Effects of Substrate Type, Soil Depth, and Drainage Type on the Growth of *Sedum kamtschaticum* in Extensive Green Roof Systems

Huh, Keun-Young* · Kim, In-Hye** · Ryu, Nam-Hyong*

*Dept. of Landscape Architecture, Jinju National University
**Division of Applied Life Science, Graduate School, Gyeongsang National University

저토심 옥상녹화 시스템에서 기린초의 생육에 대한 인공배지 종류, 토심, 그리고 배수 형태의 효과

허근영* · 김인혜** · 류남형*

*진주산업대학교 조경학과 · **경상대학교 대학원 응용생명과학부

초록

본 연구는 기존 건축물 옥상녹화에 이용 가능한 저토심 옥상녹화 시스템을 연구하고 개발하고자 수행되었다. 연구목적을 달성하기 위해서 시스템의 개념적 모델이 선행연구로부터 유추되었고 개념적 모델로부터 실험을 위한 시스템들이 제안되었다. 건축물 옥상 위에 설치된 이 시스템들에서 기린초의 생육에 대하여 인공배지 종류, 토심, 그리고 배수 형태의 효과들이 2002년 4월 3일부터 10월 18일까지 연구되었다. 인공배지 종류는 단용과 혼용이고, 토심은 5cm, 10cm, 그리고 15cm이며, 배수 형태는 저수 · 배수형과 배수형으로 하였다. 여기서, 인공배지 단용은 폐유리 미분 100에 발포제를 1~2 정도 첨가하고, 착색제를 1정도 첨가한 후, 6~8℃/min로 승온하여 750~850℃의 온도에서 발포시킨 다공질 유리를 수냉식으로 급랭하고, 분쇄기로 이송하여 10mm이하로 분쇄하고 입도를 조절하여 얻어진 다공질 유리 파쇄물과 수피를 부피비 6:4로 혼합하여 조성된 것이며 인공배지 혼용은 인공배지 단용에 양토(모래 46%, 미사 40%, 점토 14%)를 부피비 5:5로 혼합하여 조성된 것이다. 피복면적, 지상부와 지하부의 생체중과 건물중, 그리고 시각적 질을 조사하였다. 각 변수들은 던칸의 다중범위검정으로 통계처리하였으며 처리들간의 유의수준은 5%였다. 그리고 기존 건축물 옥상에 대한 과부하의 위험을 피하기 위해서 각 시스템의 중량이 평가되었다.

그 결과를 요약하면 다음과 같다. 실험기간 중에 피복면적에 대한 배수 형태의 효과는 유의성 있는 차이를 나타내지 않았다. 인공배지 혼용의 피복면적은 인공배지 단용의 것보다 통계적으로

†**Corresponding author** : Keun-Young Huh, Dept. of Landscape Architecture, Jinju National University, Jinju 660-758, Korea. Tel. : +82-55-751-3307, E-mail : sumoto@jinju.ac.kr

유의성 있게 높았다. 토심 5cm 처리의 피복면적은 나머지 처리들의 피복면적보다 통계적으로 유의성 있게 낮았다. 토심 10cm 처리와 토심 15cm 처리는 통계적으로 유의성이 없는 것으로 나타났다. 지상부와 뿌리의 생체중 및 건물중과 시각적 질에 대한 처리들의 효과는 피복면적에 대한 것과 유사하거나 동일하였다. 결과적으로, 기린초의 생육은 인공배지 단용보다 인공배지 혼용에서 더 높았고, 토심 10～15cm에서 더 높았으며, 배수 형태에서는 뚜렷한 차이를 나타내지 않았다. 이 결과를 토대로, 기존 건축물 옥상에 적용 가능한 시스템의 허용하중과 기린초의 생육을 동시에 고려해볼 때, 저토심 옥상녹화 시스템은 인공배지 종류에서는 혼용이, 토심은 10cm, 그리고 배수 형태는 배수형이 적합하다고 보았다. 제안된 조건으로 조성된 시스템은 인공배지가 포장용수량 상태일 때 그 중량이 약 115kg/m^{2}정도로 나타났다.

