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Assessment of salt resistance and performances of LID applicable plants

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ABSTRACT

Various kinds of plants are applied in low impact development (LID) facilities for the restoration of water circulation and removal of pollutants. However, de-icing substances affect plant growth retardation and cause withering of plants. The study was conducted to assess the effect of salinity on plant growth, pollutant removal efficiency, and water circulation recovery using eight kinds of plants. Selected plants applicable to LID are subdivided into three woody and five herbaceous plants. The results showed that herbaceous plants were more affected by air temperature and soil salt content than woody plants, thus showing higher withering rate. The average pollutant removal rate was over 80% due to combined soil and removal mechanisms of plants. Although withering of plants is not significant on pollutant removal efficiency, root depth, temperature sensitivity, and foliage biomass should be considered in determination of plants for enhanced LID facility performance and aesthetic value.

Keywords: $CaCl_2$; Low impact development; Mortality; Plants; Salt resistance

1. Introduction

Urbanization and industrialization have various effects on the biotics and environment of the terrestrial ecosystem and the aquatic ecosystem by increasing the impermeable area such as roads and parking lots. The increase of the impermeable area is due to the demands of humans and vehicular activities which also results in an increase of non-point source (NPS) pollutants from vehicles [1–3]. In urban areas, most of the NPS pollutants coming from the impermeable area during rainfall events are discharged to rivers and lakes without undergoing a particular treatment. The NPS pollutants such as nutrient and heavy metals flowing into rivers and lakes disturb ecosystems and deteriorate water quality. To reduce such water quality degeneration and ecosystem deterioration by the discharge of NPS pollutants, the Ministry of Environment of Korea revised the Act of Water Quality Improvement and Aqua-ecosystem Protection in 2006 to introduce a program on NPS BMP (Non-point Source Best Management Practices) establishment to develop projects. In addition, for the implementation of NPS BMPs, the 2nd NPS Management Strategy was established in 2012, including the application of low impact development (LID) techniques among the main methods of NPS management in the urban area. The LID techniques refer to the methods of maintaining the hydrological mechanisms (infiltration, retention, and evapotranspiration) that nature had before development as much as possible and minimizing the problems caused by the distortion of water circulation after development [4,5]. The key hydrological mechanisms of the LID techniques include the increase of water infiltration, retention and evapotranspiration to mimic the pre-developed hydrologic state of an area. The environmental mechanisms include adsorption, filtration, biodegradation, plant uptake, and the chemical separation mechanisms of pollutants through functions of soil, microorganisms, and plants [6,7].

Among the types of LID techniques, plants are considered important in infiltration type, vegetation type, and retention type which include vegetated swale, bioretention, rain garden, infiltration planter, and constructed wetlands [5,8]. Plants absorb substances such as nutrients and heavy metals contained in rainfall–runoff during the processes of photosynthesis and respiration to reduce the pollutant content in rainfall

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runoff and contribute to water circulation through evapotranspiration [7,9]. Moreover, the plants applied to LID facilities contributes to the creation of green space, improvement of the scenic attraction, and provision of aesthetic value to people [10,11]. In addition, the plants applied to LID facilities can be responsible for urban temperature cooling and prevention of flooding. Due to the diverse functions of the plants, various plants are applied to LID facilities. However, withering of plants caused by spraying of de-icing substances and a sudden water content change in the soil are considered as problems. De-icing substance sprayed to eliminate snow on the roads in winter causes withering of plants by inhibiting the water absorption function of roots. It has been also reported that salts scattered in the air during dry season cause damage to a wide range of plants [12]. When calcium chloride ($CaCl_2$), used as a de-icing agent, flows into the soil through rainfall runoff, it causes stress on plant roots and a direct contact with it may cause growth inhibition due to osmotic pressure. Excessive exposure of plants to calcium chloride may cause withering of a certain plant part or withering of an entire plant [13]. Despite the report about the severe effect of calcium chloride on plants, the effect on the various plants applied to LID in South Korea as well as in other countries has not been studied sufficiently. Therefore, in this study, the effects of salts on the plants applied to LID were assessed through laboratory experiments. Eight kinds of plants applicable to LID facilities were selected.

