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Adapting northern herbs for desertification control in Poyang Lake, China

Haijing XIAO[1,2], Zhenwu BIAN[3], Junyu XU[1,2], Shimeng LI[1,2], Mengting XIAO[1,2], Min GUO[1,2], Xianglong BU[3], Muhammad RAFIQ[1,2,*], Chunsong CHENG[1,2]

[1]Jiangxi Key Laboratory for Sustainable Utilization of Chinese Materia Medica Resources, Lushan Botanical Garden, Chinese Academy of Sciences, Jiujiang, Jiangxi, China

[2]Jiujiang Xinglin Key Laboratory for Traditional Chinese Medicines, Jiujiang, Jiangxi, China

[3]Department of Student Affairs Management, Anhui Professional College of Art, Hefei, Anhui, China

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Abstract: Desertification poses a pressing global challenge, threatening both environmental stability and socioeconomic well-being, and it requires detailed monitoring of its dynamics and drivers to inform land restoration and sustainable development strategies. Around Poyang Lake, China's largest freshwater lake, desertification has triggered profound ecological degradation and economic losses, intensified by human activities and climate change. This study investigates these challenges by evaluating an integrated revegetation approach that combines Beach vitex (*V. rotundifolia*) with nitrogen-fixing licorice (Glycyrrhiza spp.) to improve soil quality, stabilize environmental conditions, and foster sustainable land management. Field experiments examined the drought tolerance and soil enhancement capabilities of five licorice landraces from three species, tracking soil pH, temperature, and moisture across different planting configurations. Findings revealed that rainfall elevated surface soil pH on flat terrains (6.5–7.6) while exerting limited influence on sloped areas (5.6–6.4). Interplanting with Beach vitex (*V. rotundifolia*) lowered surface sand temperatures by as much as 5 °C, boosted soil moisture retention, and enhanced the survival and vigor of *Glycyrrhiza glabra* seedlings. Licorice demonstrated strong root growth, effective nitrogen fixation, and substantial capacity to enrich sandy soils. This combined planting model offers a promising solution for combating desertification, converting degraded sandy expanses into fertile agricultural land, and advancing ecological recovery alongside economic resilience in southern China.

Key words: Desertification, licorice, sand dunes, Poyang Lake, land improvement

1. Introduction

Artificial intervention in desertification in southern China has long been one of the crucial challenges over the years (Lyu et al., 2020; Miao et al., 2015). Despite centuries of effort to achieve sustainable management, the humid deserts around lakes and watersheds have remained unresolved issues (Cao et al., 2022). Especially, acute issues such as how to balance human activities with ecological preservation arise in major water body areas. This means that thousands of miles along the continuous river systems—including the Yellow River basin, Yangtze River, and Huai River—comprise hundreds of thousands of hectares of fertile land that have been turned into sand (Wine and Laronne, 2020). Unfortunately, much of this land remains underutilized due to the persistent challenges posed by desertification. Indeed, human activities have further aggravated this situation, resulting in the expansion of sandified areas and the emergence of mobile dunes. These factors further disturbed farming activities and prevented localized sustainable development (Lyu et al., 2020; Li and Squires, 2009; Kirkby, 2021). This problem is especially evident in areas surrounding major lakes—such as Dongting Lake, Poyang Lake, and the Qiantang River—where the advancement of desertified land threatens to hinder urban growth and regional stability (Zhang et al., 2023; Wu et al., 2019).

Poyang Lake, the largest freshwater lake in China, has been greatly affected by desertification (Liu et al., 2021). The surrounding deserts of Poyang Lake have been gradually degraded ecologically (Tao et al., 2021), forming an unsustainable and fragile landscape that is not only environmentally vulnerable but also economically underutilized (Liu et al., 2024a). They are influenced by major causes of desertification in this area, such as palaeogeological factors, water level fluctuations, human-induced deforestation, and improper land use, which have caused soil erosion and expansion of barren sandy dunes (Figure 1) (AbdelRahman, 2023; Chen, 2020). The dunes around Poyang Lake, being desertified, have kept a weak and dotted vegetation for thousands of years (Yang

* Correspondence: rafiqsabqi@gmail.com

Figure 1. The threat landscape caused by desertification around Poyang Lake, including agricultural threats and channel blockages, demonstrates that limited scattered human interventions still cannot stop sand movement and soil erosion.

et al., 2010), since indigenous plant species hardly survive because of the bad fertility of the ground and extremely hot summer on mobile and semifixed sand lands (Wu et al., 2021; Wang et al., 2006). This ecological inefficiency has led to a low diversity of plant life, further exacerbating the region's vulnerability to desertification.

The area of sand lands around Poyang Lake is 38,900 hm^2 (Chen et al., 2004), and in recent decades, the harm caused by desertification and siltation has been very severe. In recent years, the intensification of sand mining activities has exacerbated the damage to lake shore vegetation and the ecological environment, leading to the continued expansion of desertification (Zhang, 2020), with 17,200 hm^2 of desertified land added since 1999. Although there have been some results in sand control efforts over the years, the mobility of sand lands has not been effectively contained. Importantly, for thousands of years, humans have been unable to utilize sand lands for agricultural and economic development (Roskin and Taxel, 2021). According to surveys, the usable area of sand lands with frequent human activity around Poyang Lake exceeds 7000 hm^2 (Li et al., 2020). Effectively implementing ecological restoration of mined sand lands and broadening the transformation channel from "green mountains and clear waters" to "golden or silver mountains" remains a challenge (Worlanyo and Jiangfeng, 2021).