주요어 : 기린초, 배수 형태, 인공배지, 옥상녹화, 토심

Ⅰ. INTRODUCTION

In the process of urban growth and economic development, open spaces and undisturbed land have given way to buildings and roads. Sealed with concrete and asphalt, these surfaces no longer allow water to infiltrate the ground. Dark rooftops and pavement absorb and store solar energy during the day and radiate it at night. The results are increased stormwater runoff; greater temperature differences between urban areas and open, undisturbed land; altered weather patterns; and a loss of greenery in metropolitan areas(Seoul Metropolitan Government, 2000).

Green roof system is a solution that can simultaneously improve the energy performance, air quality, and the urban ecology without taking up additional land(Hyundai Institute of Construction Technology, 1997; Korea National Housing Corporation, 1995). Nothing could be more inventive and resourceful than using plants to adorn our dusty metropolitan roof surfaces. Thus, Green roofs, or rooftop gardens, became increasingly remarkable in Seoul, Busan, and other metropolis. According to green roof policy for ecologically healthy city, Seoul Metropolitan Government has already offered incentives to building owners in utilizing green roofs. Seoul Metropolitan Government(2000) revealed that total roof area of the existing buildings in Seoul might be about 200km^2, which was approximately 70% of the urbanized area(363.31km^2). However, the load bearing capacity of the underlying roof is 180～200kg/m^2 in most of them. Thus, extensive green roof system must be applied.

Extensive green roofs which are primarily built for their environmental benefits are shallow in soil depth, involving low maintenance and plant diversity. These are not designed for public use but can be accessed for routine maintenance walks, generally performed once a year. These are thoroughly engineered systems which address all the critical aspects of design, including: the weight of the system and load bearing capacity of the underlying roof deck; moisture and root penetration resistance of the waterproofing membrane; resistance to wind shear; management of drainage; and the suitability of the proposed plant material. Thus, substrate types and vegetation are the most important of these systems.

The types of substrate are some media to improve water retention capacity. However, the structural loading capacity of a building often determines the type of substrate. An extensive green roof system should be designed with a minimal critical weight of about 100kg/m^2(Huh *et al.*, 2003; Seoul Metropolitan

Government, 2000). Plants also determine the success or failure of the system, depending on their hardiness. Most commonly used plants are succulents or other ground cover plants capable of storing water in either fleshy leafs, bulbs or roots(Stephenson, 1994).

As a sort of the studies to develop light weight modular green roof systems, this study was carried out to investigate the effects of substrate type, soil depth, and drainage type on the growth of *Sedum kamtschaticum* in the experimental systems on rooftop. And, the results of this study were expected to verify and generalize the extensive green roof system proposed in the study on the growth of *Sedum sarmentosum*(Huh *et al.*, 2003). Because *Sedum kamtschaticum* is characterized by vigorous root growth and deep-rooted as compared with *Sedum sarmentosum*. To achieve these goals, the experimental systems were deduced from the conceptual model of extensive green roof system which was induced by past studies. Substrate types included an alone type and a blending type of an artificial substrate formulated by blending of crushed porous glass and bark(Huh and Shim, 2001). Soil depths included 5cm, 10cm, and 15cm. Drainage types included a drainage type and a reservoir-drainage type.

II. MATERIALS AND METHODS

This study was carried out in two parts. The first part was to investigate the effects of substrate type, depth, and drainage type on the growth of *Sedum kamtschaticum* in the experimental systems. The second part was to measure average weight of each system to take account of the superimposed load resulting from a landscaped roof.

1. Treatment effects on the growth of *Sedum kamtschaticum* in the experimental systems

1) Plant and substrate

Sedum kamtschaticum was selected because the conditions of rooftop are harsh and quite different from those of the ground. Sedum species are said to be one of the plants suitable for extensive landscaping(Park, 2000; Stephenson, 1994). Sedum species commonly known as Stonecrops are a variety of small succulent plants that can be found over a wide area of tropical and temperate regions in the northern hemisphere, and perennial ground cover plants belonging to the Crassulacaea family(Ryu, 2000; Sendl *et al.*, 1993). Sedum species are generally strong against heat, cold and dry conditions, generally pest and disease free, and more importantly can grow in barren land or thin soil layers. *Sedum kamtschaticum* is native mainly to the locations with dry and semi-dry conditions or with rocky surfaces in Korea. They are characterized by vigorous root growth and deep-rooted as compared with other sedums(Kwon and Joeng, 1999; Lee, 1996). *Sedum kamtschaticum* is said to be one of the best in extensive green roof(Seoul Metropolitan Government, 2000).

