Membrane and Water Treatment, *Vol. 10, No. 1 (2019) 039-044*
DOI: https://doi.org/10.12989/mwt.2019.10.1.039

Assessment of environmental impacts of LID technologies on vegetation

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(Received May 4, 2018, Revised August 17, 2018, Accepted August 31, 2018)

Abstract. LID facilities do not consider environmental factors, and due to inappropriate vegetation planting causing degradation in efficiency due to plant damage and difficulty in maintenance. Therefore, in this study, assessment of impact environmental factor by seasonal variation of chlorophyll and growth of vegetation planted in LID technologies and change of pollutant reduction were conducted. In the case of B-SJ and B-RI, growth rate decreased after summer (August), and B-MG showed steady growth until autumn (September). Chlorophyll was found to increase during spring season while it decreased during autumn season. The chlorophyll concentration was found to affect the plant growth pattern. TN reduction efficiency was highest with greater than 80% efficiency in summer, and it was analyzed that plants were identified as the main factor affecting the seasonal reduction efficiency of TN. Also, temperature and relative humidity were analyzed to affect plant growth, activity and pollutant removal efficiency. Plant type and growth pattern are considered as factors to be considered in selection of appropriate plant types in LID technologies.

Keywords: clorophyll; growth; low impact development; meteorological characteristics; vegetation

1. Introduction

Since the mid-20th century, rapid industrialization and urbanization have caused various hazards to the ecosystem environment in which life forms. Rapid industrialization and urbanization led to an increase in the impervious layers which increased the outflow during rainfall and caused the transfer of various pollutants such as nitrogen and phosphorus into rivers. This led to the degradation of water ecosystems such as deterioration of water quality and algae due to eutrophication. LID technologies were introduced to prevent water ecosystem distortion, to build a healthy water cycle and to reduce nonpoint pollutants (Seoul Metropolitan Government 2010, MOE 2014). LID technology has various technologies such as infiltration type, filtration type, and vegetation type technologies including vegetated swale, bioretention, rain garden, and planter.

Various vegetation-type facilities included plants for landscaping, aesthetics and environmental functions. These plants reduce various pollutants through hydrological storage, evapotranspiration, and photosynthesis of its roots and leaves. The roots in the soil stabilize the body and absorb water and nutrients, and feed them to the plant body through a water pipe. The roots in the soil were also used to store the remaining nutrients, absorb oxygen and release carbon dioxide; this therefore helps the plants to be effective in reducing urban temperature and reducing pollutants (Choi 2017, Denich *et al.* 2013). As such, these plants play an important role in LID facilities, but plants' activities were hindered by various factors such as climate, soil, and biological. Especially in the Asian monsoon climate like Korea, seasonal precipitation variation is large which may sometimes lead to flood damage due to heavy precipitation (Cho and Choi 2014). There are insufficient studies on the environmental and seasonal effects and selecting LID plants in Korea at present. LID facilities do not consider environmental factors, and due to inappropriate vegetation planting causing degradation in efficiency due to plant damage and difficulty in maintenance. Therefore, in this study, assessment of impact environmental factors by seasonal variation of chlorophyll and growth of vegetation planted in LID technologies were conducted. The changes in pollutant reduction efficiency of the LID technologies were also conducted.

2. Materials and methods

2.1 Physical design and experimental procedure

In order to evaluate the environmental impact of vegetation planted in the LID technologies, monitoring and test run were conducted in the bioretention technologies with different shrubs and trees. Plants of age 2 to 3 years were investigated in this study such as *Spiraea prunifolia f. Simpliciflora Nakai* (SJ), *Rhododendron indicum* (L.) sweet (RI) and *Metasequoia glyptostroboide Hu et Chung* (MG). Bioretention pilot plants were 1 m (L) × 0.4 m (W) × 0.6 m (H) in size, considering the stability of the plants exhibited in Table 1. The bioretention pilot plant was designed to have with varying depth of 0.3 to 0.8 m in order to provide sufficient depth for plant growth however minimum depth required for plant growth was found to be 0.6 m which is equivalent to 80 kg of soil. Thus, the weight of soil used for

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http://www.techno-press.org/?journal=mwt&subpage=7
ISSN: 2005-8624 (Print), 2092-7037 (Online)