Since 2023, our group has shown great commitment and scientific dedication in a collaborative garden project, pioneering the cultivation of licorice in sand lands under the concept of "growing licorice in the south by using the northern herbs." The first batch of licorice seedlings has bloomed, generating valuable firsthand data on licorice cultivation in sand lands and providing theoretical support for their utilization and ecological restoration. licorice is an ideal candidate for this intervention due to its proven adaptability to arid and semiarid environments (Zhang, 2020). Studies have demonstrated that licorice has a deep taproot system, which allows it to access water and nutrients from deeper soil layers, making it particularly effective in stabilizing sandy soils prone to erosion (Öztürk et al., 2018; Goudarzi et al., 2024). Additionally, licorice exhibits strong nitrogen-fixing capabilities, like legumes (Xie et al., 2019), which significantly improve soil fertility and promote the growth of other plant species in degraded areas (Mosier et al., 2021). The cultivation of licorice also holds substantial economic value, as its roots are widely used in the pharmaceutical, food, and cosmetic industries (Ding et al., 2022). This dual ecological and economic benefit makes licorice a strategic choice for sustainable land management around Poyang Lake. Moreover, studies conducted in northern China have shown that planting licorice in degraded lands can lead to a 30% increase in soil organic matter within 5 years, along with a significant reduction in soil erosion rates (Khaitov et al., 2021). When combined with nitrogen-fixing legume crops, the soil quality is further enhanced, leading to improved vegetation cover and greater biodiversity (Yan et al., 2024). The selection of these species, which possess both deep root systems and high economic value, aligns with the goal of achieving long-term ecological restoration and socioeconomic development in the Poyang Lake region.

The selection of northern herb species for desertification control in the Poyang Lake region is based on their inherent adaptability to harsh environmental conditions, including drought, extreme temperatures, and poor soil fertility (Zhang et al., 2024). These species have evolved mechanisms such as deep root systems, efficient water-use strategies, and enhanced stress tolerance, making them well-suited for stabilizing degraded soils (Montaño, 2024). Compared to other plant types, northern herbs exhibit superior resilience in arid and semiarid environments, allowing them to establish and thrive in regions affected by desertification (Lyu et al., 2020). Additionally, many of these species possess medicinal and ecological benefits, further enhancing their value in sustainable land restoration efforts (Feng et al., 2019). By leveraging their natural adaptations, this study aims to explore their potential role in improving soil quality, promoting vegetation recovery, and mitigating desertification in the Poyang Lake region.

In this study, we report for the first time that five landraces of three medicinal licorice species were planted in the south, in the sand lands around Poyang Lake. By integrating licorice and legume crops into the reforestation strategy, this study aims to create a more resilient and sustainable ecosystem around Poyang Lake. The use of species with nutrient-acquiring abilities, such as nitrogen fixation, coupled with their economic potential, ensures that the intervention is both ecologically effective and economically viable. This strategy not only addresses the immediate challenge of desertification but also provides a model for the sustainable use of southern desertified lands.

2. Material and methods

2.1. Selection of plant species

The study began with the selection and screening of medicinal licorice (*Glycyrrhiza uralensis* Fisch.; *G. inflata* Bat.; *G. glabra* L.) suitable for plantation in Poyang Lake desert conditions. The lateral root materials of three medicinal licorice species, including five landraces (Figure 2), provided by Professor Ying Wang from the South China Botanical Garden, Chinese Academy of Sciences, were evaluated based on their adaptability to arid environments, root system characteristics, and potential for nitrogen fixation. After extensive screening, the species best suited to withstand the harsh desert conditions surrounding Poyang Lake was identified for further experimentation.

2.2. Root preparation and treatment

The selected licorice lateral roots, which are crucial for successful germination and growth in desert environments, were carefully chosen for plantation. Prior to planting, the lateral roots were cut into lengths of 10–15 cm, soaked in a carbendazim solution at working concentration for 5 min, and then soaked in a rooting powder solution for 2 h to prevent fungal infections, which are common in arid soils with low microbial activity (Bahroun et al., 2018). In the middle of March, the lateral roots were dug up, and care was taken to maintain ventilation and prevent exposure to sun and rain during transportation and storage. According to the plant and row spacing of 20 cm, the lateral roots were planted as required, with a planting depth of 20 cm and a soil cover of 20 cm.