Substrates were an alone and a blending type of the artificial soil recommended by sedum nurserymen. Alone type was formulated by blending crushed porous glass with bark(v/v, 6:4). Crushed porous glass was produced by steps of mixing wasted fine-grained glass powder with foaming agent and pigment [glass powder : foaming agent : pigment(w/w/w) = 100 : 1-2 : 1], heating this mixture at a temperature from 750℃ to 850℃(6~8℃/min), cooling formed porous glass at ambient temperature, and crushed down under 10mm diameter by Crusher(Huh and Shim, 2001). Blending type was formulated by blending alone type with loam(v/v, 5:5)(Huh et al., 2003; Huh and Shim, 2000). The physicochemical properties of alone and blending type were as follows(Tables 1 and 2).

Table 1. Physicochemical properties of substrates used in the experiment

Item	Unit	Substrates	
		Alone type[a]	Blending type[b]
Bulk density	g/cm^3	0.38	0.87
Porosity	%	67.8	50.4
Field capacity	%	37.6	41.2
Saturated hydraulic conductivity	cm/s	0.19×10^{-2}	8.20×10^{-2}
pH	-	7.0	6.8
EC	mS/cm	0.71	0.97
Org. C	g/kg	62.6	27.9
T-N	g/kg	0.73	1.82
Bray 1-P	mg/kg	7.3	81.6
CEC	cmol/kg	11.2	8.6
Ex-Ca	cmol/kg	4.74	8.8
Ex-Mg	cmol/kg	0.67	1.44
Ex-K	cmol/kg	0.31	0.37
Ex-Na	cmol/kg	0.42	0.36

[a]: Alone type was an artificial substrate formulated by blending crushed porous glass with bark(v/v, 6:4).
[b]: Blending type was formulated by blending the alone type with loam(v/v, 1:1).

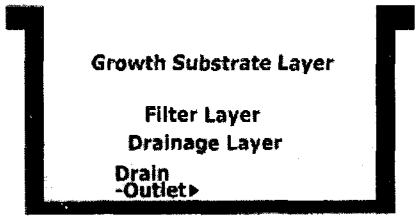
Table 2. Particle size distribution of substrates used in the experiment

Particle size (mm)	Particle size distribution of substrates (weight, %)	
	Alone type[a]	Blending type[b]
>2.00	72	36
2.00~0.05	25	36
<0.05	3	28

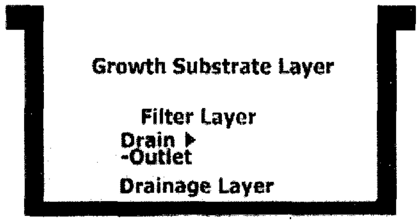
[a]: Alone type was an artificial substrate formulated by blending crushed porous glass with bark(v/v, 6:4).
[b]: Blending type was formulated by blending the alone type with loam(v/v, 1:1).

2) Experimental system and treatment

The conceptual model of extensive green roof system was induced by past studies(Figure 1). This was divided into two basic types: drainage and reservoir-drainage type. There is no difference except the location of drain-outlet between two types. Drainage type could drain excessive water but couldn't keep water because drain-outlet is located at the bottom of a drainage layer. Reservoir-drainage type could keep water and drain excessive water at the same time because drain-outlet is located at 3~5 cm height from the bottom. In common, starting from the bottom of two types, a drainage layer is installed to draw excess moisture away from substrate, followed by a filter layer to prevent soil from clogging the drainage system, and a growth substrate layer.



a: drainage type



b: reservoir-drainage type

Figure 1. Conceptual model of extensive green roof system

The experimental systems deduced from the conceptual model were divided into 12 treatments(Table 3). Each treatment was a combination of substrate type, soil depth, and drainage type. Substrate types were an alone and a blending type. Soil depths were 5cm, 10cm, and 15cm. Drainage types were a reservoir-drainage type and a drainage type. In common, drainage layer depth was 5cm in all treatments.