Table 1 Summary of bioretention pilot plants' design and configuration

Acronym	Name	Picture
Spiraea prunifolia f. simpliciflora Nakai	SJ	
Rhododendron indicum (L.) Sweet	RI	
Metasequoia glyptostrobodides HU & W.C. Cheng	MG	

the design was highlighted. To investigate the growth of each plant three bioretention technologies were prepared to which each species of plants was placed. Three ports were made at the bottom of the bioretention pilot plants to measure the effluent water concentration and flow rate for analysis. The bioretention pilot plants were referred to as B-SJ, B-RI and B-MG for systems planted with SJ, RI and MG species, respectively. In order to provide nutrients and reduce pollutants to the vegetation in the bioretention pilot plant, a ratio of 3:7 Masato sand and soil was employed (Kim *et al*. 2008). In this study, assuming that the area of LID technologies ($0.4m^2$) is 1% of the catchment area (CA) and the rainfall of 20mm which corresponds to 80% cumulative rainfall frequency in Korea the inflow rate was calculated as 10 L/hr. The experiment was conducted for two hours after the start of inflow while flow rate was measured at the intervals of 0, 30, 60, 90 and 120 minutes. The artificial rainfall was prepared by adding the sediments collected from the expressway sweeper sieved using #100 sieves into the influent. Influent sample was prepared from the sediment sample collected from the cleaning of expressway of Cheonan office of road construction. Which was further dried at 100°C for 24 hours and sieved through 150μm thereby preparing sample equivalent to 100 to 150 mg/L (Lee *et al*. 2005).

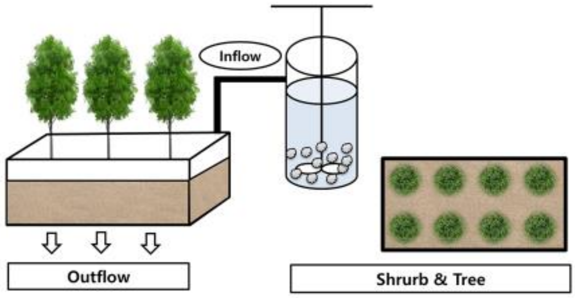


Fig. 1 Bioretention pilot plants' design

Based on the influent, the water quality was monitored once or twice a month and the. Influent and effluent of the bioretention pilot plants were analyzed for nutrient content including TN and TP according to the standard method for examination of water and wastewater (APHA/AWWA/WEF, 2005) to which the pollutant removal efficiency of the systems developed was calculated. The pollutant removal efficiency of the systems was calculated by subtracting the ratio of outflow mean concentration with the inflow mean concentration to 1 and multiplying the difference to 100. In winter, the soil was frozen and the pollutant abatement efficiency could not be calculated. Vegetation monitoring including chlorophyll and plant height measurement was performed once or twice a month. For chlorophyll measurement, SPAD-502 was used. Chlorophyll was measured twice a day between 9 am and 3 pm on a clear day. These plants are affected by various environments during their growth. Therefore, the meteorological factors directly affecting the vegetation height and chlorophyll were analyzed.

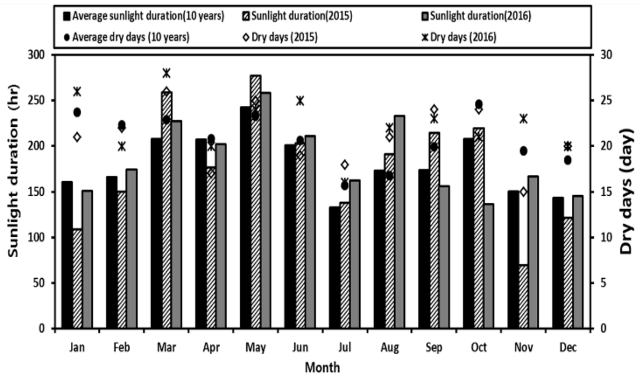
2.2 Statistical analysis

Pearson correlation analysis was performed to determine the linear relationship between each vegetation and meteorological factors. Factors including temperature, humidity, and sunlight duration were analyzed using data and observations from Korea Meteorological Administration in Cheonan city.