2.3. Planting and seedling management

Sandy soil with different slopes (1°–45°) was selected as the planting site to test the optimal planting environment, and the water content and pH conditions of the sandy soil were continuously tracked (Di Matteo et al., 2021). Following the antifungal treatment, the treated lateral roots were buried in the desert sand at predetermined depths to promote optimal germination. The plantation site was selected based on the sand's pH and the local temperature conditions. Initial irrigation was withheld to simulate the natural conditions of the desert environment, with water applied only after a few days to stimulate germination. This approach was designed to mimic the natural rainfall patterns of the region and to test the roots' resilience and capacity for germination under minimal water conditions. The temperature and humidity in the field were constantly monitored manually. In view of the bare system, it was necessary to promptly fill the soil, bury the roots, and carry out effective replanting for those that failed to survive.

During the period of high temperature and humidity (July–September), microbial fertilizers (primarily actinomycetes and cyanobacteria) were used to increase resistance, thereby reducing the growth of fungi and molds.

The first intertillage weeding was performed when the seedlings reached a height of 5 cm. Weeds in the field were removed early and frequently in the 1st year, and weeding was no longer needed after the 2nd year as seedlings reached a height of approximately 10–15 cm. Phosphate fertilizer was applied 1–2 times at a rate of 150 kg/ha before rainy days.

2.4. Field control of plant diseases and insect pests

Pest control for imported varieties should be strictly quarantined, with ecological and biological control prioritized in prevention and control, and chemical control used as little as possible. Chemical control was carried out strictly in accordance with the provisions of GB4285 and GB/T8321, and high-risk pesticides prohibited by the state, along with their mixtures, were not used (Jiang et al., 2023). To manage powdery mildew at the initial stage of the disease, a 15% triadimefon solution (diluted 1000–1500 times) was used. For rust, 15% triadimefon was also applied at the same dilution. For brown spot disease, a 75% chlorothalonil wettable powder was sprayed at a 500–600-fold dilution during the early stage of infection. For the management of underground pests, during soil preparation, 500 mL of phoxim was mixed with 3000 mL of water per 667 m^2, combined with 20 kg of fine sand, evenly spread on the surface, and incorporated into the soil. For surface pests such as aphids, licorice leaf beetles, and short-haired grass elephants, pyrethroids were sprayed at a 1000–1500-fold dilution. A 2.5% deltamethrin solution was applied at a 2000–4000-fold dilution during the peak pest infestation period.

Figure 2. Five landraces of three medicinal licorice species as the first representatives of the "North Herb" project.

2.5. Environmental measurements

Throughout the plantation process, the temperature of the desert environment and the pH of the sand were closely monitored. The LabSen pH818 (Apera Instruments, Columbus, OH, USA) was used to measure the pH of the sand and soil on different days under varying environmental conditions. The pH of the sand was measured using a calibrated pH meter to ensure the suitability of the soil conditions for licorice growth. The water content of the sandy soil and ambient humidity (within 30 cm above ground) were also monitored within 3 days after rainfall. Temperature readings were taken using a digital thermometer at various times of the day and during the hottest month, to capture the diurnal temperature variation typical of desert climates. These measurements were recorded regularly to assess their influence on the germination and growth of the licorice plants.

2.6. Data processing and statistical analysis

Excel 2019 (Microsoft Corporation, Redmond, WA, USA) was used for data processing; R language v4.1.3 (R Foundation for Statistical Computing, Vienna, Austria) was used for data analysis; Origin 2018 (OriginLab Corporation, Northampton, MA, USA) and GraphPad Prism 9 (GraphPad Software Inc., San Diego, CA, USA) were used for plotting; IBM SPSS Statistics v25.0 (IBM Corp., Armonk, NY, USA) was used for one-way variance analysis, and the least significant difference (LSD) test was used to determine statistical significance at the 0.05 or 0.01 level.

3. Results

3.1. Soil properties and pH of the sand lands surrounding Poyang Lake

The sand lands surrounding Poyang Lake exhibit varying levels of desertification, which significantly impact the pH levels and overall fertility of the sandy soil. To understand the influence of environmental factors on soil pH, measurements were taken at three different depths (10 cm, 20 cm, and 30 cm) across flat and sloped lands under two conditions: after rainfall and on clear days. In flat land at a depth of 10 cm, pH values ranged from approximately 6.5 to 7.6, with the highest values recorded after rainfall, as shown in Figure 3. Significant variations in pH were observed between rainy and clear days, suggesting a strong influence of rainfall on surface soil acidity. On sloped land, pH values were slightly lower (5.6–6.4), with no noticeable increase in pH after rainfall, highlighting the sensitivity of sloped soils to precipitation. pH values at 20 cm and 30 cm depths were more stable, ranging from 5.7 to 7.1 for both flat and sloped lands. The minimal variation between rainy and clear days indicates that the impact of rainfall on pH diminishes with soil depth. The pH on flat sand lands showed a slight increase after rainfall. In contrast, sloped land pH showed no notable differences between conditions, particularly after rainfall, reflecting the deeper soil's capacity to retain moisture and nutrients.

3.2. Temperature regulation in sand cultivation by interplanting Beach vitex (*V. rotundifolia* L. f.)

Extreme high temperatures of desert sandy soil should be monitored to provide a scientific basis for the management of medicinal licorice cultivation. In the lush forest of *V. rotundifolia*, an indigenous dominant species, the temperature regulations in the desert were recorded at three different times (10:00 AM, 12:00 PM, and 02:00 PM) over three consecutive clear days, with measurements taken at varying heights above the sandy ground.

