Desalination and Water Treatment
www.deswater.com

doi: 10.5004/dwt.2019.24253

158 (2019) 225–232
August

Assessment of the influence of urban stormwater runoff on the growth of *Spiraea prunifolia* var. *simpliciflora*

Hyeseon Choi, Franz Kevin Geronimo, Jungsun Hong, Lee-Hyung Kim*

Department of Civil & Environmental Engineering, Kongju National University, 1223-24, Cheonan-daero, Seobuk-gu, Cheonan, Chungnamdo, 31080, Republic of Korea, Tel. +82-41-521-9312; email: leehyung@kongju.ac.kr (L.-H. Kim)

Received 16 March 2018; Accepted 10 February 2019

ABSTRACT

Plants applied to low impact development (LID) technologies reduce stormwater runoff pollutants through bioaccumulation of nutrients, heavy metals, and other pollutants during photosynthesis and respiration, and contributed to the restoration of natural water cycle through evapotranspiration. However, studies on the type of pollutants and environmental factors affecting *Spiraea prunifolia* var. *simpliciflora* growth LID technologies were still insufficient. Therefore, this study assessed the contaminants and environmental factors affecting the *Spiraea prunifolia* var. *simpliciflora* applied to LID techniques. In this study, a planter and a rain garden, which has different environmental conditions, were assessed. Amount of chlorophyll varied according to the TN and TP concentrations was also found to be essential for vegetation growth. In addition, it was also found that the influent concentration has a large influence on vegetation growth. The chlorophyll concentration was observed to be higher in the inflow part of both the planter and rain garden. The difference of chlorophyll content between the inflow part and outflow part was larger in the planter than that of the rain garden.

Keywords: Low impact development; Plants; Planter; Rain garden; *Spiraea prunifolia* var. *simpliciflora*

1. Introduction

Urbanization and industrialization have caused the reduction of permeable land cover including green spaces, agricultural areas, and forests, and increased the proportion of impervious land uses such as buildings, parking lots, and roads. The percentage of impervious areas in South Korea was estimated to be almost 15% of its total land area [1]. The increase in impervious land has resulted to high pollutant load per unit area generation and a higher volume of stormwater runoff containing various toxic substances [2–4]. In addition, the effects of climate change have become more apparent in cities with high urbanization rate due to various developments such as road construction and logging. Other combined effects of climate change and decrease in green spaces include environmental problems such as changes in rainfall patterns, reduction of the hydrophilic space in rivers, and natural water cycle disruption. Low impact development (LID) technologies have been introduced as a major solution to the problems caused by the change in hydrological characteristics and increase in emission of non-point source pollutants brought about by urbanization. LID technologies preserve natural hydrological functions in areas by mimicking its pre-developed hydrological properties and restores natural water cycle. LID technologies also refer to the technical elements that include storage, infiltration, filtration, and evapotranspiration functions to be considered in the land use planning stage [5–8]. Green spaces that are essential for eco-friendly urban construction, and various functions such as water purification in the city, restoration of the aquatic ecosystem, environmental function, and leisure activities were converged in LID technologies [9]. The main physicochemical and biological components of LID affecting non-point pollution control were infiltration

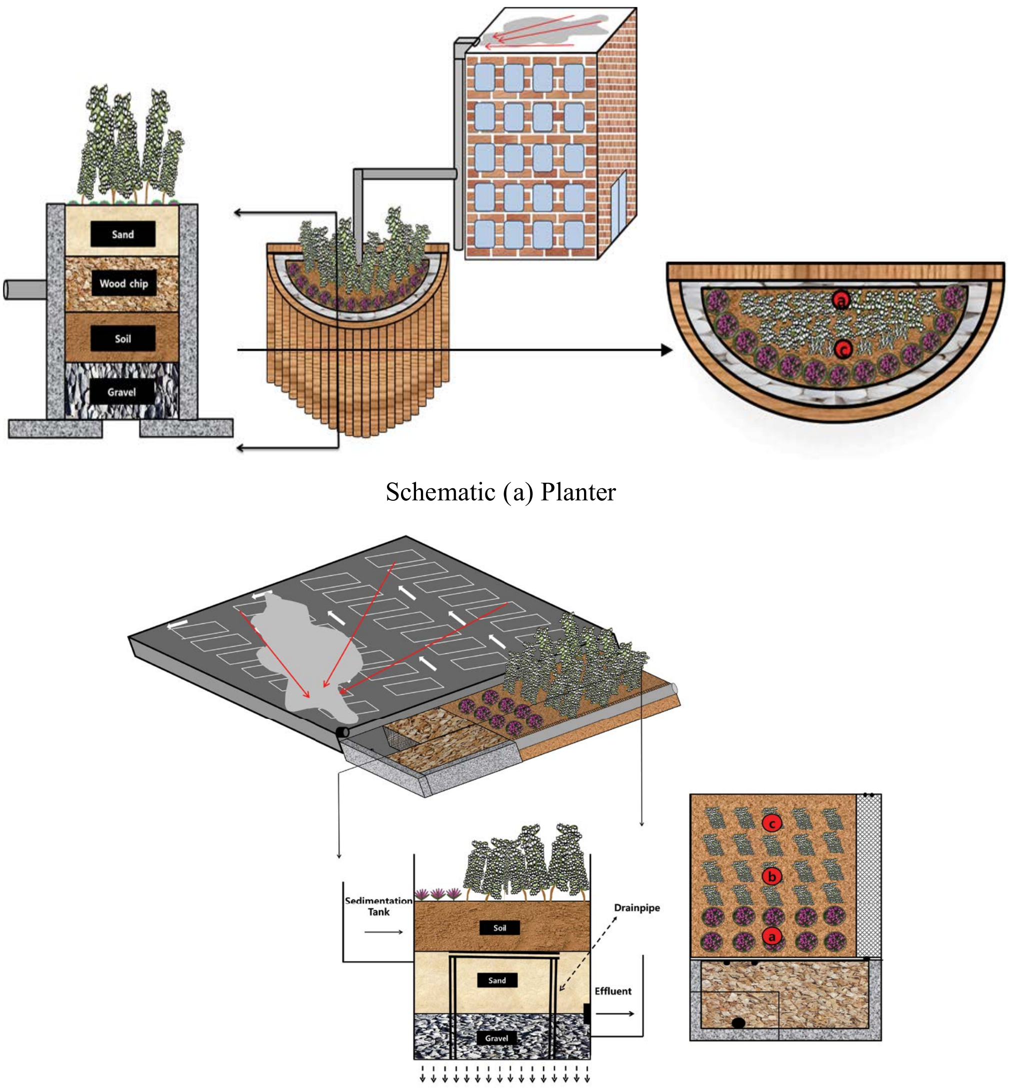
* Corresponding author.