Table 3. Experimental treatments followed by drainage type, substrate type, and soil depth

Treatment code	Drainage type	Substrate type	Soil depth (cm)
Treatment 1	Drainage type	Alone type	5
Treatment 2	Drainage type	Alone type	10
Treatment 3	Drainage type	Alone type	15
Treatment 4	Drainage type	Blending type	5
Treatment 5	Drainage type	Blending type	10
Treatment 6	Drainage type	Blending type	15
Treatment 7	Reservoir-drainage type	Alone type	5
Treatment 8	Reservoir-drainage type	Alone type	10
Treatment 9	Reservoir-drainage type	Alone type	15
Treatment 10	Reservoir-drainage type	Blending type	5
Treatment 11	Reservoir-drainage type	Blending type	10
Treatment 12	Reservoir-drainage type	Blending type	15

3) Plant growth

The experiment was conducted from 3 Apr. to 18 Oct. 2002 at the rooftop of a four story building which was exposed to unshaded natural photoperiods. Plants of *Sedum kamtschaticum* were clonally propagated from a single genotype. Plants were transplanted into each container(volume size: 44cm× 34cm×H10cm, H15cm, H20cm) on 3 Apr. 2002 which were grown individually in 9cm diameter and 8.5cm depth pots in sandy loam and were of similar size. All plants were watered once a day for a week period of establishment, then they were not watered and dependent on rainfall. The plants were not fertilized.

As a whole, the experiment involved three factors: substrate type, soil depth, and drainage type. Treatments were replicated three times. Plants were replicated two times per a treatment. All containers were arranged in a completely randomized design on a insulation layer of 5cm expanded polystyrene.

4) Measure and analysis

Covering area, fresh and dry weight of above-part and root, and overall visual quality were measured. Covering area was measured once a month. It was photographed with equal ratio directly at the container where two plants were grown and calculated with AutoCAD 2000(Autodesk, Inc., 1996). Fresh and dry weight of above-part and root were measured on 11 Oct. 2002. Overall visual quality was measured twice a month. It was evaluated on color(greenness), shape, wilting, and spoilage of two plants in each container and rated on a scale of 1 to 9: 1 =worst; 5 = medium; 9 = best(Boivin *et al.*, 2001; Kostka, 2000; Shepard and DiPaola, 2000). Each variable was analyzed to determine treatment effects by Duncan's multiple range test with SAS Ver. 6.12(Statistical Analysis System, SAS Institute Inc., 1989) and the differences between treatment means were considered significant when $P<0.05$.

2. The superimposed load resulting from an extensive green roof system

Each system weight was measured with three replication on 17 Sep. 2002 when the growth was enough and the substrate was in field capacity. Though system weight must be based on its saturated state, it was measured in field capacity because two type substrates were characterized by high saturated hydraulic conductivity(Table 1). Total precipitation was 114.5mm from 15 to 16 Sep. 2002. After container weight was subtracted from total system weight, the average weight per 1m^2 of each system was calculated and estimated to avoid the risk of overload on the existing rooftops.

III. RESULTS AND DISCUSSION

1. Treatment effects on the growth of *Sedum kamtschaticum* in the experimental systems

1) Covering area

There was no difference in 12 treatments from 3 Apr. to 9 May(Table 4). Though differences appeared on 12 Jun., these were obscure. The significant differences appeared on 12 Jul. Covering areas in treatment 5, 6, 11, and 12 were higher than those in the rest. These treatment effects tended to be consistent from Jul. to Oct.. The lowest covering area appeared continuously in treatment 1, 3, and 7. As a whole, there was no significant difference between drainage and reservoir-drainage type in the experiment. The effect of drainage type was obscure. But, substrate type and soil depth affected covering area. Covering area in blending type was higher than that in alone type. This difference was statistically significant. Covering area in soil depth 5 cm was lower than those in the rest. This difference was statistically significant. Soil depth 10cm was not significantly different from Soil depth 15cm.

