

Analysis of Roof Garden Plant Allocation and Its Benefits in Guanzhong Area under the Background of Human Settlement: A Case Study of Yangling Demonstration Area

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Abstract. Taking the Yangling demonstration area as the research object, this paper analyzes the local climate and combines the micro-environmental characteristics of rooftop gardens in Yangling to explore the principles of plant configuration in rooftop gardens. It selects suitable plants for rooftop gardens and investigates their ecological benefits in improving the urban heat island effect, reducing rainwater accumulation, and purifying the air, providing a reference for the construction and management of rooftop gardens in the Guanzhong region.

Keywords: roof garden, plant allocation, ecological benefits, Yangling District

1. Introduction

With the continuous development of urbanization in China, rapid urbanization processes have led to emerging issues, deepening public awareness of habitat environments, and increasing demands for quality living conditions. Consequently, there is a growing emphasis on utilizing plants, as highlighted by Wang Xiaoman et al. [1], who conducted a detailed survey of garden plant resources in Shuyang County. Due to urban land constraints, rooftop gardens have emerged as a prominent urban greening form. They not only improve local environments but also bring various benefits to residents and cities alike. Shaanxi's Guanzhong region, a crucial agricultural area situated at the northern foot of the Qinling Mountains, features unique terrain and climate characteristics. The construction and improvement of habitat environments in this region have garnered significant local attention.

Taking Yangling Agricultural Demonstration Zone in the Guanzhong region as an example, the accelerated urbanization has increased the area of hardened surfaces, exacerbating issues such as sandstorms and flooding due to the Qinling Mountains blocking cold and moist air from the north and sand and dust. Rooftop gardens, with their unique vertical greening model, offer advantages such as minimal ground area usage and significant development potential, presenting new solutions to these habitat challenges.

Nevertheless, variations in natural conditions such as climate and soil across different regions result in considerable differences in suitable plant species for public green spaces, including rooftop gardens. Moreover, local economic conditions influence the development and prospects of rooftop gardens. Therefore, it is imperative to study plant configurations suitable for rooftop gardens in the Guanzhong region, summarize principles for optimal plant selection, and analyze their role in improving habitat environments, enhancing ecological benefits, extending building lifespans, and providing emotional value. This research aims to provide a scientific basis for the construction of rooftop gardens in the Yangling area.

2. Feasibility of Constructing Rooftop Gardens in Yangling Demonstration Zone

2.1. Climate Conditions in Yangling Demonstration

Yangling Agricultural High-tech Industry Demonstration Zone belongs to the East Asian warm temperate semi-humid and semi-arid climate zone, characterized by windy springs, hot and rainy summers, cool autumns with prolonged cloudy and rainy days, and cold, dry winters typical of temperate continental monsoon climates. The annual mean temperature is 12.9°C with a frost-free

period of 211 days. It receives an average annual sunshine duration of 2164 hours, total solar radiation of 114.76 kcal/m²/year, average annual precipitation of 835 mm, and evaporation of 993 mm [2].

Table 1. Monthly Average Temperature, Wind Speed, and Precipitation in Yangling Demonstration Zone in 2023

Month	High Temperature (°C)	Low Temperature (°C)	Air Quality	Wind Speed (km/h)	Precipitation (mm)
1	7	-4	175	5.9	4.4
2	9	-1	142	6.9	13
3	18	4	62	6.8	0.6
4	21	8	69	8	267.7
5	24	13	44	8	96.4
6	30	17	68	7.7	37.9
7	33	21	63	8.2	310.3
8	32	21	49	7.9	14.1
9	27	17	41	6.5	14.1
10	21	10	48	6.4	7.7
11	15	2	67	7.5	2.2
12	6	-4	104	7.2	5.6

Yangling's dry and windy climate conditions during winter and spring impose specific requirements on the wind resistance and lodging resistance of plants in rooftop gardens. The hot and rainy summers easily lead to pest and disease issues, demanding plants with high resistance capabilities.

Moreover, Yangling experiences an annual average precipitation of 835mm and a high evaporation rate of 993mm. With minimal precipitation in March (only 0.3mm), constructing rooftop gardens in the area faces significant drought challenges. Therefore, selecting drought-tolerant plants, ensuring reliable and convenient irrigation facilities, and considering the local climate characteristics are crucial for the sustainability and ecological benefits of rooftop gardens.