and storage, filtration and adsorption through the soil and other media, and bioaccumulation through plants and microorganisms. Several vegetation type techniques include vegetated swale, bioretention, rain gardens, planters, and constructed wetlands. Plants in the LID facilities uptake pollutants in the stormwater runoff, such as nutrients and heavy metals, during photosynthesis and respiration, and contribute to the water circulation through the evapotranspiration. In addition, these plants helped store the remaining nutrients, absorb carbon dioxide and emit oxygen, and were effective in reducing urban temperature and reducing pollutants [10–13]. Plant growth depends on different environmental factors such as temperature, salinity, pollutants, and drying. Moreover, unexpected changes in environmental factors can cause damage to plants [14–17]. *Spiraea prunifolia* var. *simpliciflora* is a plant species widely utilized in Korea, Japan, China, and North America as vegetation for sidewalks around residential areas. Especially, *Spiraea prunifolia* var. *simpliciflora* was usually planted in gardens and parks. However, studies on the type of pollutants and environmental factors affecting *Spiraea prunifolia* var. *simpliciflora* growth LID technologies were still insufficient [18]. Therefore, this study was conducted to investigate the effects of pollutants and environmental factors on *Spiraea prunifolia* var. *simpliciflora* applied to the LID technique.

2. Materials and methods

2.1. Design and operation of pilot plant

Two vegetation type LID facilities including a planter and rain garden were constructed in Kongju National University located in Cheonan city, South Korea. Fig. 1 exhibited the schematic diagram of the two vegetation type LID technologies. The planter and rain garden were designed to treat the pollutants in roof runoff and parking lot runoff, respectively. The planter and rain garden were both planted with *Spiraea prunifolia* var. *simpliciflora* with an



Schematic (a) Planter

Schematic (b) Rain garden

Fig. 1. Schematic of monitoring site.

average plant density of nine plants per m^2 and 11 plants per m^2, respectively. The optimum density for *Spiraea prunifolia* var. *simpliciflora* was found to be 20 plants/m^2 to ensure suitable living environment [19]. Other characteristics of the two vegetation type LID technologies were listed in Table 1. Woodchip media was placed in the pre-settling basin of the rain garden to remove particulate matter from the first flush or initial stormwater runoff. The filter media zone of the rain garden is composed of soil, sand, and gravel layers which holds the vegetation and located after the pre-settling tank. The parking lot where the rain garden receives stormwater runoff has a catchment area of 481 m^2 and the rain garden technology has a surface area of 8.64 m^2. On the other hand, the planter was designed to allow roof runoff to flow directly into the filter media zone. Soil (Masato), sand, bottom ash, and wood chips were used as filter media for a suitable environment which allows microorganism growth. The planter has a facility total volume of 2.4 m^3.

2.2. Monitoring and analyses

A total of 21 storm events were monitored in the rain garden and the planter from 2014 to 2016. Water samples from the inflow and outflow ports of both LID technologies were collected as soon as the runoff flowed in and out of the rain garden and planter and after 5, 10, 15, 30, 60 min and an hourly interval thereafter until the rainfall stopped [5,20]. Water quality parameters including particulates such as total suspended solids (TSS), organic matters such as biological oxygen demand (BOD), chemical oxygen demand (COD) and oil and grease (O&G), nutrients such as total nitrogen (TN) and total phosphorus (TP) and total heavy metals including chromium (Cr), iron (Fe), nickel (Ni) and copper (Cu) were analyzed according to the standard methods for the examination of water and wastewater [21]. Monthly plant height was measured to assess the plant growth while chlorophyll content was measured twice a month using SPAD-502 to investigate the chlorophyll activity in the vegetation at varying environmental conditions. Monthly plant height was measured on the same day of each month. On the other hand, chlorophyll was measured between 9 AM and 3 PM during which the activity of vegetation was high, and photosynthesis was active [22–25]. Eq. (1) was used to estimate the event mean concentration (EMC) of the influent and effluent. EMC is commonly utilized in urban runoff studies as characteristics of runoff concentrations and a critical parameter for estimating the total emission rate as well as the contribution of runoff to receiving water [26,27]. EMC can be calculated by dividing the total cumulative contaminant released over the entire duration of the *T* duration by the total cumulative outflow [28]. Here $C(t)$ and $Q_{\mathrm{TRu}}(t)$ represents the concentration and the flow rate.

