Evaluation of Growth and Green Coverage of Ten Ornamental Species for Planting as Urban Rooftop Greening

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Rooftop gardening or green roof establishment, one of the afforestation methods for urban greening, has many benefits for the environment, economy, and urban landscape. Various environmental stresses including heat, strong wind, sunshine and drought prevent most plants from growing well with extensive green roof systems. For the establishment of urban rooftop gardening in summer, we evaluated ten ornamental plant species (Evolvulus pilosus, Fragaria × ananassa, Hedera helix, Lampranthus spectabilis, Ophiopogon japonicus, Pelargonium × hortorum, Petunia × hybrida, Thymus serphyllum, Verbena × hybrida, Vinca major) to use for greening with shallow soil (10 cm depth) on the flat rooftop of a four-story building. We measured the area increase in green coverage as a total growth rate, photosynthetic ability of detached leaves, stomatal conductance of an attached leaf, soil surface and canopy air temperature. Thymus, Evolvulus, Petunia, and Fragaria are excellent plant species for rooftop gardening judging from their speedy green coverage with high growth rates (90% in Thymus, 65% in Evolvulus, 60% in both Petunia and Fragaria at maximum for about three months in summer). Thymus and Fragaria showed high performance of water saving with relatively low stomatal conductance under semi-dry conditions and did not need to be replanted every year unlike Evolvulus and Petunia. Evolvulus had the highest photosynthetic activity at 40°C. Petunia and Verbena did not grow continuously but maintained active blooming without increasing their green coverage (about 60%) throughout midsummer. Lampranthus tolerated extremely hot and dry conditions on the rooftop but grew very slowly. As Vinca and Pelargonium died back due to both heat stress and strong wind, we suggested these were not suitable for rooftop gardening. All vegetations showed a 6–8°C lower temperature of soil surface than that of the concrete rooftop during summer nights. We concluded that rooftop greening has a significant effect on cooling a building and saving energy for air-conditioning in summer.

Key Words: afforestation, green roof, heat-island effect, photosynthesis, stomatal conductance.

Introduction

Rapid urbanization in Japan was caused the severe environmental destruction to become a serious problem. In urban areas, high night temperatures caused by the heat-island effect makes it difficult to live there comfortably in summer. A practical way to cope with the heat-island phenomenon is urban greening, but available space for greening is limited to rooftops and outside walls of buildings. Rooftop gardening is expected to reduce absorption of excessive solar energy, resulting in a significant energy saving for air-conditioning in a building. Wong et al. (2003) showed that green coverage reduced both the room temperature and the air-conditioning costs under the rooftop. Consequently it contributes to mitigating the urban heat-island effect. In addition, vegetation on the roof improves the prevailing dry climate in a city with humidification by their transpiration and also contributes to air purification. Recently, just as the role of indoor plantscapes comes to be recognized scientifically as it improves the physical environment and reduces the mental stress level in living spaces (Park et al., 2008), so rooftop gardening has additional benefits such as aesthetics and an increase in biodiversity. Rooftop gardening has been most prevalent in Germany where various Sedum spp., grasses, and herbaceous perennials are planted with very shallow substrates (Monterusso et al., 2005). Panayiotis et al. (2003) investigated the efficacy of substrate constituents as roof garden vegetative layers to sustain growth of Lantana camara.
Recently in Japan, Turf and Sedum became popular as vegetation for rooftop green coverage. But turf must be cut periodically during the summer and blooming must not be attractive. Sedum has been most commonly used as a greening plant because it is very tolerant to extremely high temperatures, low fertility, and a limited water supply under the dry climate prevailing on rooftops. VanWoert et al. (2005) reported that some Sedum species lived 88 days without irrigation on rooftops. However, they grow very slowly because of their facultative crassulacean acid metabolism (CAM) photosynthetic characteristic, and Sedum stems are easily blown away by strong winds and then root as a weed around the building. Some Sedum spp. can bloom but they are limited in both flower color and blooming season. If we therefore want good vegetation on rooftops to mitigate the urban heat-island effect and to improve the aesthetic quality of the urban environment, we must choose adapted plant species that grow easily with beautiful plantscapes to establish green coverage on rooftops in the extremely hot summer.