On day 1, the temperature readings showed a consistent decrease of 1–3 °C at all three times. The best cooling effect of *V. rotundifolia* was observed at 15–20 cm above the ground at 10:00 AM and 12:00 PM, while at 02:00 PM the optimal cooling occurred at 5–10 cm above the ground. As the day progressed, temperatures rose significantly, peaking at 02:00 PM, indicating the desert's rapid warming under direct sunlight. Under continuous high temperatures, *V. rotundifolia* was able to reduce the surface sand temperature by about 2 °C on average.

On day 2, a similar pattern was observed, showing that under high temperatures, *V. rotundifolia* could reduce the temperature at 5–15 cm above the ground. The temperature at 10:00 AM or 02:00 PM showed a steady decrease with height.

Day 3 followed the same trend, with temperature increases observed from 10:00 AM to 02:00 PM across

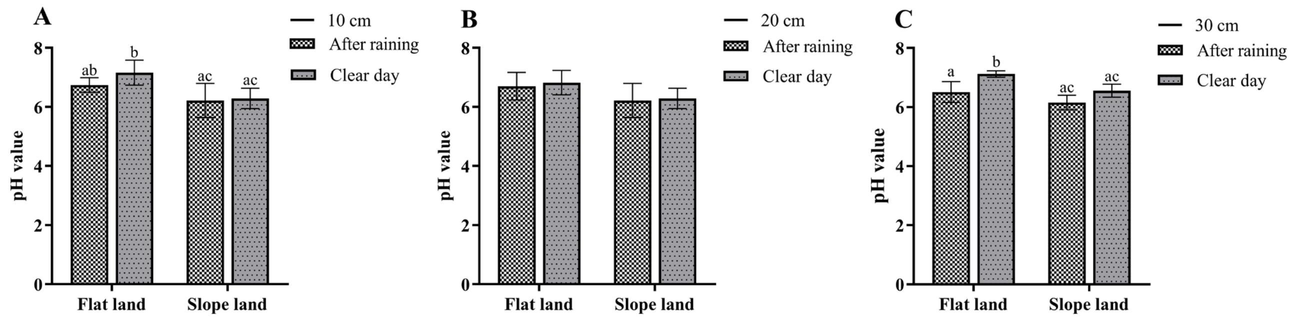

Figure 3. pH measurements at three depths (10 cm, 20 cm, and 30 cm) across flat and sloped lands under two conditions: after rainfall and on clear days (N > 6, t-test, ab: $p < 0.05$; bc: $p < 0.05$). A: pH at 10 cm depth; B: pH at 20 cm depth; C: pH at 30 cm depth.

all heights. However, compared to the previous 2 days, the ground temperature peaked on the 3rd day, and the cooling effect of *V. rotundifolia* was more pronounced, reducing the ground temperature by an average of 3 °C and up to 4.3 °C at its maximum.

In addition, temperatures were also measured at different depths underground (5–30 cm). As shown in Figures 4 and 5, the results of three consecutive sunny days demonstrated that the accompanying plant *V. rotundifolia* could reduce the temperature by 4–5 °C at the shallow surface (5 cm underground). With increasing depth, the cooling effect of *V. rotundifolia* gradually decreased, but within 30 cm underground, it could still provide a relatively cooler rhizosphere environment of 1–2 °C. Compared to the above-ground temperature reduction, interplanting *V. rotundifolia* can reduce the rhizosphere sandy soil temperature more effectively and stably, thereby improving the survival rate of *G. glabra* seedlings under harsh high-temperature summer conditions.

3.3. Regulation of aboveground humidity by interplanting Beach vitex (*V. rotundifolia* L. f.)

The humidity levels in the desert area surrounding Poyang Lake were measured at three different times (10:00 AM, 12:00 PM, and 02:00 PM) across three consecutive days at varying heights above the desert surface. The results indicated a clear diurnal pattern in humidity variation, closely linked to the temperature fluctuations observed throughout the day. Generally, *V. rotundifolia* increased the environmental humidity above ground in the experimental licorice planting field. Humidity levels increased most at 10:00 AM on the 1st clear day after rain across all heights, with a significant decrease observed at 12:00 PM, as shown in Figure 6. This pattern suggests that as the day progresses and temperatures rise, the moisture content in the air diminishes due to increased evaporation. The consistency of this pattern across multiple days underscores the influence of desert temperature on humidity levels. Humidity was generally increased by *V. rotundifolia* at the surface level. This indicates that plant transpiration significantly contributes to atmospheric moisture, which diminishes with height due to the dispersal of water vapor.

On the third day, after three consecutive days of high temperatures, the test results showed that the increase in ground humidity at 12:00 PM and 02:00 PM was much higher than during the same periods on the previous 2 days under the interplanting of *V. rotundifolia*. Under extremely dry and high-temperature conditions, *V. rotundifolia* can greatly improve ground humidity and support the survival of other plants.