$$\mathrm{EMC} = \frac{\text{Discharged mass during an event}}{\text{Discharged volume}} = \frac{\int_0^T C(t) \times Q_{\mathrm{TRu}}(t)\,dt}{\int_0^T Q_{\mathrm{TRu}}(t)\,dt} \tag{1}$$

3. Results and discussion

3.1. Analysis of meteorological characteristics of Cheonan city

Fig. 2 shows the monthly weather characteristics in Cheonan city from 2014 to 2016 including rainfall depth, temperature, sunshine duration, and relative humidity. In the Asian monsoon region, more than 70% of annual rainfall occurs in summer (June to August) [29,30]. During the monitoring period, the average annual temperature was 12.8°C. The maximum temperature was 29.2°C observed during summer season while the lowest temperature was –10.3°C observed during the winter season. The annual rainfall in Cheonan city was 1,020.5; 728; and 1,004.8 mm in 2014, 2015, and 2016, respectively. The lowest precipitation was observed in 2015 while almost similar rainfall depths were observed in 2014 and 2016. Korea's climate showed the highest amount of rainfall occurred in summer during which, the highest humidity of more than 47% was also observed. On the other hand, it was found that the lowest precipitation occurred during winter, which is about 9% of annual precipitation. The longest sunshine duration was observed in May

Table 1
Summary on the characteristics of the LID technology

Properties	LID technology	
	Planter	Rain garden
Year constructed	2014	2014
Runoff source	Roof	Parking lot
Media	Sand, soil, gravel	Sand, soil, woodchip
Infiltration capability	Yes	
N Storm events	21	21
Dimension, m	2 × 1.5(r × H)	6 × 1.2 × 1.2 (L × W × H)
Pretreatment volume, m^3	–	0.14
Storage volume, m^3	0.98	2.88
Runoff source catchment area, m^2	81	481
[a]SA/CA, %	2.1	1.5
Vegetation	Bridal wreath (*Spiraea prunifolia* var. *simpliciflora*)	

[a]Ratio of facility surface area to catchment area.