There are two kinds of rooftop gardening, intensive and extensive management (Panayiotis et al., 2003). Intensive green roof uses a planting ground with thick soil to enable many kinds of plants including trees to grow. To establish a thick soil layer on a rooftop, the rooftop foundation must be improved at great expense. On the other hand, extensive green roof uses a planting ground with shallow and light substrates without significant structural alteration to the building. Only limited plant species can grow in the shallow soil or substrate layer with a little water holding capacity, so we must irrigate frequently. We have to select plants that have high drought tolerance. As such, the intensive green roof can use more plant species but at greater cost for maintenance of rooftop gardening than extensive one. Recently, mat plants have been used for rooftop gardening (Shibata, 2001). The morphological benefits of these plants are that they make roots in a shallow layer like a fibrous mat. Mat plants are very light and thin, so they are good for use as a greening plant for extensive green roofs. Additionally, greening with them is very fast because of their easy establishment. But making mat plants has been limited to a small number of ground cover plant species. We need more information about greening plants that grow quickly and thrive on the rooftops of buildings with an extensive maintenance.

The objective of this research was to evaluate the availability of greening plant species suitable for extensive rooftop gardening, by comparing the area of green cover as a growth index, photosynthesis, transpiration, and temperatures of soil surface and canopy of ten plant species cultivated with shallow soil on the rooftop of a four-story building.

Materials and Methods

Plant materials and planting ground
Ten plant species [(Evolvulus pilosus L. ‘American Blue’, Fragaria × ananassa Duch. ‘Summer Berry’, Hedera helix L. ‘Golden Child’, Lampranthus spectabilis Haw., Ophiopogon japonicus L., Pelargonium × hortorum L. ‘H. Bailey ’P. zonale F. Pinto strain’, Petunia × hybrida hort. Vilm. ‘Bluette’ (Daiichi Engei Co., Ltd.), Thymus serpyllum L., Verbena × hybrida Voss ‘Hanatemari’ (Suntory Holdings, Ltd., Osaka, Japan), Vinca major L.)] were grown in containers on the flat rooftop of a four-story building located in an urban area of Kobe city from May 22 to October 20, 2006. Plant growth conditions were under full sunlight and windy on the rooftop surrounded by no buildings or obstacles. The rooftop surface was very hot in summer because it was made from dark colored concrete. Each planting ground was 90 × 45 cm size and 10 cm depth filled with constituent substrates of 3 : 4 : 3 as volume ratio of reddish soil, leaf mold, and vermiculite, respectively (Fig. 1). Both soil component and depth were determined by considering a lightly loaded planting on the rooftop structure. A permeable barrier sheet and wire net were set at the bottom of the container to hold substrates and to drain well. All plant materials were obtained from a local nursery as seedlings. The average seedling height was about 10 cm, established in a 9-cm-diameter vinyl pot. Eight seedlings for each species were planted 20 cm apart in two rows in half the area of the container. Irrigation was done every day for one month to allow rooting. After taking root, each container was watered with 5 L every other day for plants not to be subjected to water stress. A rainy day (more than 5 mm precipitation) was treated as an irrigation day. Delayed-release fertilizer (N : P : K : Mg = 6 : 40 : 6 : 15, one-year-effect) was applied to each plot at a rate of 200 g·m⁻² as a base dressing. Additional fertilization was not used during the cultivation period. At the same time, 5 g·m⁻² of Diazinon granular (10% active ingredient, Nippon Kayaku Co., Ltd., Tokyo, Japan) was applied as a pesticide. Weed and pest insects were controlled by hand.

![Fig. 1. A design for planting with a cultivation bed on a rooftop.](image)
Pinching was done once a week as needed to stimulate branching for about one month from planting, especially for *Evolvulus*, *Pelargonium*, *Petunia*, *Verbena*, and *Vinca*. The upright elongating spindly shoots were removed to keep the canopy height below 20 cm. All dead leaves, flowers, and branches were also removed. All measurements were started from May 22 and continued to October 20. To evaluate the planting suitability as a greening plant for rooftop gardening, the ratio of green coverage, photosynthetic ability, and leaf conductance at different leaf temperatures, and temperatures of soil surface and ambient air at 15 cm above the soil surface were measured.