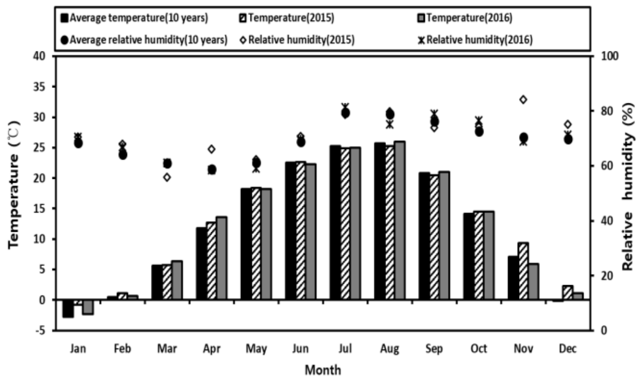
3. Results and discussion

3.1 Monitored of meteorological characteristics

Aside from the type and geographical location of vegetation, Plant growth was also influenced by seasonal changes in temperature and precipitation (Rodriguez-Iturbe 2000, Teuling *et al*. 2007, Seneviratne *et al*. 2010). Generally, the temperature in South Korea is higher than that in Asian countries experiencing Asian monsoon climate due to latitude and topography (Lee *et al*. 2015). Inland mountainous regions have lower temperatures and more than 70% of the annual rainfall in the Asian monsoon region occurred during summer season (June to August) (Qian *et al*. 2002, Chen *et al*. 2004). The characteristics of the city where the bioretention pilot plants were constructed were



(a) Sunlight and dry days



(b) Temperature and relative humidity

Fig. 1 Meteorological characteristics of the Cheonan city in South Korea

shown in Fig. 1. 10 year-average of dry days, temperature, relative humidity, Sunlight duration and monitoring period (2015-2016). During spring and autumn in Cheonan, the dry days are 22.3 and 21.3 days, and the average monthly dry days were over 70%. The duration of sunshine, which affects plant photosynthesis, was highest in May with accumulated duration of 242.5 hrs and the lowest was 133 hrs during the rainy season. The average temperature in Cheonan city was about 13°C, of which the highest temperature was about 26°C which occurred between the months of July and August. On the other hand, the lowest recorded temperature occurred in January amounting to -3°C. The average humidity ranged from 60% to 75% all throughout the year. In summer (July and August), the humidity ranged from 70% to 85%, and the humidity was high due to rainfall. These climate factors were found to have affected the vegetation applied to LID facilities and these climate factors should be considered in LID design (Ryan 1991).

3.2 Plants height and chlorophyll

Plants can supply oxygen to the bottom soil, decrease the groundwater layer by evaporation and introduce oxygen from the atmosphere into the soil, which increases the water conductivity of the soil and the pollutant reduction as the plant roots penetrate the soil (Kim and Lee 1997). Fig. 2 shows the monthly changes in plant height and chlorophyll. The chlorophyll content was highest in SJ, followed by RI and MG, respectively. The growth of SJ, RI and MG was

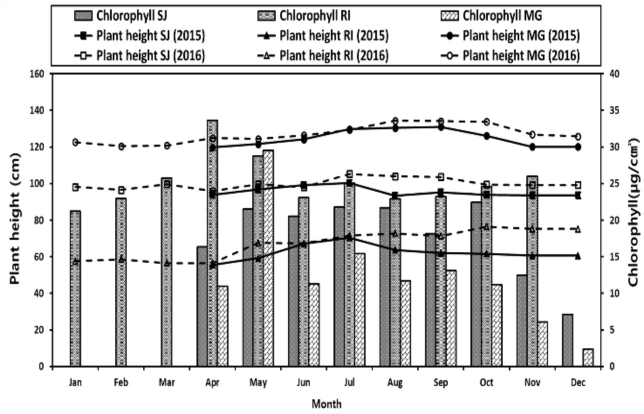


Fig. 2 Bioretention pilot plants' design

steady at 11cm, 20cm, and 14cm, respectively for 2 years. RI attained the highest growth rate among the three vegetation's amounting 12.8%, 12.3% compared to SJ and MG, respectively. In the case of SJ and RI, the average growth slowed from July to August by 4% compared to the month of May while MG showed steady growth until September. The steady growth of these plants was observed due to presence of enough water content in the media layer for the plant physical development. On seasonal basis, The seasonal average growth rate in spring, summer and autumn was 1.5%, 2.0%, -2.1%, respectively. Three plants showed higher growth of 1.5% from spring to summer however plants growth was in decreasing order of -2.1% in autumn (Silva *et al*. 2004).

In addition, Chlorophyll monitoring showed the highest amount of chlorophyll in the month of May with concentration amounting to 33 ug/cm^2 and 30 ug/cm^2 for RI and MG, respectively. It was found that, RI plants observed the active blooming during this period while MG was observed to have the most active growth and blooming. The sharp chlorophyll change in plants can be observed during spring and summer. Furthermore, the growth of plants also decreased with decreasing amount of chlorophyll, implying that the chlorophyll concentration affected the plants' growth pattern. As such it can be concluded that the removal efficiency pollutants will be different in autumn and winter when plant undergoes dormancy and their growth slowdown, unlike in spring, when plants grow and bloom.