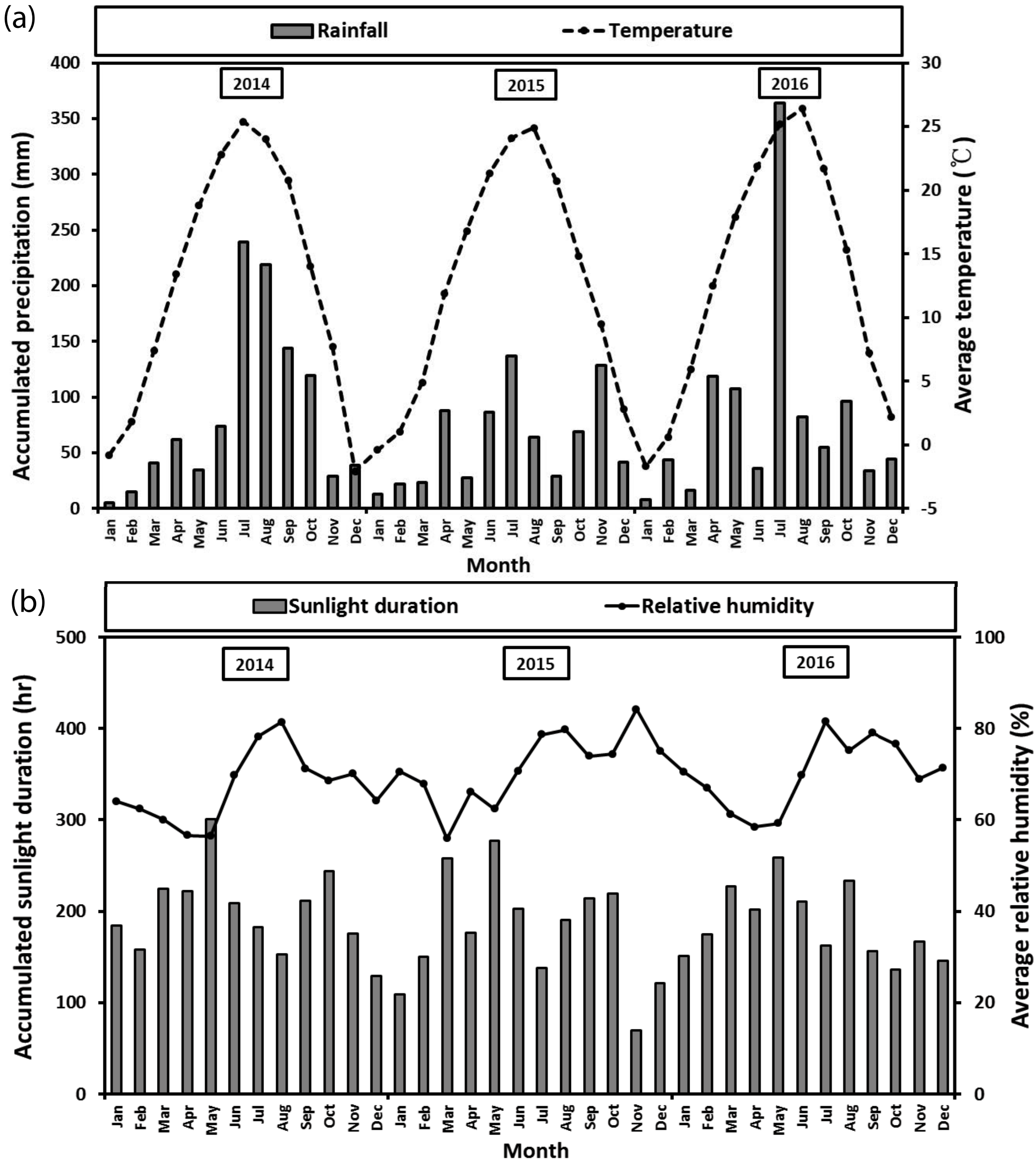


Fig. 2. Monthly weather information in Cheonan city from 2014 to 2016. (a) accumulated precipitation and average temperature and (b) accumulated sunlight duration and relative humidity.

while the shortest sunshine duration was observed in winter from December to February.

3.2. Inflow water quality characteristics

The inflow EMC concentrations of stormwater runoff from the roof and parking lot entering the planter and rain garden, respectively, are exhibited in Table 2. TSS, BOD, and COD EMC were 25.2, 9.1 and 62.5 mg/L, respectively, for roof. On the other hand, TSS, BOD, COD, TN, and TP EMC were 65.9, 11.2, 91.4, 4.0, and 0.2 mg/L, respectively. TN and TP EMC were two times higher in roof compared with the parking lot. The concentration of Zn, Cu, and Pb in the roof was 1.4 times higher than that of the parking lot. Cd, Pb, Cr, and Fe were found to be 1.1 times higher in parking lot compared with the roof because of the effects of sediment and tire wear [31].

3.3. Changes in plant height and chlorophyll

The changes in plant height and chlorophyll concentration from 2014 to 2016 in planter and rain garden are

Table 2
Inflow water quality characteristics for different catchment areas

Parameter	Catchment area							
	Planter				Rain garden			
	Mean	Minimum	Maximum	Standard deviation	Mean	Minimum	Maximum	Standard deviation
TSS, mg/L	25.2	2.3	72.8	18.3	65.9	0.1	468.2	110.9
BOD, mg/L	9.1	0.4	31.0	8.2	11.2	0.1	64.2	16.4
COD, mg/L	62.5	4.1	234.3	57.1	91.4	0.1	498.0	130.1
TN, mg/L	7.9	1.0	34.2	7.5	4.0	0.1	15.2	4.7
TP, mg/L	0.9	0.1	8.5	1.9	0.2	0.1	0.9	0.3
Oil and grease	1.3	0.1	5.6	1.3	2.5	0.1	9.5	2.6
Cr, μg/L	0.097	0.003	0.246	0.068	0.100	0.001	0.533	0.121
Fe, μg/L	0.188	0.281	4.120	0.874	0.868	0.001	4.924	1.105
Ni, μg/L	0.115	0.002	0.794	0.175	0.075	0.001	0.353	0.086
Cu, μg/L	0.125	0.018	0.490	0.114	0.089	0.001	0.345	0.093
Zn, μg/L	0.352	0.153	0.735	0.181	0.168	0.001	0.574	0.146
Cd, μg/L	0.050	0.001	0.192	0.051	0.057	0.001	0.328	0.082
Pb, μg/L	0.052	0.001	0.177	0.050	0.073	0.001	0.310	0.073

demonstrated in Fig. 3. Monthly plant height of *Spiraea prunifolia* var. *simpliciflora* was found to be increasing throughout the year. The height of *Spiraea prunifolia* var. *simpliciflora* in the planter ranges from 72 to 140.2 cm from 2014 to 2016 with the highest growth amounting to 40.2 cm was observed in a month. On the other hand, *Spiraea prunifolia* var. *simpliciflora* in the rain garden grew from 66.9 to 92.6 cm from 2014 to 2016. This growth was relatively low compared with those in the planter. The growth rate of *Spiraea prunifolia* var. *simpliciflora* planted in the rain garden and planter were ranging from 1.5% to 38.5% and 11.9% to 93.9%, respectively. The concentration of TN and TP which affected vegetation growth was higher in roof runoff compared with parking lot runoff which enters the planter and rain garden, respectively. The amount of chlorophyll in the *Spiraea prunifolia* var. *simpliciflora* increased steadily from spring to summer (June to August) and decreased in autumn. Chlorophyll was highest in July and August for *Spiraea prunifolia* var. *simpliciflora* in the planter, while the chlorophyll was almost similar for *Spiraea prunifolia* var. *simpliciflora* in rain garden. The difference in the chlorophyll content of the *Spiraea prunifolia* var. *simpliciflora* planted in the rain garden and in the planter is the largest in July and August which may be attributed to pollutants entering and storm events happening during these months.