**Area estimation of green coverage**

To estimate the area of green coverage, planting plots were photographed with a digital camera from directly overhead. Capture timing was unified at twilight in order to unify the contrast of all pictures and to avoid shadows, but flash photography was not used. The area of green coverage in each planting plot was measured by computer processing of the picture. To calculate the area, a picture was converted to monochrome (greening area to black and bare ground to white) with Adobe Photoshop 5.0 (Adobe Systems, Inc., CA, USA). Then, it was prepared to estimate percent area covered with vegetations by using an image processing software, ImageJ (National Institutes of Health, MD, USA). Green coverage was calculated on the pixel basis of a photograph.

**Canopy and soil surface temperatures**

To evaluate the potential effect of green coverage on cooling ambient and rooftop surface temperatures in summer, we monitored temperatures of the soil surface under the canopy and ambient air at 15 cm above the soil surface every twenty minutes with button-shaped temperature data loggers (Thermochron, KN Laboratories Co., Osaka, Japan) on a typical summer sunny day on August 24. Data loggers were wrapped with aluminum foil to avoid exposure to direct sunshine. At the same time, temperatures of surface and ambient air at 15 cm above the concrete rooftop were monitored in the same way. Official weather data in Kobe city (Fig. 2) obtained from Kobe Marine Meteorological Observatory (at latitude of N34°41′8″ and at longitude of E135°12′7″) showed maximum and minimum air temperatures of 32.8°C and 25.2°C, an average relative humidity of 59%, an average wind velocity of 2.5 m·s⁻¹, and sunshine duration of 12.4 h.

**Photosynthetic ability**

To evaluate the potential growth activity at extremely high temperature on the rooftop, the oxygen evolution rates of detached leaves were measured by using the gas-phase oxygen electrode method (Hansatech system, Norfolk, UK) under CO₂ (5%) and light (1500 μmol·m⁻²·s⁻¹ photosynthetic photon flux density (PPFD)) saturated conditions. Measurements were done with mature leaves fully expanded between August 30 and September 11. The oxygen evolution rates were measured at 40°C to evaluate as maximum photosynthetic capacity in typically hot summer and at 25°C as a control. Mature leaves were cut then immediately put them into a constant-temperature chamber to measure photosynthetic oxygen evolution rates. Leaves were quickly weighed after being measured. We repeated the measurement five times at each temperature.

**Leaf conductance of transpiration**

To evaluate normal leaf conductance as a measure of plant species’ suitability for extensive culture on the rooftop, a very dry and windy postplanting environment, stomatal conductance of an attached leaf and leaf temperature were measured with a SC-1 Leaf Porometer (Decagon devices, Inc., Pullman, WA, USA) under the

![Fig. 2. Daily solar radiation and maximum air temperature during the research of rooftop gardening in 2006.](image-url)
rooftop conditions. As leaf temperatures of most plants were over 35°C and they kept their stomata closed even in the morning on sunny-warm days in August, conductance measurements were conducted in the morning (average leaf temperature of 27±1°C) in sunny days on October 19 and 20 with five mature unfolded leaves for each plant species. All plants were irrigated sufficiently on the day before measurements. Air temperature was between 18.5 and 25.0°C. Conductance of each adaxial or abaxial side of a leaf was measured separately and was recorded as an average value of both surfaces. The succulent leaves of *Lampranthus* were too thick to be measured with this porometer.

**Results**

*Area of green coverage*

We measured the areas of green coverage on May 22, June 12, July 10, August 7, and September 4. The daily mean air temperature and the number of sunshine days throughout the experiment were 14.6 to 23.2°C and 19 days in May, 20.9 to 26.6°C and 21 days in June, 22.5 to 29.7°C and 19 days in July, 26.8 to 31.7°C and 25 days in August, and 21.6 to 29.2°C and 21 days in September (Fig. 2). As the variation in area ratio of green coverage at transplanting stage was unignorable among species, we calculated the rates of increase in area ratio of green coverage from transplanting stage on May 22 to the growing stage during the intensely hot period (average value obtained on September 4 and August 7). Increase rates were −18% in *Vinca*, −69% in *Pelargonium*, 1% in *Verbena*, 27% in *Lampranthus*, 24% in *Hedera*, 81% in *Ophiopogon*, 72% in *Thymus*, 95% in *Evolvulus*, 100% in *Petunia*, and 119% in *Fragaria*, respectively. We classified the ten species into four types according to the significant differences among these increase rates of green coverage (Fig. 3).