The climatic conditions in Yangling Demonstration Zone pose certain challenges for rooftop garden construction, necessitating the scientific selection of plant species that are suitable for local conditions and comply with principles of rooftop garden plant configuration. It is essential to integrate these choices with rational management and irrigation practices tailored to local climate characteristics to ensure the sustainability and ecological benefits of rooftop gardens.

3. Principles and Strategies for Rooftop Garden Plant Configuration

Plant configuration in rooftop gardens requires enhancing the rationality of plant combinations to ensure both garden aesthetics and plant survival rates [3]. Specifically, the following principles should be observed:

3.1. Principle of Plant Ecological Adaptation

For plants to grow normally in a rooftop garden, the environment must not exceed the plants' maximum ecological adaptability and range. Under this condition, the closer the rooftop garden environment is to the plants' original growth environment, the better the plants will grow, resulting in higher landscape aesthetics and ecological benefits.

Plants must thrive within the rooftop garden environment without exceeding their maximum ecological adaptation capacity. In Yangling, considerations should focus on several aspects:

1. Cold resistance: Given the cold winters and springs in Yangling, with prolonged periods of sub-zero temperatures, priority should be given to plants resistant to cold. Selecting plants capable of withstanding low temperatures and avoiding frost damage ensures normal growth during cold seasons.

2. Drought resistance: Considering the semi-arid climate of Yangling and the high evaporation rates due to strong sunlight and high wind speeds, plants in rooftop gardens must exhibit significant drought resistance. Choosing species that efficiently utilize water resources during dry seasons reduces dependency on external irrigation, conserving valuable water resources in the Northwest region.

3. Wind resistance and lodging resistance: Yangling's windy springs necessitate plants in rooftop gardens to possess strong wind and lodging resistance characteristics. Opt for robust plants with sturdy stems to minimize damage and lodging caused by strong winds.

3.2. Principle of Building Safety Priority

While rooftop gardens enhance ecological and emotional values and improve habitat environments, ensuring building and user safety remains paramount during their construction. Effective landscape utilization hinges on maintaining safety while enjoying the benefits of rooftop gardens [4]. Consider the following aspects during plant configuration and construction:

1. Prefer shallow-rooted tree species: Plants in rooftop gardens should be planted within a substrate layer. The thickness of the substrate layer directly affects the load-bearing capacity of the roof slab. Extensive root systems may penetrate waterproof layers and undermine load-bearing capacities, posing serious safety hazards.

2. Opt for shrubs and small trees: Larger plants exert greater weight and require thicker cover layers. Choosing shrubs and small trees prevents exceeding load capacities [5]. Moreover, avoiding large trees mitigates risks associated with falling branches, ensuring safety for users and preventing potential hazards of falling debris.

3. Choose slow-growing tree species: Slow-growing plants have root systems that expand gradually, remaining within the substrate layer and not penetrating waterproof layers or structural slabs. This minimizes threats to building safety. Slow-growing plants also reduce the frequency of pruning and maintenance, lowering operational costs and labor while preserving root health.

In addition to optimizing building safety through plant configuration, employing engineering techniques can also safeguard rooftop gardens:

1. Use lightweight landscape ornaments: Heavy landscape elements (e.g., rockeries, pergolas, fountains) impose specific load requirements and affect the center of gravity, complicating design and construction. Substitute smaller ornaments, such as sun umbrellas, for load-limiting pergolas or employ terrain undulations covered with lawn to replace rockeries.

2. Utilize main load-bearing structures: Position heavier plants, terrains, and landscape ornaments above primary load-bearing columns, beams, and walls. Transmit weight to these major load-bearing components to enhance building stability and safety.

3. Employ low-density cushion layers and substrates: Substitute garden soil and peat soil, which are heavy and absorbent, with lightweight substrates composed of gravel, wood chips, or vermiculite. For instance, the Guizhou Dushan County Government Center rooftop garden utilizes a cultivation formula of light soil: peat soil: sawdust: perlite = 5:3:1:1 to reduce rooftop loads.

3.3. Principles of Maintenance and Management Simplification

Roof gardens are green spaces constructed on small platforms atop residential buildings, where the use of machinery like lawn mowers for trimming is impractical. Maintenance heavily relies on manual efforts, including trimming, irrigation, fertilization, and overall garden management. Therefore, the initial plant selection plays a crucial role in reducing the time, labor, and material costs required for maintaining roof gardens. Several aspects of plant suitability should be considered for achieving simplified maintenance and management:

1. Drought Tolerance:

Fertilization in roof gardens poses significant challenges. Firstly, it involves substantial labor that users alone find difficult to manage. Secondly, fertilization inevitably disrupts the soil layer and damages ground cover plants, thereby compromising landscape aesthetics. Thirdly, certain fertilizers emit distinct odors, rendering roof gardens inaccessible during and shortly after fertilization. Addressing these concerns, selecting plants resilient to nutrient-poor environments during the initial design phase of roof garden vegetation is crucial and effective.