3.4. Change in chlorophyll content with respect to facility length

In general, nutrients are essential for plant growth because these nutrients were involved in physiological responses such as plant growth, leaf area expansion, and internode elongation [32,33]. Fig. 4 shows the chlorophyll changes of the *Spiraea prunifolia* var. *simpliciflora* measured in the inflow (A), middle (B), and outflow (C) areas of the rain garden and the planter. In rain garden, chlorophyll of *Spiraea prunifolia* var. *simpliciflora* was the highest in point A while the difference between the chlorophyll in A and C was about 0.8–2.1 μg/cm^2. The difference between A and C was found to be highest during summer season (July) when most rainfall occurred, and the lowest in April and October when the flowers are blooming and wilting, respectively. The decrease of chlorophyll in B was almost in the same range as the decrease from A to C after autumn. The difference in chlorophyll between the A and B was about 0.1–2.6 μg/cm^2 for *Spiraea prunifolia* var. *simpliciflora* in the planter. The concentration of chlorophyll in point A was high except in May due to low rainfall. On the other hand, chlorophyll was observed to be higher in the months of July and August wherein the largest difference between the inflow and outflow chlorophyll was also observed. This was attributed to the TN concentration which was also higher in July when the mean rainfall amounting to 246.7 mm occurred. The concentration of TN was found to highly affect the growth of *Spiraea prunifolia* var. *simpliciflora* and its corresponding chlorophyll content while TP has a relatively small effect compared with TN.

3.5. Relationship between pollutants and chlorophyll

Illustrated in Fig. 5 where the standardized plots for inflow EMC and chlorophyll affecting the growth of *Spiraea prunifolia* var. *simpliciflora* in the vegetated LID technologies. The inflow pollutant EMC in the rain garden was divided by inflow pollutant EMC in the planter for standardization. The relative ratio between TN and TP EMC and chlorophyll concentration which is essential for vegetation growth were also standardized. The results showed that TSS has the highest EMC ratio followed by O&G, COD, BOD, Chlorophyll, TN, TP, and heavy metals, respectively. The EMC ratio of

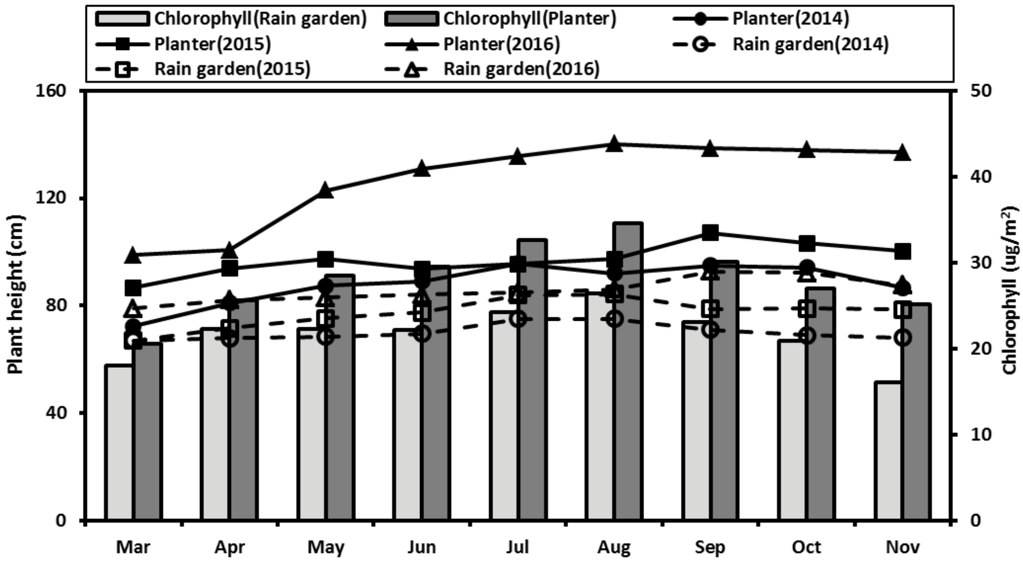


Fig. 3. Month changes in plant height and chlorophyll.