Type I includes *Thymus*, *Evolvulus*, *Petunia*, and *Fragaria*, all of which had increase rates over 70% and grew well from early to middle summer. These species are very suitable for rooftop gardening in summer. From August 7 to September 4, the area ratio of green coverage with *Thymus* decreased slightly, while the other three kept growing. *Thymus* had the highest coverage (90%) and a quite high density of leaves. The other three species showed almost the same increases in area of green coverage and their green coverage finally reached to at least 50%.

Type II includes only *Ophiopogon* that was distinguished as being different from Type I based on its very slow growth and small area of green coverage (36%) even though it had a high increase rate of green coverage. Though *Ophiopogon* grew well especially during the middle of summer from August 7 to September 4, this species didn’t satisfy the desired growth characteristics of large increases in both growth rate and the area ratio of green coverage in the short term.

Type III includes *Hedera*, *Verbena*, and *Lampranthus*, all of which had increase rates below 30%. They didn’t grow well but kept their vegetations a little higher than in the transplanting stage. *Verbena* could keep growing during the hottest period from August 7 to September 4 with final area of green coverage of 60%. By contrast, *Hedera* and *Lampranthus* showed small decreases in their areas of green coverage during the same period. Although most of test plants in this study showed no or negative growth during the hottest summer, both

![Fig. 3. Changes in the area percentage of green coverage with ten ornamental species. Data were shown as an average percentage of total green coverage with each plant species (n=8) to a cultivation bed area (20×20 cm) by using a digital image analysis. Bars show SE.](image-url)
Ophiopogon and Verbena kept growing even in the lingering heat conditions on the rooftop in summer.

Type IV includes Pelargonium and Vinca, both of which showed decreasing rates of green coverage increase from July 10 to September 4 and finally showed the decreased areas of green coverage compared with at transplanting stage. High ambient temperature and windy conditions on the rooftop made them turned down and run dry. So they seem not to be suitable for rooftop gardening.

**Canopy and soil surface temperatures**

Changes in soil surface temperature and canopy air temperature at 15 cm above the soil surface were measured on a typical summer day on August 24 (Fig. 4). We found four representative tendencies of those diurnal changes classified based on the significant differences in diurnal temperatures (11:00 to 15:00) as group-1 (Lampranthus and Thymus), group-2 (Hedera and Verbena), group-3 (Evolvulus, Vinca, and Ophiopogon), and group-4 (Petunia, Pelargonium, and Fragaria). During daytime (6:00–18:00), the temperature of the concrete surface was highest and reached up to 50°C at 15:00, which was about 20°C higher than the air temperature at the same time. Diurnal temperature of soil surface with vegetation rose up to 30–40°C at maximum. Comparing the maximum temperatures within the four groups, Lampranthus showed the highest temperature of about 14°C higher, Hedera showed the second highest of about 10°C higher, Evolvulus showed the third highest of about 7.5°C higher, and Petunia showed the lowest of about 3°C higher than air temperature. Their soil surface temperatures decreased about three hours earlier than ambient air temperature in the late afternoon. During nighttime (18:00–6:00), air and concrete surface temperatures were almost the same and were 6–8°C higher than those of the vegetated soil surface. There were no significant differences of temperatures in all species.

Canopy air temperatures at 15 cm above the soil surface with vegetation were about 5°C higher than air temperature on the rooftop at daytime. The differences of canopy temperature within plant species were smaller than those at the soil surface, especially in the daytime. Compared with temperatures at the soil surface, diurnal changes in canopy temperature were smaller due to quick heat exchange by the strong wind.