2. Leaf Drop:

Leaf clearance is a critical consideration not only for street trees but also in the design of roof garden plantings within urban residential environments. Roof gardens, often built on platforms adjacent to residential buildings, have limited space, making leaf clearance labor-intensive and cumbersome, with potential safety hazards from falling leaves. Opting for ground cover and evergreen shrubs during plant selection reduces the workload associated with leaf removal while maintaining the winter landscape.

3. Disease Resistance:

Given that roof gardens are integral to residential environments and closely integrated with residential areas, minimizing diseases and pests by selecting plants with strong disease and pest resistance is essential.

Firstly, robust disease and pest-resistant plants facilitate healthy growth, reducing the impact of diseases and pests, thereby enhancing landscape aesthetics and overall quality.

Secondly, choosing these plants helps prevent the spread of diseases and pests indoors, maintaining indoor cleanliness and enhancing residents' quality of life.

Thirdly, reliance on chemical pest control measures is minimized, reducing risks of pollution to human health and the environment, and fostering environmentally friendly residential spaces.

Establishing an ecologically healthy environment through the selection of disease and pest-resistant plants promotes a comfortable and safe leisure space for residents, thereby enhancing physical and mental well-being and quality of life.

4. Slow Growth and Pruning Tolerance: Selecting plants that grow slowly and tolerate pruning offers several advantages:

Control over plant height: In roof gardens with limited space, slow-growing tree species facilitate easier control of tree height, preventing excessive growth that may hinder surrounding plant growth or obstruct sightlines.

Reduced pruning frequency: Opting for plants resilient to pruning means they adapt better to pruning, minimizing the negative impact of frequent and heavy pruning, significantly reducing maintenance efforts and frequency in roof gardens.

Aesthetic enhancement: Slow-growing tree species, when pruned, maintain attractive forms suitable for bonsai or neatly trimmed orderly landscapes, enhancing garden aesthetics and visual appeal.

Reduced tree competition: Planting slow-growing tree species in limited spaces reduces competition among trees, preventing overcrowded root systems that may hinder plant growth and soil health.

Increased tree stability: Slow-growing tree species typically have sturdy trunks and stable structures, better withstanding wind and external environmental factors, thereby enhancing tree growth stability in roof gardens.

3.4. Planting Strategy Focused on Herbaceous Ground Cover Plants

This strategy involves selecting fast-growing and effective ground cover plants such as Bermuda grass (*Cynodon dactylon*), white clover (*Trifolium repens*), dandelion (*Taraxacum officinale*), and carnation (*Dianthus plumarius*). These plants quickly form a green carpet, enhancing the overall aesthetic of roof garden landscapes right from the initial construction phase.

Ground cover plants possess strong shading capabilities, effectively covering exposed soil surfaces and reducing the risk of soil erosion. Additionally, they exhibit good water retention, efficiently absorbing and storing water, thus maintaining good growth even in dry conditions. This feature is advantageous for alleviating water scarcity in landscaped environments.

Furthermore, selecting ground cover plant varieties that are tolerant to pruning and resilient to adverse conditions significantly reduces the maintenance workload. These plants typically grow rapidly, require less frequent pruning, and withstand pests and unfavorable weather conditions, thereby facilitating easier management.

3.5. Planting Strategy Integrating Flower Beds and Fruit/Vegetable Cultivation

Flower beds simulate the mixed growth patterns of wildflowers on forest edges in natural settings [6]. The development of flower beds has become increasingly refined, categorized based on plant materials used, duration of attractiveness, colors, light requirements, moisture levels, and functional aspects.

Considering the unique characteristics of Yangling's roof garden environment, several suitable types of flower beds include:

Perennial Flower Beds: Perennial flowers exhibit strong adaptability, thriving and growing even under drought conditions. Their well-developed root systems enhance water absorption from the soil, reducing evaporation losses. Perennial flowers have longer growth cycles, some flowering across three seasons, offering sustained aesthetic value over extended periods and minimizing the need for frequent plant replacements.