2) Fresh and dry weight of above-part and root

The analysis of the results showed that treatment effects on above-part were similar or equal to those on root and consistent with those on covering area(Table 5 and Figure 2). Fresh and dry weight of above-part and root in treatment 5, 6, 11, and 12

Table 4. Effects of drainage type, substrate type, and soil depth on covering area of Sedum *kamtschaticum* during the experimental period

Treatment code	Drainage type	Substrate type	Soil depth (cm)	Covering area(m^2)					
				9 May	12 Jun.	12 Jul.	5 Aug	6 Sep.	8 Oct.
Treatment 1	Drainage type	Alone type	5	0.005a*	0.005b	0.007e	0.011b	0.018b	0.019b
Treatment 2	Drainage type	Alone type	10	0.008a	0.009ab	0.009de	0.014b	0.023b	0.025b
Treatment 3	Drainage type	Alone type	15	0.005a	0.005b	0.007e	0.014b	0.018b	0.017b
Treatment 4	Drainage type	Blending type	5	0.009a	0.009ab	0.011cde	0.020b	0.037b	0.034b
Treatment 5	Drainage type	Blending type	10	0.014a	0.013ab	0.021ab	0.057a	0.085a	0.081a
Treatment 6	Drainage type	Blending type	15	0.011a	0.011ab	0.018abc	0.049a	0.076a	0.073a
Treatment 7	Reservoir-drainage type	Alone type	5	0.006a	0.006b	0.008e	0.013b	0.019b	0.020b
Treatment 8	Reservoir-drainage type	Alone type	10	0.014a	0.013ab	0.012bcde	0.021b	0.024b	0.025b
Treatment 9	Reservoir-drainage type	Alone type	15	0.010a	0.018a	0.013bcde	0.022b	0.028b	0.031b
Treatment 10	Reservoir-drainage type	Blending type	5	0.014a	0.013ab	0.017abcd	0.025b	0.035b	0.034b
Treatment 11	Reservoir-drainage type	Blending type	10	0.011a	0.011ab	0.019abc	0.058a	0.068a	0.068a
Treatment 12	Reservoir-drainage type	Blending type	15	0.010a	0.011ab	0.022a	0.060a	0.076a	0.073a

*: Mean separation within columns by Duncan's multiple range test at P = 0.05.

Table 5. Effects of drainage type, substrate type, and soil depth on fresh(F.W.) and dry weight(D.W.) of above-part and root of *Sedum kamtschaticum* during the experimental period

Treatment codes	Drainage type	Substrate type	Soil depth (cm)	F.W. of above-part (g)	D.W. of above-part (g)	F.W. of root (g)	D.W. of root (g)
Treatment 1	Drainage type	Alone type	5	22.53b*	2.49b	9.23bcd	3.67bc
Treatment 2	Drainage type	Alone type	10	25.23b	3.69b	7.75cd	3.30c
Treatment 3	Drainage type	Alone type	15	22.53b	3.29b	6.73d	2.66c
Treatment 4	Drainage type	Blending type	5	37.88b	4.67b	10.58bcd	3.94bc
Treatment 5	Drainage type	Blending type	10	103.58a	14.00a	32.90a	11.25a
Treatment 6	Drainage type	Blending type	15	106.63a	14.19a	34.70a	12.26a
Treatment 7	Reservoir-drainage type	Alone type	5	22.95b	3.60b	7.80cd	3.11c
Treatment 8	Reservoir-drainage type	Alone type	10	40.45b	5.18b	17.50bcd	6.18bc
Treatment 9	Reservoir-drainage type	Alone type	15	34.50b	5.12b	12.28bcd	4.74bc
Treatment 10	Reservoir-drainage type	Blending type	5	36.63b	5.87b	11.28bcd	4.84bc
Treatment 11	Reservoir-drainage type	Blending type	10	82.53a	13.89a	21.60abc	8.39ab
Treatment 12	Reservoir-drainage type	Blending type	15	94.15a	16.38a	23.15ab	8.35ab

*: Mean separation within columns by Duncan's multiple range test at $P = 0.05$.