2. Materials and methods

2.1. Design and operation of pilot plant

The subjects of this study are eight kinds of plants which are generally applied or applicable to LID facilities in South Korea and known to have high soil water content and high salt resistance. The eight kinds of plants include three kinds of woody plants and five kinds of herbaceous plants. The three kinds of woody plants were bridal wreath (*Spiraea japonica* "Glenory gold", S.J), Azalea (*Rhododendron indicum* (L.) Sweet, R.I), and Metasequoia (*Metasequoia glyptostroboides* Hu et Cheng, M.G), and the five kinds of herbaceous plants were sweet flag (*Acorus calamus* var. *angustatus*, A.C), dwarf fan-shape columbine (*Aquilegia flabellata* var. *pumila*, A.F), China pink (*Dianthus chinensis* L., D.C), Pratia pedunculata (*Pratia pedunculata* Benth, P.B), and Marigold (*Tagetes patula* L., T.P).

To analyze the tolerance of the plants to salinity, a pilot plant was prepared as shown in Table 1. The size of the pots for the experiments was determined by considering the soil layer depth of the LID facilities (0.3–0.8 m) to which the plants are applied. The high-rising bridal wreath (S.J), Azalea (R.I), dawn redwood (M.G), and sweet flag (A.C) were planted in pots having the size of 1 m (L) × 0.4 m (W) × 0.6 m (H), considering the stability of the pots and the plants. Dwarf fan-shape columbine (A.F), China pink (D.C), Pratia pedunculata (P.B), and Marigold (T.P) were planted in the pilot plant having the size of 1 m (L) × 0.4 m (W) × 0.4 m (H). To investigate the growth of the plants depending on the salt concentration, four pots were used for each of the plant kinds. Three ports were made at the bottom of the pots to measure the infiltrated water concentration and flow rate for the analysis of the water and mass balances. Synthetic stormwater was applied to the system using 10 L/h flow rate which was equivalent to 20 mm rainfall. This rainfall depth is equivalent to 85% of the rainfall occurring in Cheonan city, South Korea.

2.2. Statistical concentration analysis of influent water

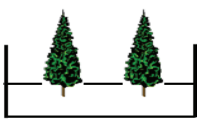
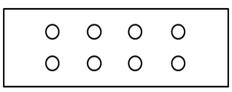
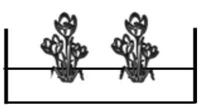
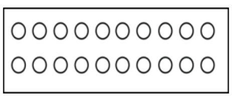
In general, the area of LID facilities is about 0.5% to 2% of the catchment area (CA) [13–15]. In this study, it was assumed that the area of the LID facilities is 1% of the CA. The experimental method was done using synthetic runoff. The quantity of the influent introduced to the experiment was determined as 20 mm with reference to 80% of rainfall occurrence frequency in Cheonan region. In each experiment, 10 L of water was used. Influent water experiment where water was given to the plants was performed one or two times per month. The pollutant concentration of the influent was referenced to the pollutant concentrations in the road runoff during rainfall events, as shown in Fig. 1. The four different concentrations of salinity (0, 0.45, 0.90, and 1.35 g/mol) were applied with reference to the de-icing scattering standard of Korea Highway Corporation (20 g of $CaCl_2/m^2$) [16]. The plant growth measurement and the water quality monitoring were performed once a month, considering the plant growth since April 2015. Total suspended solids (TSS), total nitrogen (TN), total phosphorus (TP), chloride (Cl^-), and heavy metals including lead (Pb), copper (Cu), and zinc (Zn) are the parameters to be analyzed for water quality assessment.