Ornamental Grass Flower Beds: Ornamental grasses feature deep roots and wide leaves, adapting well to dry environments. Their stems and leaves exhibit strong drought resistance, minimizing water evaporation. With diverse forms including tall grasses like *Leymus condensatus* and clump-forming grasses, ornamental grasses add layers to roof garden landscapes, optimizing visual appeal.

Xeriscape Flower Beds: Plants in xeriscape flower beds are typically drought-tolerant varieties. Design emphasis is on water conservation and retention, employing suitable irrigation systems and covering materials to reduce water evaporation and waste. Xeriscape flower beds create distinctive garden styles adapted to arid regions by selecting plants that thrive in dry conditions and employing rational layouts, reducing dependence on water resources.

In the development of roof gardens, the cultivation of fruit trees and vegetables initially began in secluded corners of rooftops. As roof gardens evolved, those featuring fruit and vegetable cultivation grew more prevalent. Apart from greening benefits, they also offer substantial economic returns. Fruit and vegetable cultivation enhances the functionality of roof gardens, creating more recreational and leisure spaces for users [7].

4. Roof Garden Benefits

4.1. Building Benefits

Roof gardens play a significant role in lowering indoor temperatures and extending the lifespan of buildings. Jiang Jing's software simulations revealed that during winter, buildings with roof gardens maintained higher indoor and surface temperatures compared to those without roof gardens. Conversely, in summer, buildings with roof gardens consistently had lower surface temperatures, with differences reaching up to 1.53 degrees Celsius [8]. This indirectly confirms that roof gardens contribute to maintaining appropriate temperatures for building usage, preserving the initial performance of roof materials, and enhancing the overall lifespan and stability of buildings. Additionally, roof gardens constructed using special methods can serve as seismic strengthening structures. Liu Jianhong et al. explored roof garden seismic mitigation methods based on liquefied soil, utilizing the viscous fluid properties exhibited by saturated liquefied soil to design roof gardens as tuned liquid dampers [9].

4.2. Ecological Benefits

Roof gardens serve as supplements to urban green spaces, offering a beneficial approach to improving living environments and effectively addressing urban green space shortages, thereby increasing urban green coverage [10]. Through research on the

ecological benefits of roof gardens and their greening plant configurations, Cui Jie found that constructing roof gardens is an effective means of enhancing ecology. They scientifically evaluated the capabilities of 25 commonly used greening plants in roof gardens, measuring their abilities in carbon sequestration, oxygen release, temperature reduction, humidity increase, dust suppression, and absorption of harmful gases [11]. By conducting scientific research and strategically configuring greening plants in roof gardens, their ecological benefits can be maximized.

Simultaneously, roof gardens and their irrigation systems maximize rainwater interception on rooftops and platforms, reducing urban surface runoff, mitigating urban flooding, and lowering the risk of rainstorm flooding. Plants in roof gardens exhibit good water retention capabilities, effectively absorbing and storing water to reduce water waste. Through scientific irrigation management, water-saving irrigation practices can be implemented to enhance water resource utilization efficiency.

5. Discussion and Prospects

Roof gardens, particularly exemplified in the Yangling Demonstration Zone in the Guanzhong region, demonstrate significant feasibility and potential. The key lies in selecting plants suitable for planting based on local climate conditions and specific rooftop garden microenvironment characteristics. Plant selection considerations include ecological adaptability, building safety, and ease of maintenance and management principles. Strategies focusing on herbaceous ground cover, flower beds, and integrating fruit and vegetable cultivation are viable choices.

The construction of roof gardens positively impacts building efficiency by reducing indoor temperatures, prolonging building lifespan, and providing shock absorption benefits. In terms of ecological benefits, roof gardens increase urban green coverage, improve living environments, mitigate urban heat island effects, reduce rainstorm flooding risks, purify air, and facilitate carbon sequestration and oxygen release.

However, challenges persist in the construction and management of roof gardens in the Guanzhong region, necessitating further research. Challenges include selecting plant species adapted to arid conditions, rational use of limited water resources for irrigation, and balancing roof garden integration with building safety. Moreover, additional research is needed on the ecological and economic benefits of roof gardens in the Guanzhong region, as well as their promotion and application in social awareness and urban planning.

The construction and management of roof gardens in the Guanzhong region hold immense potential. Through scientific plant configurations and proper management practices, roof gardens can provide local residents with improved living environments, enhance ecological benefits, and promote sustainable development. Future research and practices should further explore suitable roof garden construction models and management strategies for the Guanzhong region to achieve optimal benefits and sustainability.

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