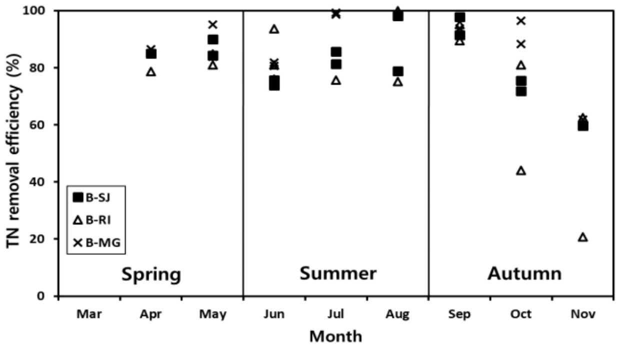
3.3 Change of pollutant removal efficiency by season

Fig. 3 shows the seasonal changes in pollutant removal efficiency by the bioretention pilot plants. This study, Influent Event Mean Concentrations (EMC) ranged 7.46 ± 8.62mg/L for TN and 0.76 ± 0.90mg/L for TP, respectively. The average TN reduction efficiency is more than 70%. In spring (April), TN reduction efficiency was observed to increase, but the efficiency decreased sharply from September when the autumn season starts. This was the period when the temperature increases in spring, and falls below 10°C in autumn (Hong *et al*. 2017). In addition, the removal efficiency of B-RI and B-SJ decreased sharply compared to B-MG. Also, when the amount of chlorophyll

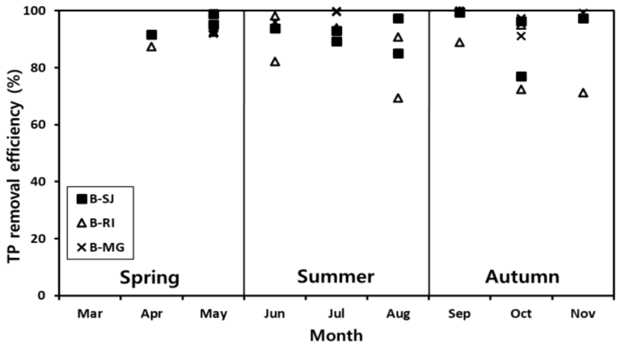
Table 2 Correlation between meteorological factors, vegetation characteristics and nutrient removal efficiencies of each bioretention pilot plant

	T[1]	SD[2]	RH SD[3]	SJ C[4]	RI C	MG C	B-SJ TNRE[5]	B-RI TNRE	B-MG TNRE	B-SJ TPRE[6]	B-RI TPRE	B-MG TPRE	SJ H[7]	RI H	MG H
T	**1**														
SD	-0.997	**1**													
RH	**0.989**	-0.498	**1**												
SJ C	**0.631**	**0.93**	**0.781**	**1**											
RI C	**0.894**	**0.697**	**0.969**	**0.912**	**1**										
MG C	**0.984**	0.469	**0.999**	**0.760**	**0.960**	**1**									
B-SJ TNRE	**0.976**	0.09	**0.908**	0.449	**0.777**	**0.922**	**1**								
B-RI TNRE	**0.957**	0.014	**0.874**	0.380	**0.726**	**0.889**	**0.997**	**1**							
B-MG TNRE	**0.873**	-0.79	**0.956**	**0.930**	**0.999**	**0.946**	**0.747**	**0.694**	**1**						
B-SJ TPRE	**0.607**	**0.574**	0.424	-0.234	0.187	0.454	**0.764**	**0.811**	0.141	**1**					
B-RI TPRE	**0.96**	**0.558**	**0.998**	**0.823**	**0.984**	**0.995**	**0.877**	**0.838**	**0.975**	0.359	**1**				
B-MG TPRE	0.177	**0.885**	-0.036	-0.652	-0.282	-0.003	0.385	0.454	-0.326	**0.89**	-0.106	**1**			
SJ H	**0.645**	**0.705**	**0.75**	**0.823**	-0.945	**0.954**	**0.941**	**0.964**	0.477	**0.938**	**0.662**	**0.675**	**1**		
RI H	**0.776**	**0.825**	**0.86**	**0.704**	**0.868**	**0.993**	-0.815	0.857	-0.223	-0.997	-0.436	-0.849	-0.963	**1**	
MG H	**0.973**	**0.989**	**0.996**	0.325	-0.566	**0.945**	**0.811**	**0.764**	**0.995**	0.243	**0.992**	-0.227	**0.565**	-0.322	**1**

[1]Temperature (°C); [2]Sunlight duration (hr); [3]Relative humidity(%); [4]Chlorophyll (μg/cm^2); [5]TN Removal efficiency; [6]TP Removal efficiency; [7]Height; Bold Values: Values which have pearson r value greater than 0.5.