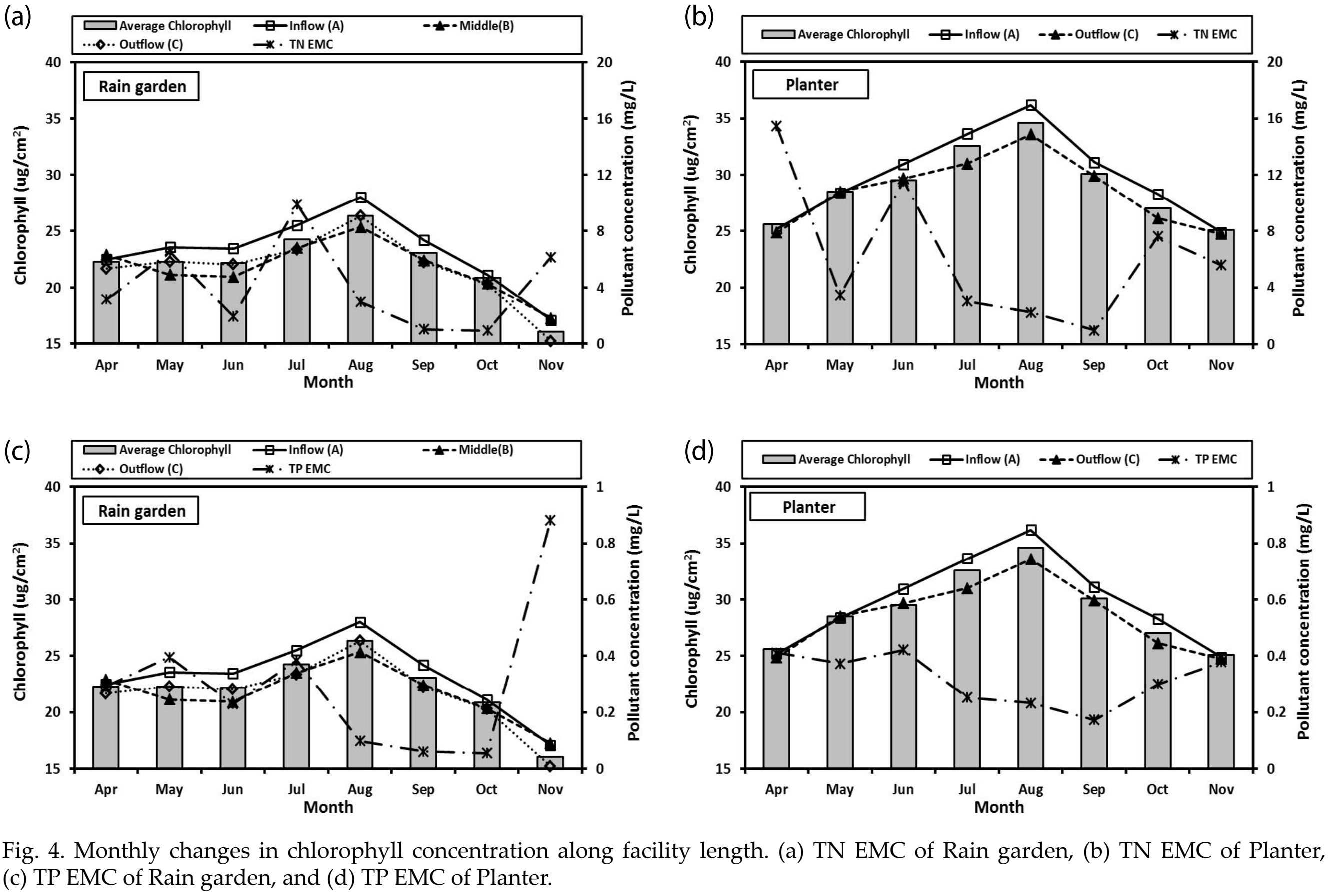


Fig. 4. Monthly changes in chlorophyll concentration along facility length. (a) TN EMC of Rain garden, (b) TN EMC of Planter, (c) TP EMC of Rain garden, and (d) TP EMC of Planter.

the rain garden to the planter was found to be more than 1 for TSS, BOD, COD, O&G, and less than 1 for nutrients, heavy metals, and chlorophyll. These findings implied that the runoff from parking lots contained more TSS, BOD, COD, and O&G. This finding is useful for selecting appropriate LID technology applicable to address a certain stormwater management objective. Fig. 5b shows the monthly ratio of the nutrient concentration of the rain garden to the planter. The EMC ratio of TN was found to be the maximum in July while that of TP was maximum in November. In addition, the chlorophyll ratio tended to decrease slightly as the TP EMC ratio increased, but the chlorophyll ratio remained