3. Results and discussion

3.1. Monthly mortality rate of plants

Plants grow through processes of photosynthesis and respiration. In the photosynthesis process, uptake of water

Table 1
Characteristics of pilot plants

Type	Schematic	Plant arrangement	Pot size (L × W × H , m)	Plant species
A			1 × 0.4 × 0.4	Bridal wreath, Azalea, Metasequoia, sweet flag
B			1 × 0.4 × 0.6	Dwarf fan-shape columbine, China pink, Pratia pedunculata, Marigold

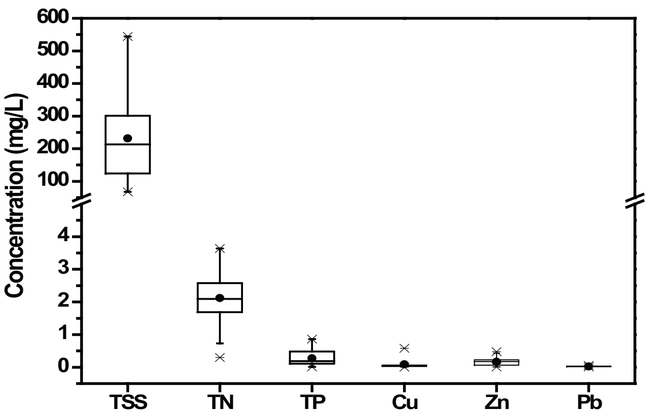


Fig. 1. Boxplots of influent concentrations.

and nutrients happens through the root, and uptake of carbon dioxide (CO_2) and discharge of oxygen and water molecules take place through the foliage. Plant roots not only play the key roles in the photosynthetic process but also create an environment for soil microbial activities, and retardation and reduction of physical pollutants. The monthly growth state of the eight kinds of plants planted in the pilot plant is shown in Table 2, it can be seen that the three woody plants including bridal wreath (S.J), Azalea (R.I), and dawn redwood (M.G) are the vertically grown type of plants. In the cases of the herbaceous plants, sweet flag (A.C), dwarf fan-shape columbine (A.F), and Marigold (T.P) are also vertically grown types, while China pink (D.C) and Pratia pedunculata (P.B) were of the horizontal type of growth.

Fig. 2 shows the accumulated mortality rate of the plants in each month. The plant mortality was dependent on the air temperature and the salinity in the soil. The plant growth has generally stopped or slowed down after August as the air temperature was decreased. Among the three woody plants, the effect of calcium chloride was strong in the order of bridal wreath (S.J) > Azalea (R.I) > dawn redwood (M.G), and the mortality was increased at concentrations higher than 0.90 g/mol $CaCl_2$. In the cases of the five herbaceous plants, the mortality rate was in the order of Pratia pedunculata (P.B) > dwarf fan-shape columbine (A.F) > Marigold (T.P) > China pink (D.C) > sweet flag (A.C). It was found that sweet flag (A.C) and China pink (D.C) had high resistance to air temperature change and high salt concentration, showing a low mortality rate. Dwarf fan-shape columbine (A.F) and Pratia pedunculata (P.B) were very sensitive to salt concentration and air temperature, whereas T.P was found to be most sensitive to salt concentration only.

3.2. Changes of pollutant removal efficiency with $CaCl_2$ concentrations

Generally, road rainfall runoff contains various heavy metals due to the activities of vehicles. Cu, Pb, and Zn are the heavy metals most frequently detected in the road and urban area rainfall runoff, and the concentrations are also higher than other heavy metals [3]. In this study, the efficiency of pollutant removal by the plants applied to the LID techniques was calculated, and the effect of salinity on the reduction efficiency was investigated. The pollutant removal efficiency was analyzed with respect to the nutrients and heavy metals which may be removed by plants and soil microorganisms.

Fig. 3 shows the pollutant removal efficiency of the individual plants in the pilot plant. Regardless of the salinity injected, the pollutant removal efficiency was 60% or higher with respect to TN, and 80% or higher with respect to TP and heavy metals. The nitrifying and de-nitrifying bacteria, as well as the uptake by plant photosynthesis, allowed high removal efficiency of TN. However, the TN removal efficiency was decreased as salinity was increased, which is related to the activities of decreased de-nitrifying bacteria and decreased plant activity due to osmosis. In the case of TP, the removal efficiency was also high. This is attributed to the physical adsorption mechanism. The salinity of plants has partly affected removal efficiency due to minimized plant activity.