Overall, these findings highlight the strong correlation between temperature and humidity in desert areas, with humidity peaking in the cooler morning hours and declining steadily as the day progresses. Understanding this relationship is vital for planning any agricultural or ecological interventions in south desertified regions.

3.4. Observational data for a growing cycle of licorice

The growth cycle of medicinal licorice (*Glycyrrhiza glabra*) was carefully monitored throughout a full seasonal cycle, from germination to maturity, as shown in Figure 7. The licorice roots were planted in sandy soil, began emerging visibly within 2 weeks, and the first true leaves appeared around the 3rd week. By the 2nd month, the plants exhibited significant lateral root development, and reached an average height of 20–25 cm by the end of the vegetative phase, with no significant pest or fungal infections noted during this stage. Flowering normally occurs uniformly with no major variations in plant height, and the plants divert most of their energy to root development, demonstrating a high capacity for nutrient uptake, supported by the presence of nodules indicating nitrogen-fixing activity. Typically, after 6 months, the aboveground parts of the plants largely dry out, signaling the end of the active growing period. Throughout the entire growing cycle, environmental factors such as temperature, soil pH, and moisture levels influence optimal growth conditions.

As shown in Figure 8, after a period of observation using *Glycyrrhiza glabra* as an example at different stages

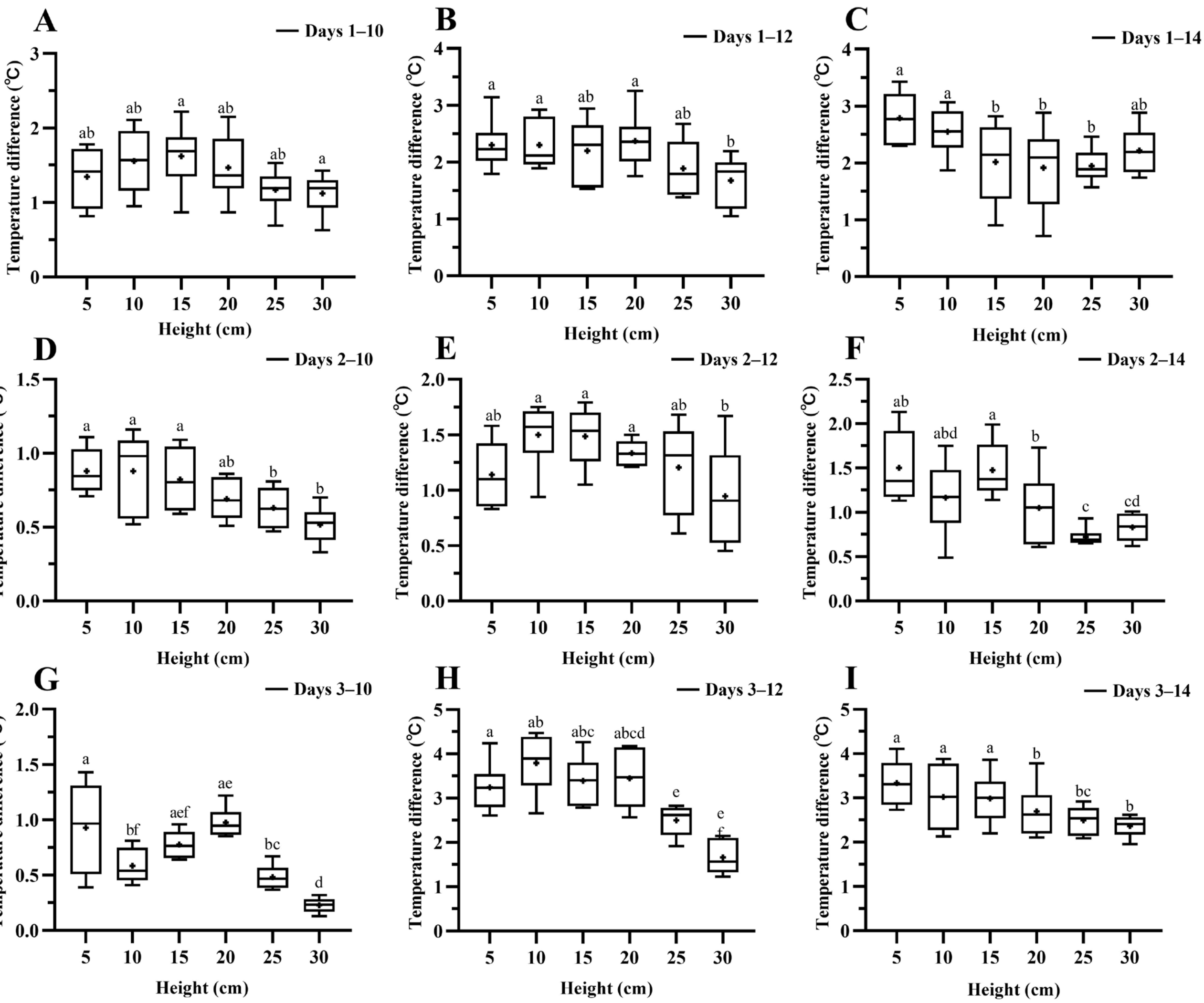

Figure 4. The interplanted species Beach vitex (*V. rotundifolia*) effectively reduces ambient temperature, supporting the growth and development of medicinal licorice (*Glycyrrhiza glabra*) during the seedling stage. A–C: Three time points (10:00 AM; 12:00 PM; 02:00 PM) on the 1st sunny day after rain in summer; D–F: Second day; G–I: Third day.