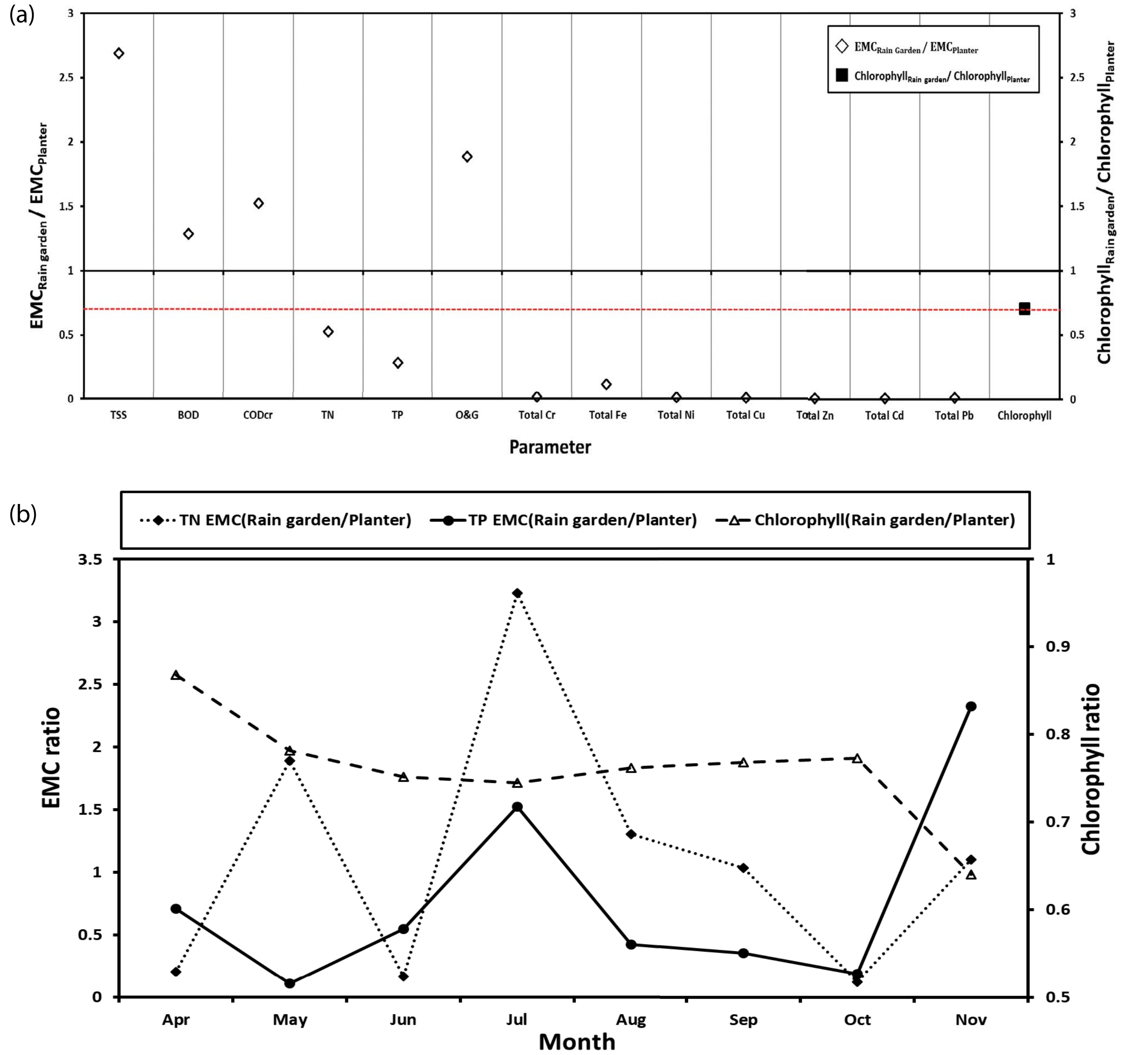


Fig. 5. Standardized plot for chlorophyll and pollutants. (a) EMC and Chlorophyll ratio of rain garden to Planter and (b) nutrient EMC and Chlorophyll ratio of rain garden to Planter.

almost constant between 0.7 and 0.8 without any significant relationship with TN EMC ratio.

4. Conclusions

Plants applied to low impact development (LID) technologies reduce stormwater runoff pollutants through bioaccumulation of nutrients, heavy metals, and other pollutants during photosynthesis and respiration, and contributed to the restoration of natural water cycle through evapotranspiration. However, studies on the type of pollutants and environmental factors affecting *Spiraea prunifolia* var. *simpliciflora* growth LID technologies were still insufficient. As such, this study was conducted to investigate the effects of pollutants and environmental factors on *Spiraea prunifolia* var. *simpliciflora* applied to the LID technique. Based on the results of this research, the following conclusions were drawn:

- Amount of chlorophyll varied with respect to TN and TP concentration which was necessary for vegetation growth. It was also found that the concentration of stormwater influent has a large influence on vegetation growth.
- Chlorophyll was found to be highest in the inflow for both facilities due to high influent concentration from catchment area compared with the other parts of each LID technologies. In addition, the concentration of influent from the roof and parking lots and the environmental conditions provided by rain garden and planters were

found to be suitable for *Spiraea prunifolia* var. *simpliciflora* growth. These findings implied that providing a suitable environment for *Spiraea prunifolia* var. *simpliciflora* growth could help optimize the pollutant removal mechanisms of LID technologies.

- The rain garden has higher inflow EMC for TSS, BOD, COD, and O&G while nutrients and heavy metals EMC were found to be higher in planter implying that the runoff from parking lots contained more TSS, BOD, COD, and O&G. In addition, it was observed that the chlorophyll ratio decreased slightly as the TP ratio of the rain garden and the planter increased. Concentrations of nutrients were evaluated as factors affecting the growth and activity of the *Spiraea prunifolia* var. *simpliciflora* in LID technologies.

Acknowledgments

This research was supported by a grant (E416-00020-0602-0) from Public Welfare Technology Development Program funded by the Ministry of Environment of the Korean Government.