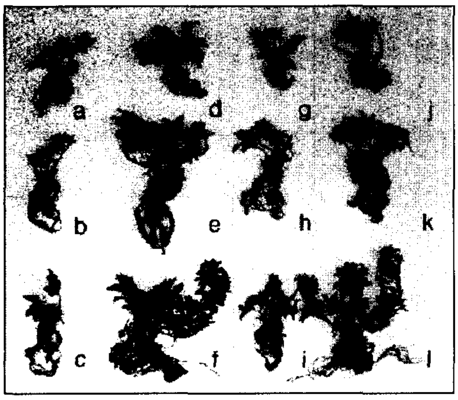


Figure 2. The plants of *Sedum kamtschaticum* in each treatment on 11 Oct. 2002
a: treatment 1; b: treatment 2; c: treatment 3; d: treatment 4; e: treatment 5; f: treatment 6; g: treatment 7; h: treatment 8; i: treatment 9; j: treatment 10; k: treatment 11; l: treatment 12

were significantly higher than those in the rest in statistics. As a whole, the effect of drainage type was obscure. The effects of substrate type and soil depth were equal or similar to those on covering area.

3) Overall visual quality

The change of visual quality appeared ∧-curve in season because *Sedum kamtschaticum* was a deciduous and perennial plant in the domestic(Table 6). Overall visual quality was highest in treatment 12 and lowest in treatment 7 on 12 Jun., on 6 Aug. and 8 Oct., treatment 4, 5, 6, 11, and 12 showed significantly higher overall visual quality than the rest. The lowest overall visual quality appeared in treatment 10 on 6 Aug. and in treatment 3 on 8 Oct.. These results revealed that treatment effects on overall visual quality were similar to those on covering area. However, it was remarkable that overall visual quality was excellent in treatment 4 where covering area, fresh weight, and dry weight were not so high.

Finally, the analysis of the results showed that the growth was higher in the blending type than in the alone type and the highest in 10~15 cm soil depth. There was no significant in the drainage type. The difference of the growth between two substrate types

Table 6. Effects of drainage type, substrate type, and soil depth on overall visual quality of *Sedum kamtschaticum* during the experimental period

Treatment code	Drainage type	Substrate type	Soil depth (cm)	Visual quality		
				12 Jun.	6 Aug.	8 Oct.
Treatment 1	Drainage type	Alone type	5	6.50bc*	7.06b	4.01cd
Treatment 2	Drainage type	Alone type	10	6.50bc	7.39b	4.33cd
Treatment 3	Drainage type	Alone type	15	6.72bc	7.50b	3.90d
Treatment 4	Drainage type	Blending type	5	6.17cd	8.17a	6.71a
Treatment 5	Drainage type	Blending type	10	6.78bc	8.50a	6.95a
Treatment 6	Drainage type	Blending type	15	6.94bc	8.50a	7.24a
Treatment 7	Reservoir-drainage type	Alone type	5	5.06e	7.00b	4.81bc
Treatment 8	Reservoir-drainage type	Alone type	10	5.39de	6.83b	4.62bcd
Treatment 9	Reservoir-drainage type	Alone type	15	6.24cd	7.44b	5.33b
Treatment 10	Reservoir-drainage type	Blending type	5	6.56bc	5.14c	5.19b
Treatment 11	Reservoir-drainage type	Blending type	10	7.50ab	8.22a	6.62a
Treatment 12	Reservoir-drainage type	Blending type	15	8.06a	8.22a	6.95a

*: Mean separation within columns by Duncan's multiple range test at P = 0.05.

might be attributed to the water holding capacity or property. In the observation with the naked eye, the water holding content and duration of blending type were higher than that of alone type though the air permeability was lower. These were attributed to the particle size distribution of blending type(Table 2). The air permeability might be enough. The difference among the treatments of soil depth might be attributed to the buffering capacity on the environmental stress from the outside. The growth substrate layer of soil depth 5cm might be sensitive to the environmental change or stress from the outside, that is, it might be inadequate for the healthy growth of *Sedum kamtschaticum*. The growth substrate layer of soil depth 10cm might be enough. No difference between two drainage types might be attributed to an acclimation on drought or a stress by flooding. *Sedum kamtschaticum* is a kind of sedum species which can tolerate harsh conditions including dry conditions as well as very cold to hot temperature and can be grown in barren land or thin earthen layers(Lee, 1996; Ryu, 2000; Stephenson, 1994). In spite of adequate water supply, the growth in reservoir-drainage type was not significantly better than that in drainage type. The water content of the substrate in reservoir-drainage type might often be excessive for the growth, that is, reservoir-drainage type might often bring about flooding in the substrate. The growth seems to be reduced by flooding as well as drought(Nash and Graves, 1993).