(a) TN removal efficiency



(b) TP removal efficiency

Fig. 3 Seasonal changes in nutrient removal efficiency

was higher during the summer season, the efficiency of TN reduction was more than 80% which was higher than its performance during spring and autumn season. These findings implied that the activity of microorganisms in soil and the decrease in plant activity including growth rate and chlorophyll content changes influenced the TN reduction efficiency of the systems developed. TP reduction efficiency of B-SJ and B-MG was greater than 90% disregarding the seasonal effect while TP reduction efficiency of B-RI was more than 70%. TP removal efficiency of B-SJ and B-MG was greater than RI due to the difference in the area surrounding the vegetation roots (rhizosphere). TP removal efficiency was found to be affected the physicochemical adsorption process of soil compared to the plant growth and chlorophyll content changes (Van de Moortel *et al*. 2010).

3.4 Correlation between environmental factors and plants

Most plants were affected by climate factors such as temperature or precipitation (Shin *et al*. 2006, Kasuga, Mie *et al*. 1999, Spieles and Mitsch 1999). Table 2 shows the correlation between climate factors (temperature, sunlight duration, and humidity), plant characteristics (height and chlorophyll content) and bioretention pilot plant pollutant removal efficiency. In addition, the temperature exhibited high Pearson correlation value (r) of greater than 0.6 chlorophyll content with SJ, RI, and MG. MG was observed to have the highest r value of 0.984. Also, the correlation between temperature and TN reduction efficiency of B-SJ, B-RI, and B-MG was high with r value greater than 0.8. Temperature was also determined to be highly correlated to vegetation growth with r value greater than 0.6 for all the plant species. Therefore, it was concluded that the temperature affected not only chlorophyll but also TN reduction efficiency of the bioretention pilot plants. Chlorophyll of MG had the highest correlation with temperature followed by RI and SJ. The temperature in media layer affects the plant growth and microorganism activity in the LID system (Hong *et al*. 2018). This finding was attributed to due to the removal efficiency of soil microorganisms and plant activity (Spieles and Mitsch 1999, Aylor and Sutton 1992). In addition, the amount of chlorophyll in each plant is correlated with the TN reduction efficiency, which indicates that the plant activity also influenced the reduction efficiency of the systems developed. Relative humidity was correlated with chlorophyll, TN removal efficiency, and plant growth, which was considered to be a factor affecting plant growth conditions. Sunlight duration and vegetation growth showed a high correlation with r value greater than 0.7. This finding implied that sunlight duration was the most influential factor in the growth of RI and MG. Apparently, optimum sunlight duration affects plant growth. According to Gibson and Paulsen, 1999 the optimum sunlight duration for the plant growth was 16hrs (Gibson and Paulsen 1999). Therefore, meteorological factors such as temperature and relative humidity were found to affect vegetation growth and activity.

5. Conclusions

In this study, factors affecting the plant growth in pilot scale bioretention systems planted with shrubs and a tree and the corresponding nutrient removal efficiencies were analyzed and evaluated. Based on the results of this study, the following conclusions were drawn.

- The growth and activity of plants were found to be affected by seasonal changes, temperature, precipitation, type and geographical location of vegetation, and chlorophyll content. And Climate factors were found to have affected the vegetation applied to LID facilities and these climate factors should be considered in LID design.
- In the summer season when the amount of chlorophyll is high, the TN reduction efficiency of the systems developed was more than 80%, which was higher than the TN removal efficiency during spring and autumn season. This was due to the Environmental conditions such as the high activity of microorganisms and plants during the summer season.
- The removal efficiency pollutants will be different in autumn and winter when plant undergoes dormancy and their growth slowdown, unlike in spring, when plants grow and bloom.
- Depending on the target nutrient parameter, the pollutant removal efficiency of the LID technology may be optimized when appropriate plant according to the application environment and its characteristics were selected. In addition, it can be used as a basis for LID plant selection considering plant growth and environmental conditions

Acknowledgments

This research was funded by the Kongju National University in Korea Research Project 2018. The authors were grateful for their support.

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