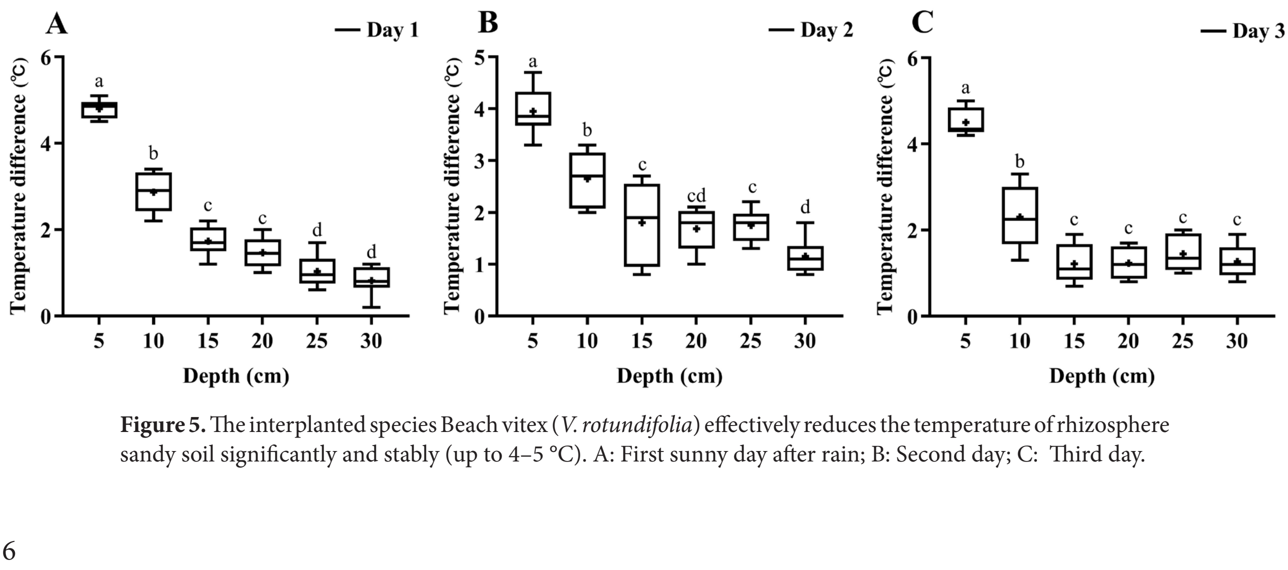

Figure 5. The interplanted species Beach vitex (*V. rotundifolia*) effectively reduces the temperature of rhizosphere sandy soil significantly and stably (up to 4–5 °C). A: First sunny day after rain; B: Second day; C: Third day.