2. The superimposed load resulting from an extensive green roof system

Alone type was 5～15kg/m^2 lighter than blending type within drainage type(Table 7). Whenever soil depth increased 5cm, the increment was 25～35 kg/m^2 within drainage and alone type and 30～35 kg/m^2 within drainage and blending type. Alone type was about 10kg/m^2 lighter than blending type within reservoir-drainage type. Whenever soil depth increased by 5cm, the increment in weight was about 37kg/m^2 within drainage and alone type and 40kg/m^2

Table 7. The weight of each green roof system in field capacity

Treatment code	Drainage type	Substrate type	Soil depth (cm)	Weight (kg/m^2)
Treatment 1	Drainage type	Alone type	5	64.4±3.1
Treatment 2	Drainage type	Alone type	10	100.1±2.9
Treatment 3	Drainage type	Alone type	15	126.4±2.6
Treatment 4	Drainage type	Blending type	5	68.3±3.3
Treatment 5	Drainage type	Blending type	10	115.8±1.3
Treatment 6	Drainage type	Blending type	15	142.1±3.8
Treatment 7	Reservoir-drainage type	Alone type	5	98.2±5.6
Treatment 8	Reservoir-drainage type	Alone type	10	135.8±5.4
Treatment 9	Reservoir-drainage type	Alone type	15	172.6±1.1
Treatment 10	Reservoir-drainage type	Blending type	5	99.1±1.7
Treatment 11	Reservoir-drainage type	Blending type	10	141.7±4.3
Treatment 12	Reservoir-drainage type	Blending type	15	181.2±5.7

within drainage and blending type. Drainage type was lighter than reservoir-drainage type by 35~45 kg/m^2 within alone type and 25~40kg/m^2 within blending type.

The superimposed load resulting from a green roof system must be taken into account to avoid the risk of overload on the existing rooftops. However, the load bearing capacity of the underlying roof is 180~200kg/m^2 in most of the existing buildings(Seoul Metropolitan Government, 2000). If rooftop were taken as a shelter under the emergencies, an extensive green roof system should be designed with a minimal critical weight of about 100kg/m^2 to be applied to the existing buildings. Thus, the weight of treatment 6, 11 and 12, aren't permissible for the existing buildings though the plant growth in them was excellent. The weight of treatment 4, 5, and 10 are permissible. Among all treatments, treatment 5 should be the best in consideration of the superimposed load on the existing rooftops and the plant growth in the system. As a whole, the system should adopt the blending type in artificial substrate type, about 10cm in soil depth, and the drainage type in drainage type. But, special regard had to be paid to the fact that the reservoir-drainage type be adopted to keep water in store for the dry season and the volume of the water kept in store be minimized within the limits of the possible.

The final system as previously stated was revealed to be similar or equal to the system proposed for *Sedum sarmentosum* though *Sedum kamtschaticum* was characterized by vigorous root growth and deep-rooted as compared with *Sedum sarmentosum* (Huh *et al*., 2003). *Sedum kamtschaticum* acclimated to the shallow soil depth(about 10cm). In the shallow soil depth, a large portion of the roots spread out horizontally after attached to the fabric of filter layer, that is, the root system became shallow-rooted (Figure 3). However, a portion of the roots penetrated the filter fabric and spread into drainage layer(Figure 4). It is necessary that a root barrier layer be installed to prevents plant roots from penetrating beneath a waterproofing membrane.