**Photosynthetic ability**

Evolvulus, Fragaria, and Verbena showed high photosynthetic ability at 25°C (Fig. 5). Only Evolvulus kept the highest rate at 40°C. Photosynthetic ability of Fragaria decreased with increasing temperature and the rate measured at 40°C was about 74% of that measured at 25°C. So Evolvulus seems to maintain higher photosynthetic performance than Fragaria at extremely high temperatures. As mentioned previously, the soil surface temperature of Evolvulus vegetation reached up to about 35°C in very hot daylight. Evolvulus is able to grow under scorching hot conditions on the rooftop. Verbena had a high photosynthetic ability at 25°C but the rate at 40°C decreased to 76% of that measured at 25°C. Hedera, Thymus, Pelargonium, Vinca, and

![Fig. 4](image-url)  
**Fig. 4.** Soil surface temperature (A) and canopy air temperature at 15 cm above soil covered with vegetation (B) measured on August 24 (a typically hot summer day). Soil surface temperatures are shown for four representative species, which diurnal temperatures were significantly different (Average ± SE measured from 11:00 to 15:00, 41.4 ± 0.7°C for Lampranthus, 37.2 ± 0.4°C for Hedera, 34.9 ± 0.5°C for Evolvulus, 32.6 ± 0.4°C for Petunia, Tukey-Kramer HSD multiple range test, P < 0.05, n = 15). Solid smooth line shows the air temperature and dotted smooth line shows the surface temperature of the concrete rooftop.

![Fig. 5](image-url)  
**Fig. 5.** The photosynthetic ability of detached leaves measured at 25°C and 40°C by oxygen electrode method. Bars show SE (n = 5). Significant differences within ten species are shown in uppercase (25°C) and in lowercase (40°C) characters (Tukey-Kramer HSD multiple range test, P < 0.05). Difference between two temperatures is shown with an asterisk on the species name (Student T-test, P < 0.05).
Leaf conductance of transpiration

Leaf conductance is shown in Figure 6 as an average value measured at 27 ± 1°C of leaf temperature at morning in mid-October. During the extremely hot days in August, leaf temperatures of most plants quickly rose too high to close stomata even in the morning as air temperature rose on the rooftop conditions (data not shown). We evaluated the data measured for plants under actual growing conditions with shallow soil as a drought stress. Leaf conductance of transpiration rates. As Thymus and Evolvulus are more suitable than Thymus and Petunia based on their high photosynthetic abilities. Evolvulus, especially, had a significantly higher photosynthetic ability at 40°C leading to high increase rate of green coverage (95%). However, Evolvulus must be planted every spring because it is an annual species in Japan. As Thymus and Fragaria are perennials, we can use them to establish continuing extensive rooftop gardening with low maintenance for years. Thymus has a low photosynthetic ability leading to the lowest increasing rate of green coverage (72%) compared with other Type I species (about doubling), however, it kept the highest area ratio of green coverage with low transpiration rates. As Thymus has high drought tolerance and generally grows well under semi-dry conditions, rooftop gardening with Thymus is expected to provide good effects from the psychological and physiological aspects for rooftop gardeners.

Fragaria also had a high photosynthetic ability leading to a high increase rate of green coverage (119%), but its area increase of green coverage retarded during midsummer. As leaf conductance was not so high at 27°C of leaf temperature, its growth might be inhibited due to further decreasing of conductance at higher leaf temperatures. Kadir and Sidhu (2006) showed a significant inhibition of the assimilation rate due to a large decrease in stomatal conductance of Fragaria grown at high temperatures (40/35°C at day/night).

The growth and the flowering of Petunia were inhibited by low irrigation, but those of Verbena were unaffected by irrigation level (Henson et al., 2006; Scheiber and Beeson, 2006). The amount of irrigation or precipitation largely affects the plant growth. Both Verbena and Petunia flowered well on the rooftop with a lot of sunshine. We think that rooftop gardening with flowering plants attracts butterflies and other insects. Brenneisen (2004) confirmed that rooftop gardening in urban areas contributes to improving the ecosystem with biodiversity, which was previously lost by buildings construction.