References

[1] Seoul Metropolitan Government, Water Circulation Effect Analysis and Infrastructure Construction Technology Development Research Service Report, 2015.
[2] K.H. Bang, J.H. Lee, M.J. Yu, A study on the runoff characteristics of nonpoint sources in small urban watersheds, Korean Soc. Water Environ., 13 (1997) 79–21.
[3] R. Field, M. O'shea, M.P. Brown, The detection and disinfection of pathogens in storm-generated flows, Water Sci. Technol., 28 (1993) 311–315.
[4] V. Novotny, Gordon Chesters, Handbook of Nonpoint Pollution: Sources and Management, Van Nostrand Reinhold Cia, 1981.
[5] US EPA, The Use of Best Management Practices (BMPs) in Urban Watersheds, 2004.
[6] Ministry of Environment (MOE), Guidelines for Low Impact Development (LID) Technology Elements for Establishing a Healthy Water Cycle System, 2013.
[7] M.C. Maniquiz-Redillas, L.H. Kim, Fractionation of heavy metals in runoff and discharge of a stormwater management system and its implications for treatment, J. Environ. Sci., 26 (2014) 1214–1222.
[8] M.E. Dietz, Low impact development practices: a review of current research and recommendations for future directions, Water Air Soil Pollut., 186 (2007) 351–363.
[9] J.S. Hong, M.C. Maniquiz-Redillas, J.Y. Choi, L.H. Kim, Assessment of bioretention pilot-scale systems for urban stormwater management, Desal. Wat. Treat., 63 (2017) 412–417.
[10] H.S. Choi, J.S. Hong, L.H. Kim, Assessment of salt resistance and performances of LID applicable plants, Desal. Wat. Treat., 101 (2018) 116–122.
[11] C. Denich, A. Bradford, J. Drake, Bioretention: assessing effects of winter salt and aggregate application on plant health, media clogging and effluent quality, Water Qual. Res., 48 (2013) 387–399.
[12] M.C. Maniquiz-Redillas, J.M.R. Mercado, L.H. Kim, Determination of the number of storm events representing the pollutant mean concentration in urban runoff, Desal. Wat. Treat., 51 (2013) 4002–4009.
[13] S.Y. Lee, Assessment of Pollutant Removal Capacity of LID Processes with Long Term Monitoring, Master's Thesis, Kongju National University, 2015.
[14] S.J. Oh, J.G. Kim, M.J. Oh, S.C. Koh, Diurnal and seasonal variation of chlorophyll fluorescence from Korean fir plants on Mt. Halla, Korean J. Environ. Biol., 19 (2001) 43–48.
[15] R.A. Raff, C.R. Marshall, J.M. Turbeville, Using DNA sequences to unravel the Cambrian radiation of the animal phyla, Annu. Rev. Ecol. System., 25 (1994) 351–375.
[16] W.F. Hunt, R.G. Traver, A.P. Davis, C.H. Emerson, K.A. Collins, J.H. Stagge, Low Impact Development Practices: Designing to Infiltrate in Urban Environments, Effects of Urbanization on Groundwater: An Engineering Case-Based Approach for Sustainable Development, 2010 pp. 308–343.
[17] P.B. Reich, J.P. Lassoie, Effects of low level O_3 exposure on leaf diffusive conductance and water-use efficiency in hybrid poplar, Plant Cell Environ., 7 (1984) 661–668.
[18] C. Hinman, Low Impact Development: Technical Guidance Manual for Puget Sound, Puget Sound Action Team, 2005.
[19] C.B. Lee, Coloured Flora of Korea, Hyangmonsa, Seoul, 2006, 990 p.
[20] L.H. Kang, J.H. Kang, Determination of event mean concentrations and pollutant loadings in highway storm runoff, J. Korean Soc. Water Environ., 20 (2004) 631–640.
[21] APHA (American Public Health Association), AWWA (American Water Works Association), and WEF (Water Environment Federation), Standard Methods for the Examination of Water and Wastewater, 21st ed., Washington, D.C., 2005.
[22] T. Takashima, K. Hikosaka, T. Hirose, Photosynthesis or persistence: nitrogen allocation in leaves of evergreen and deciduous *Quercus* species, Plant Cell Environ., 27 (2004) 1047–1054.
[23] J.R. Evans, H. Poorter, Photosynthetic acclimation of plants to growth irradiance: the relative importance of specific leaf area and nitrogen partitioning in maximizing carbon gain, Plant Cell Environ., 24 (2001) 755–767.
[24] S. Coste, J.C. Roggy, P. Imbert, C. Born, D. Bonal, E. Dreyer, Diversity in leaf traits related to photosynthesis among seedlings from 14 rainforest tree species: is there a relationship with ecological grouping of the species?, Tree Physiol., 25 (2005) 1127–1137.
[25] J. Uddling, J. Gelang-Alfredsson, K. Piikki, H. Pleijel, Evaluating the relationship between leaf chlorophyll concentration and SPAD-502 chlorophyll meter readings, Photosynth. Res., 91 (2007) 37–46.
[26] L.B. Irish Jr, M.E. Barrett, J.F. Malina, R.J. Charbeneau, Use of regression models for analyzing highway storm-water loads, J. Environ. Eng., 124 (1998) 987–993.
[27] L.H. Kim, S.O. Ko, S. Jeong, J. Yoon, Characteristics of washed-off pollutants and dynamic EMCs in parking lots and bridges during a storm, Sci. Total Environ., 376 (2007) 178–184.
[28] L.H. Kim, S.O. Ko, B.S. Lee, S.G Kim, Estimation of pollutant EMCs and loading in highway runoff, KSCE J. Civil Eng., 26 (2006) 225–231.
[29] J.Y. Lim, Y.S. Chun, The characteristics of Asian dust events in Northeast Asia during the springtime from 1993 to 2004, Global Planet Change, 52 (2006) 231–247.
[30] W. Qian, H.-S. Kang, D.-K. Lee, Distribution of seasonal rainfall in the East Asian monsoon region, Theor. Appl. Climatol., 73 (2002) 151–168.
[31] I.O. Wallinder, Y. Hedberg, P. Dromberg, Storm water runoff measurements of copper from a naturally patinated roof and from a parking space. Aspects on environmental fate and chemical speciation, Water Res., 43 (2009) 5031–5038.
[32] S.J. Hwang, H. Muhammad, H.Y. Kim, Effect of nitrogen and silicon nutrition on bioactive gibberellin and growth of rice under field conditions, J. Crop Sci. Biotechnol., 10 (2007) 281–286.
[33] S.W. Jang, H. Muhammad, E.Y. Sonh, D.H. Shin, K.U. Kim, I.J. Lee, Studies on the effect of silicon nutrition on plant growth, mineral contents and endogenous bioactive gibberellins of three rice cultivars, J. Crop Sci. Biotechnol., 10 (2007) 47–51.