3.3. Flow reduction by plants and soil media

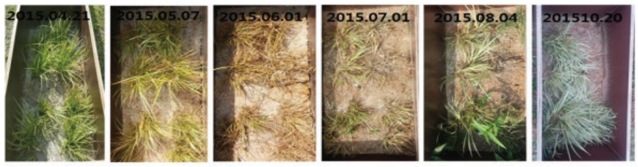
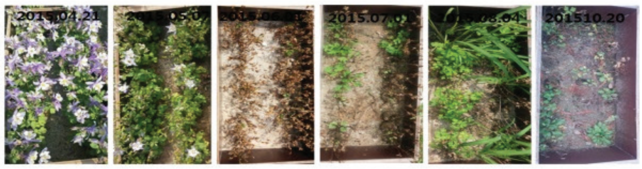
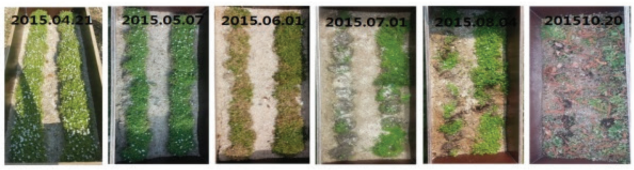
Ecological pollutant removal and recovery of natural water circulation are key functions of LID facilities. Ecological pollutant removal is manifested by the activities of plants and microorganisms and the physiochemical mechanisms of soil and media. On the other hand, the natural water circulation enhanced by the LID facilities is manifested by the increase of water retention and infiltration originated from the voids and infiltration capacity of the soil media as well as by the evapotranspiration due to the plant photosynthesis. The study was done to analyze the flow reduction by the plants applied to the LID facilities and the variation of the water retention depending on the salinity increase. Fig. 4 shows the average flow reduction by the eight kinds of plants. The average flow reduction in the pilot plant in where the plants were planted reached about 80% to 90%. The photosynthesis became slow as the salinity of the inflow was increased, but the water retention in the soil was not greatly affected because the water retention was increased by the salts accumulated in the soil. However, the plants showed different amounts of water retention. Dawn redwood showed the largest water retention caused by the void expansion in the facilities due to the high rate of photosynthesis and root growth. China pink, having shallow roots, showed the smallest water retention in the soil.

4. Conclusions

Various kinds of plants are applied in LID facilities to reduce water circulation distortion and control of NPS pollutant discharge caused by urbanization. However, a drastic change of soil water content caused by spraying of de-icing substances in winter and slowing of plant growth may cause problems such as plant withering. This study was conducted to assess salinity resistance and plant growth capacity of eight selected kinds of plants. Following conclusions were made on the basis of the results:

1. Among the woody plants, dawn redwood (M.G) showed the highest salinity tolerance in comparison with bridal wreath (S.J) and Azalea (R.I). Among the herbaceous plants, sweet flag (A.C) and China pink (D.C) showed the

Table 2
Selected LID plants and monthly plant growth

Plant species	Scientific name	Photo	Monthly change of 1.35 g/mol $CaCl_2$ pot
Bridal wreath	*Spiraea japonica* (S.J)		
Azalea	*Rhododendron indicum* (L.) Sweet (R.I)		
Dawn redwood	*Metasequoia glyptostroboides* Hu et Cheng (M.G)		
Sweet flag	*Acorus calamus* var. *angustatus* (A.C)		
Dwarf fan-shape columbine	*Aquilegia flabellata* var. *pumila* (A.F)		
China pink	*Dianthus chinensis* L. (D.C)		
Pratia pedunculata	*Pratia pedunculata* Benth (P.B)		
Marigold	*Tagetes patula* L. (T.P)		