In the Okinawa subtropical climate, some subtropical groundcover plants (Wedelia trilobata, Stenotaphrum secundatum, Ophiopogon) are suitable for rooftop greening (Fujiwara et al., 2007). Ophiopogon, which is a perennial species originating from Japan and is considerably tolerant to extremely hot or cold climate and windy conditions, can be easily grown without pruning or intensive cultivation management. It grows on the soil surface like turf, having short stems and many
long leaves. The increase rate of green coverage with *Ophiopogon* is as high as those of other plants classified into Type I, but it has very slow growth with a final area of green coverage of only 37%, which is lower than all except the Type IV species. *Ophiopogon* spreads its rhizomes just beneath the soil surface and consequently can grow in the shallow soil used preferentially for the rooftop gardening.

Type III plant species including *Hedera*, *Verbena*, and *Lampranthus* are not bad for the rooftop gardening except for their retarded growth with low increasing rates of green coverage of 30% or less. *Hedera* is a perennial ivy, which usually creeps on garden fences and covers building walls. Owing to its lateral growth character, it is suitable for planting on the rooftop. However, under strong wind conditions prevailing on a rooftop, stems of *Hedera* hardly take root because its very short roots from stem nodes might be easily blown off by the wind. Some *Hedera* species have absorption roots on their stem nodes to fix and climb on the wall. These species can easily take root on the ground. Additionally, *Hedera* is a drought tolerant species and its stomatal conductance was lowest among the ten ornamentals tested. These growth characteristics might make it suitable for rooftop gardening under windy conditions.

*Lampranthus* is a succulent plant and grows laterally with its creeping stem. This plant is remarkably tolerant to extremely high or cold temperature and dry conditions. The canopy temperature of this plant less decreased due to a lack of quick exchange of the warm air within the packed canopy. We evaluated *Lampranthus* as a suitable greening plant for rooftop gardening based on its easy establishment with extensive culture management and shallow soil, but it requires long-term cultivation because of its slow growth with very low CAM photosynthetic ability and low area ratio of green coverage of 50% or less.

Both *Pelargonium* and *Vinca* in Type IV died back due to both heat stress and strong wind prevailing on the rooftop. Both species have relatively low photosynthetic ability at high temperatures. *Pelargonium* showed a quick die back during midsummer because of its high transpiration demand in the morning when leaf temperature was still below 30°C. We determined that these two species are not suitable for rooftop gardening.

In conclusion, we attempted to evaluate some ornamentals as planting materials suitable for extensive rooftop gardening based on area of increase in green coverage affected by some physiological traits in which photosynthetic ability was measured at 40°C and leaf conductance was measured at 27°C (normal growth temperature). *Evolvulus*, *Fragaria* and *Thymus* seem to have a relatively high water-conserving capacity without quick transpiration under dry and windy rooftop conditions. The first two have also high photosynthetic ability at extremely high temperatures, but the latter has relatively low ability so its growth becomes slow. *Petunia* does not have a high photosynthetic ability at either 25°C or 40°C and was a relatively low water-conserving capacity with quick transpiration. These traits are thought to make it unsuitable for planting in shallow soil under dry and windy rooftop conditions. The other six species showed no good growth in shallow soil extensive culture under the rooftop conditions.

Finally, we also evaluated the suitability of these ornamentals as planting materials for rooftop gardening by considering the effect of cooling ambient temperature. One of the benefits of rooftop gardening is cooling the ambient temperature inside or outside a building. Liu and Minor (2005) reported that the green roofs reduced a building’s energy demand by lowering the heat flow into the top floor just below the roof, especially in summer. *Petunia* and *Evolvulus* showed a high efficiency of decreasing the temperature of the soil surface in the daytime in hot season. Arima et al. (2005) reported that the temperature of the canopy surface of lawn grass decreased by a maximum 8.9°C compared with an exposed roof surface on the hottest summer day. Ooka (2005) showed a large effect of wall and roof greening of a building on the outdoor thermal environment. We suggest that 6–8°C lower temperature of soil surface covered with vegetation rather than concrete surface has a significant effect on cooling a building in summer nighttime. Larger scale research will be needed to confirm the efficiency of cooling a building.

**Literature Cited**