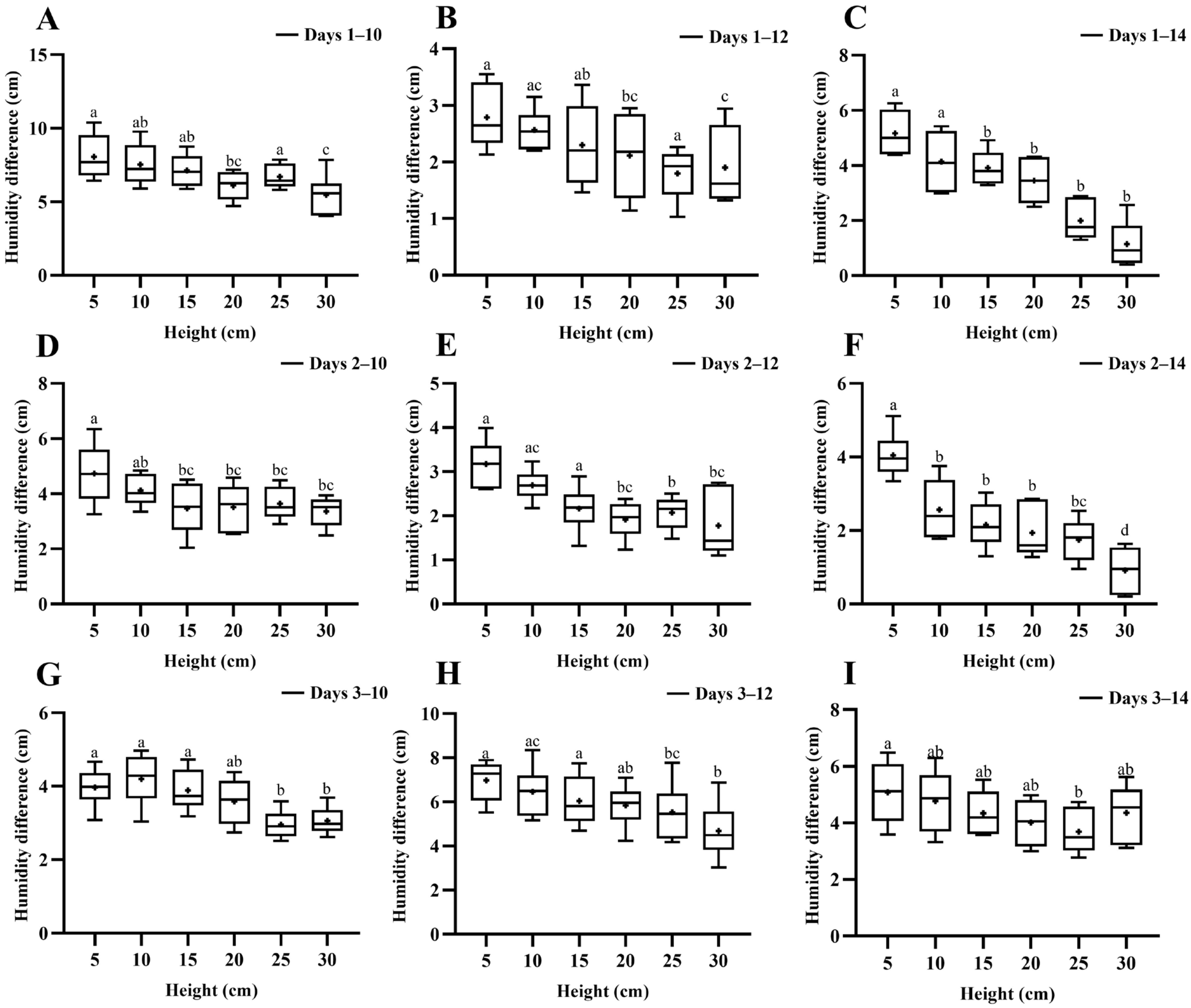

Figure 6. The interplanted species Beach vitex (*V. rotundifolia*) effectively increases humidity in the cultivation environment, supporting the seedling-stage development of medicinal licorice (*Glycyrrhiza glabra*). A–C: First sunny day after rain; D–F: Second day; G–I: Third day, each with measurements at 10:00 AM, 12:00 PM, and 02:00 PM.

of the year (April, July, and October), leaf count in the 2nd year increased by 2–3 times compared with the 1st year; Plant height did not increase significantly in the 2nd year; Root depth also increased significantly in the 2nd year; The total biomass (plant dry weight) approximately doubled in the 2nd year.

4. Discussion

4.1. Cultivation strategies for southern desertified land

When considering the cultivation of desertified lands in southern China, particularly on a large scale (over 405 ha), several factors need to be addressed to ensure both ecological sustainability and agricultural productivity. Large-scale mechanized farming is feasible if the land hardness is suitable for heavy machinery, yet this must be balanced with the need to preserve the delicate ecological integrity of these areas (Lu et al., 2024). A zoning management approach for approximately 40 ha, or even subdividing into 4–8-ha plots, may be more appropriate, particularly for preserving biodiversity and reducing soil degradation risks. Water and fertilizer management in these regions is critical due to the high rates of loss, necessitating advanced irrigation systems that are both efficient and minimize runoff (Alva et al., 2006). Furthermore, the road system in these zones must be designed to support both agricultural machinery and ecosystem preservation, ensuring minimal disturbance to natural habitats (Ji et al., 2024).

Figure 7. Growth cycle of *Glycyrrhiza glabra* from germination to maturity. Licorice roots emerged within 2 weeks, formed true leaves by the 3rd week, and reached an average height of 20–25 cm by the 2nd month. Nodules indicated nitrogen fixation and environmental factors such as temperature, pH, and moisture were monitored throughout the cycle.