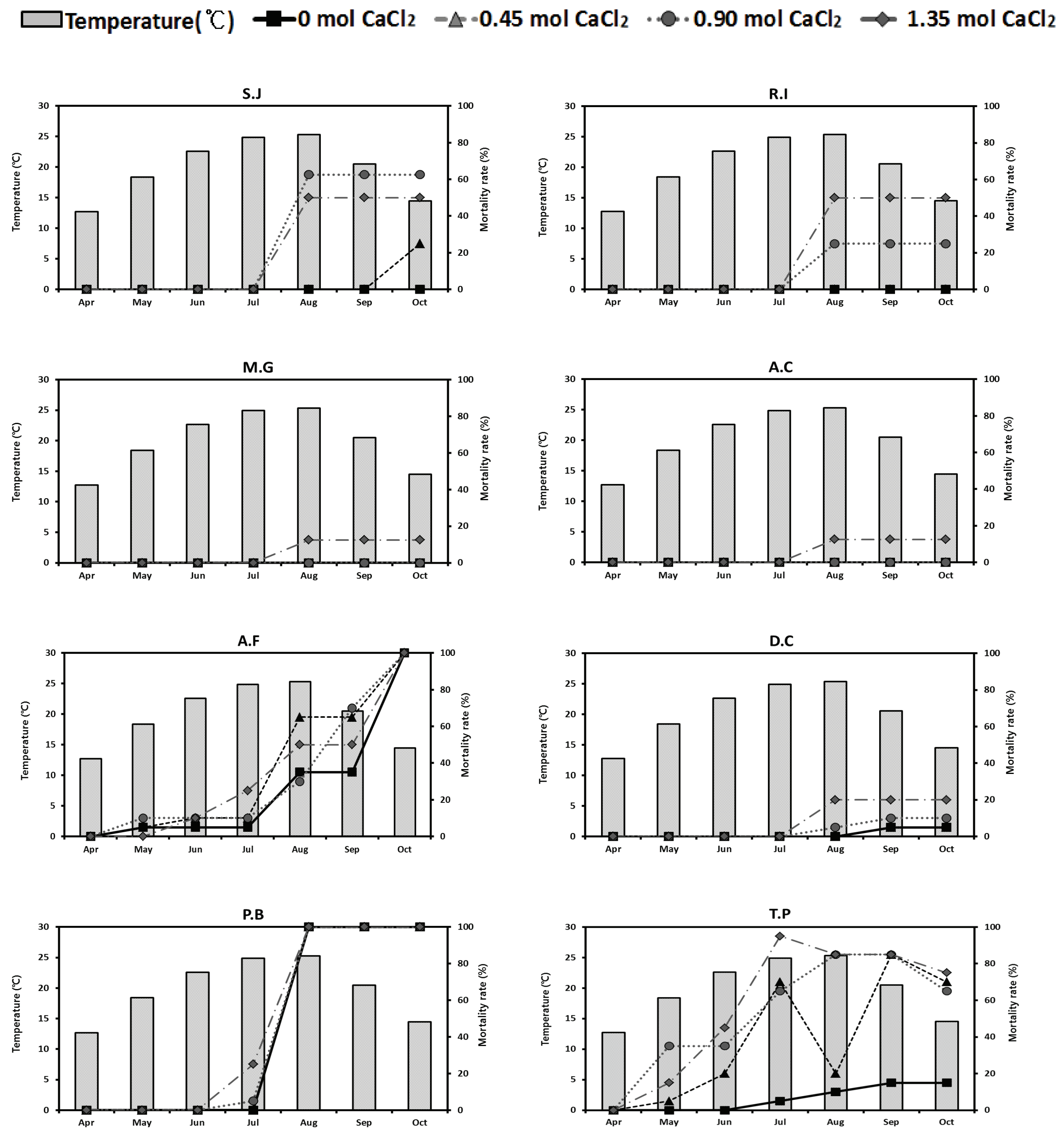


Fig. 2. Monthly mortality rate of plants.

highest salinity tolerance, while dwarf fan-shape columbine (A.F), Marigold (T.P), and Pratia pedunculata (P.B) showed low salinity tolerance. These salinity tolerance data should be considered when applying plants to LID facilities.

