), we measured seedling height, basal diameter, leaf number, and main root length every 15 days. Before final harvest, five seedlings per treatment were randomly selected for biomass analysis. Seedlings were excavated, washed, oven-dried at 75 °C to constant weight, and weighed. Relative growth rate (RGR) was calculated as: RGR = $(\ln W_2 - \ln W_1)/\Delta t$, where W_1 and W_2 represent initial and final biomass, respectively, and Δt is the time interval.

1.4 Data Analysis

Data were analyzed using SPSS 22.0 after confirming normality and homogeneity of variance. One-way ANOVA compared differences in seedling height, basal diameter, main root length, and leaf number among treatments. Two-way ANOVA examined interactive effects of precipitation amount and interval on above-ground biomass, below-ground biomass, and root/shoot ratio. Duncan’ s multiple range test assessed significant differences ($\alpha = 0.05$). Figures were generated using Origin 2021.

2 Results and Analysis

Both precipitation amount and interval significantly affected seedling height, basal diameter, main root length, and leaf number (Table 2). Under the same precipitation interval, seedling height increased with precipitation amount. The T^+ treatment reduced height by 13.26% and 16.59% compared to T under W^- and W treatments, respectively, but increased height by 12.65% under W^+. Basal diameter increased with precipitation amount across all interval treatments, with W^++T showing the largest increase (68.15% greater than W+T). Leaf number followed similar trends, with W^++T producing the most leaves (20.00 ± 3.21), significantly exceeding other treatments.

Two-way ANOVA revealed that precipitation amount had highly significant effects on above-ground and below-ground biomass ($P < 0.001$), while precipitation interval showed no significant effects ($P > 0.05$) (Table 3). Under the same interval, both above- and below-ground biomass increased with precipitation amount, peaking in the W^++T treatment (Fig. 2). At the early growing season, no significant differences in above-ground biomass existed among precipitation amounts, but W^++T showed significantly higher below-ground biomass than W+T. By season’ s end, W^+ increased above-ground biomass by 33.80% and below-ground biomass by 44.17% compared to W. The T^+ treatment consistently produced higher below-ground biomass than T under the same precipitation amount. Root/shoot ratios showed no significant differences among treatments ($P > 0.05$), though T^+ produced higher ratios than T in early season, while W^+ yielded lower ratios than W^- by season' s end.

Precipitation amount significantly affected relative growth rates of biomass ($P < 0.001$). Under the same interval, RGR of above-ground, below-ground, and total biomass increased with precipitation amount (Fig. 3). Compared to W, W^+ increased RGR of above-ground, below-ground, and total biomass by 55.42%, 20.75%, and 34.43%, respectively.

3 Discussion

3.1 Effects of Precipitation Interval on Seedling Growth

Altered precipitation intervals affect plant morphology and subsequently modify biomass allocation between above- and below-ground components. Extended intervals increase soil water evaporation, reducing seedling biomass and survival, but can also promote root elongation and increase root/shoot ratios, as observed in *R. soongorica* and *N. tangutorum*. Our results demonstrate that prolonged precipitation intervals enhanced main root growth in *M. sieversii* seedlings, consistent with findings for *R. soongorica*. This response likely represents a drought adaptation strategy, where seedlings elongate primary roots to access deeper soil moisture under water stress. At the same precipitation amount, T^+ treatment increased below-ground biomass and root/shoot ratio throughout the growing season, contrasting with some previous studies. This discrepancy may reflect differences in surface evaporation and transpiration rates between study sites. Under drought stress, plants initially close stomata to reduce water loss, then allocate more biomass to roots to enhance water absorption, thereby increasing root/shoot ratio. Our findings indicate that *M. sieversii* seedlings respond sensitively to precipitation interval changes by allocating more biomass to roots, demonstrating a morphological adaptation to drought conditions.

3.2 Effects of Precipitation Amount on Seedling Growth

Water stress triggers plastic responses in seedling growth and biomass allocation. Reduced precipitation significantly decreases total biomass in species like *Lupinus perennis*, while increased precipitation enhances biomass accumulation in *S. grandis*, *A. squarrosum*, *R. soongorica*, *N. tangutorum*, and *Q. mongolica*. In our study, *M. sieversii* seedling height, basal diameter, and leaf number all increased with precipitation amount under the same interval, mirroring responses in *A. squarrosum* and *Salix psammophila*. Under adequate precipitation, seedlings allocate more resources to above-ground structures to maximize light capture and photosynthesis, promoting biomass accumulation. Conversely, water deficit prompts reallocation to roots for exploring deeper soil resources.

Throughout the growing season, above- and below-ground biomass increased with precipitation amount under the same interval. In early season, W^++T showed greater below-ground biomass than W+T, while above-ground biomass showed no significant differences, suggesting roots respond most rapidly to precipitation changes. By season' s end, W^+ produced lower root/shoot ratios than W^-, consistent with patterns in *S. psammophila* where increased precipitation reduces root/shoot ratios. Under chronic water stress, seedlings adjust allocation to favor below-ground structures for water acquisition. The combination of increased precipitation amount and extended interval yielded the highest total biomass RGR, indicating that *M. sieversii* seedlings can adjust biomass allocation strategies to enhance survival under variable precipitation regimes. Overall, precipitation reduction had minimal impact on seedling growth, while precipitation increases promoted growth and biomass accumulation, suggesting *M. sieversii* seedlings possess adaptive capacity for future precipitation changes.

4 Conclusions

This study investigated how precipitation amount and interval affect *Malus sieversii* seedling growth and biomass allocation, yielding four key findings: (1) Extended precipitation intervals promote main root elongation and increase root/shoot ratio. (2) Increased precipitation enhances seedling height, basal diameter, and leaf number. (3) Higher precipitation amounts improve biomass relative growth rates and facilitate accumulation of above-ground, below-ground, and total biomass. (4) Future precipitation increases will likely benefit *M. sieversii* seedling growth, providing a theoretical basis for understanding plant recruitment dynamics in wild fruit forests under changing precipitation patterns.

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