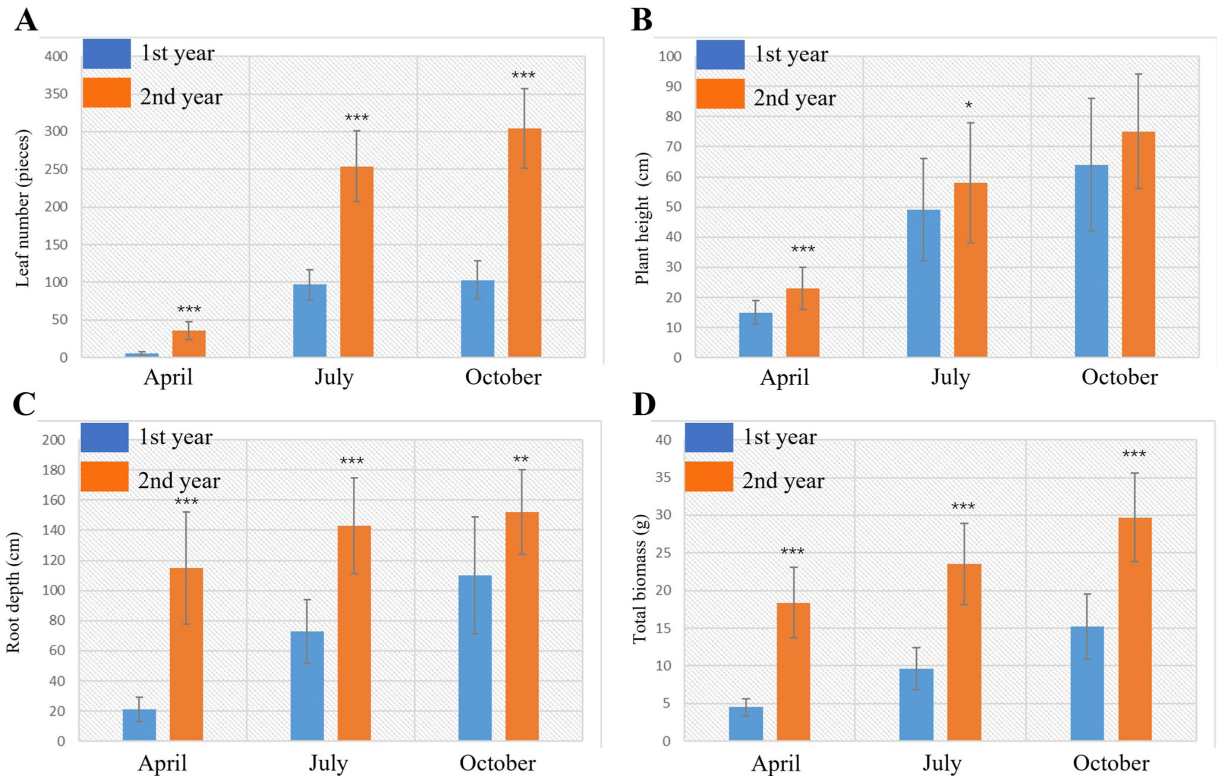

Figure 8. Comparative observations of *Glycyrrhiza glabra* across different stages of the year (April, July, and October). Leaf count increased 2–3 times, root depth increased substantially, and total biomass doubled in the 2nd year.

Additionally, integrating modern agricultural practices with scientific equipment can enhance efficiency, particularly in the application of water and fertilizers, which are prone to rapid depletion in sandy soils (Lakhiar et al., 2024; Alharbi et al., 2024). Employing precision agriculture technologies could help monitor soil moisture levels, optimize water use, and reduce the environmental impact of cultivation in these fragile ecosystems (Júnior et al., 2024; Yin et al., 2021).

4.2. Distinctive challenges of southern desertification

Due to its high moisture content and unique climatic conditions, desertification in southern China presents distinct challenges compared to northern regions (Wang et al., 2024). The southern desert, especially around Poyang Lake, experiences heavy rainfall from Qingming Festival to early summer (Liu et al., 2024b). This period is characterized by high humidity and high temperature, creating ideal conditions for fungal growth and pest infestation (Skendžić et al., 2021). Therefore, effective pest management strategies are crucial, with a focus on preventive measures tailored to the climatic conditions and specific needs of crops such as licorice (Arora et al., 2024).

An important observation is that planting in southern sandy areas is more effective in the later stages of the season, utilizing the rising temperatures in May to suppress weed growth and create favorable conditions for crop cultivation. Planting density is also important, requiring balanced spacing to ensure sufficient ventilation while avoiding overcrowding (Al-Kulabi, 2022). Choosing planting sites with a slope of 10 to 20 degrees can help maintain moisture and ensure better drainage, thereby promoting healthy plant growth (Kumawat et al., 2020).

4.3. Alternative leguminous plants for southern desertified land

While licorice has been identified as a promising candidate for mitigating desertification around Poyang Lake, other leguminous plants may also be suitable for this purpose (Gupta and Gupta, 2023). Species such as powdered oxen, Sami rind, buckwheat, bitter ginseng, and jujube offer potential economic and ecological benefits. These plants have been chosen based on their original soil and climatic conditions, which align well with the characteristics of southern China's desertified areas.

For instance, powdered oxen and bitter ginseng are known for their autonomous nutrient acquisition strategies, particularly nitrogen fixation, which can improve soil fertility without the need for extensive fertilization. Buckwheat and jujube are also valuable due to their resilience in arid conditions and ability to produce economically valuable yields, making them suitable for large-scale cultivation. Each of these plants has distinct advantages, and their integration into the southern desertified lands could diversify the ecosystem and enhance the overall sustainability of agricultural practices in these regions.

5. Conclusion

In conclusion, combating desertification in southern China requires a balanced approach that integrates large-scale mechanized farming with ecologically sensitive management. Understanding climatic differences between northern and southern deserts is key, along with selecting plant species suited to these environments. By applying advanced agricultural techniques and appropriate crops, land rehabilitation can be achieved while preserving ecological balance.

Contribution of authors

Conceptualization, methodology, investigation, and formal analysis: Z.B., H.X., J.X., S.L., and C.C.; writing—original draft preparation: M.X., M.G., and X.B.; writing—review and editing: C.C. and M.R.; supervision: C.C. and M.R. All authors have read and agreed to the published version of the manuscript.

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Data availability statement

Data supporting reported results will be made available by the authors upon request.

Conflict of interest

The authors declare no conflicts of interest.

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