Ⅳ. CONCLUSION

As this study was a sort of the studies to develop light weight modular green roof growing systems, it

Figure 3. In the shallow soil depth, a large portion of the roots spread out horizontally

Figure 4. A portion of the roots penetrated the filter fabric and spread into drainage layer

was carried out to investigate the effects of substrate type, soil depth, and drainage type on the growth of *Sedum kamtschaticum* in the experimental systems on rooftop. To achieve these goals, the experimental systems were deduced from the conceptual model of extensive green roof system which was induced by past studies. Substrate types were an alone and a blending type. Soil depths were 5cm, 10cm, and 15cm. Drainage types were a drainage type and a reservoir-drainage type. Covering area, fresh and dry weight of above-part and root, and overall visual quality were measured. Each variable was analyzed by Duncan's multiple range test and the differences between treatment means were considered significant when $P \leq 0.05$. And, the weight of each system was estimated to avoid the risk of overload on the existing rooftops. The results summarized are as follows. The effect of drainage type was obscure on covering area. Substrate type and soil depth affected covering area. In covering area, blending type was better than alone type and soil depth 10-15 cm was better than soil depth 5cm. Soil depth 10cm was not significantly different from soil depth 15cm. The treatment effects on total fresh and dry weight of above-part and root and visual quality were similar or equal to those on covering area. Finally, the growth was highest in the blending type and in 10～15 cm soil depth. The effect of the drainage type was obscure. In consideration of the permissible load on the existing rooftops and the growth, the system should adopt blending in substrate type, 10cm in soil depth, and drainage type in drainage type. This system will be about $115kg/m^2$ in field capacity.

LITERATURE CITED

1. Boivin, M. A., and M. P. Lamy, and A. Gosselin, and B. Dansereau(2001) Effect of artificial substrate depth on freezing injury of six herbaceous perennials grown in a green roof system. HortTechnology 11(3): 409-411.
2. Huh, K. Y., and K. K. Shim(2000) Characteristics of artificial soils used alone or in a blend with field soil for the greening of artificial ground. Journal of Korean Institute of Landscape Architecture 28(2): 28-38.
3. Huh, K. Y., and K. K. Shim(2001) Development of artificial soil by advanced materials for the greening of artificial ground. J. Kor. Soc. Hort. Sci. 42: 355-364.
4. Huh, K. Y., and I. H. Kim, and H. C. Kang(2003) Effects of artificial substrate type, soil depth, and drainage type on the growth of *Sedum sarmentosum* grown in a shallow green rooftop system. Journal of Korean Institute of Landscape Architecture 31(2): 102-112.
5. Hyundai institute of construction technology(1997) A study on the greenery on artificial ground. Technical report of Hyundai Engineering and Construction Co., Ltd.
6. Korea National Housing Corporation(1995) A study on the method for greenery on artificial ground in apartment housing complex. Report of Korea National Housing Corporation.
7. Kostka, S. J.(2000) Amelioration of water repellency in highly managed soils and the enhancement of turfgrass performance through the systematic application of surfactants. J. Hydrol. 231-232: 359-368.
8. Kwon, S. T., and J. H. Jeong(1999) Genetic relationship

among Sedum Species based on morphological characteristics and RAPD analysis. Kor. J. Hort. Sci. & Technol. 17: 490-494.
9. Lee, Y. N.(1996) Flora of Korea. Seoul: Kyo-Hak Publishing Co., Ltd.
10. Nash, L. J., and W. R. Graves(1993) Drought and flood stress effects on plant development and leaf water relations of five Taxa of trees native to bottomland habitats. J. Amer. Soc. Hort. Sci. 118(6): 845-850.
11. Park, J. S.(2000) New green roof system of *Sedum*. EPLA 1(2): 92-95.
12. Ryu, B. Y.(2000) Varieties and properties of native succulent plants. Report of the development and use of wildflower.
13. Sendl, A., and N. Mulinacci, and F. F. Vincieri, and H. Wagner(1993) Anti-inflammatory and immunologically active polysaccharides of *Sedum telephium*. Phytochemistry 34: 1357-1362.
14. Seoul Metropolitan Government(2000) A study on rooftop greenery. Report of Seoul metropolitan government.
15. Shepard, D., and J. DiPaola(2000) Regulate growth and improve turf quality. Golf Course Management 68(3): 56-59.
16. Stephenson, R.(1994) Sedum, cultivated stonecrops. Portland: Timber Press.

원 고 접 수 : 2003년 8월 29일
최종수정본 접수 : 2003년 10월 14일
4인익명 심사필