2. When rainfall runoff containing calcium chloride flows into a LID facility, a plant showing the horizontal type of growth with shallow roots is first affected by the salts accumulated on the plant surface. However, among the plants with shallow roots, China pink (D.C), growing well in the extreme environment, showed strong salinity tolerance, indicating that it may be applied to LID facilities.
3. The TN removal efficiency was as high as 80% in average because of the high activity of soil bacteria and the photosynthesis and pollutant uptake by the plants. The high TP removal efficiency was on the basis of physical adsorption. The high heavy metal removal efficiency

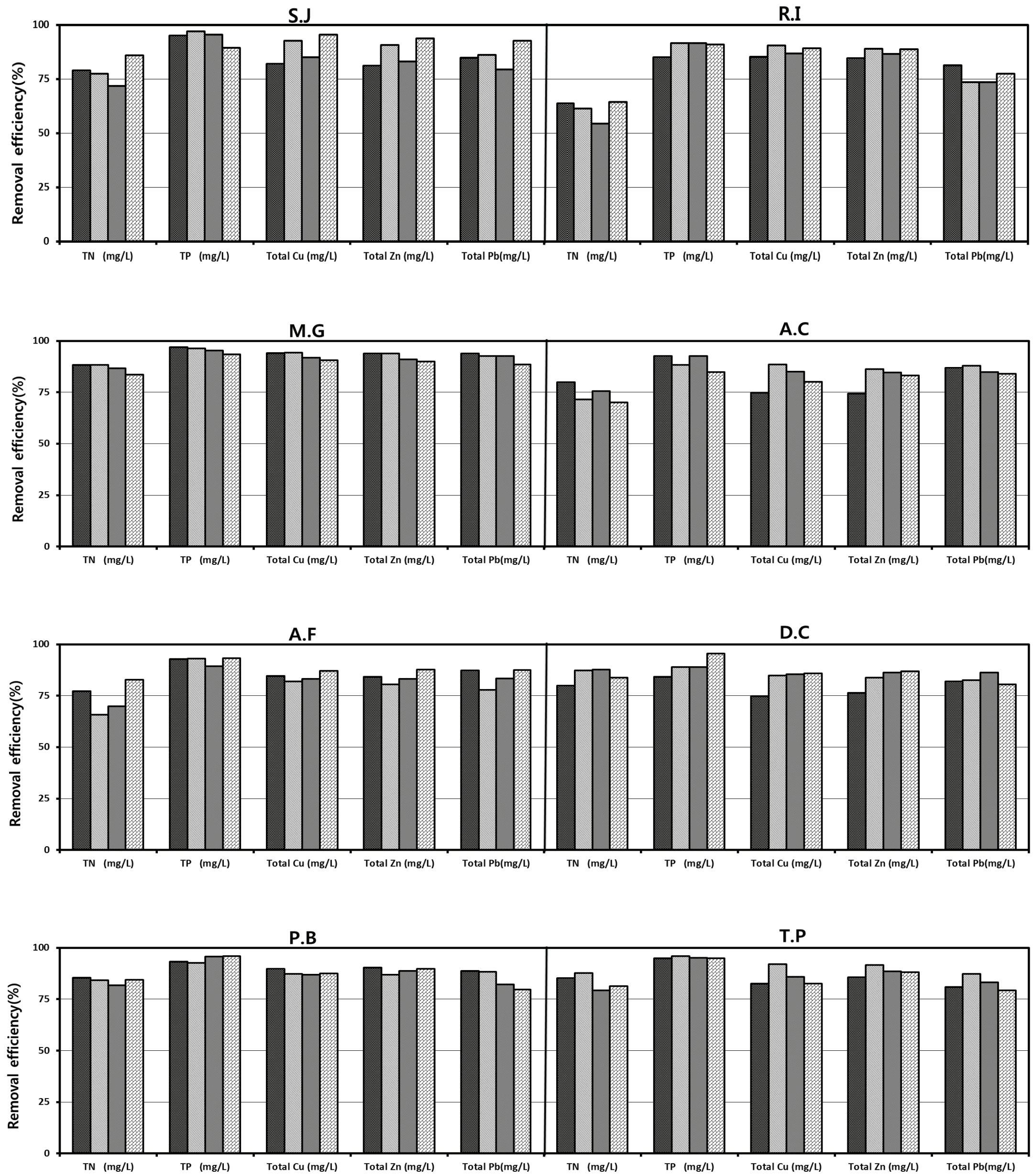


Fig. 3. Changes of pollutant removal efficiency with $CaCl_2$ concentrations.

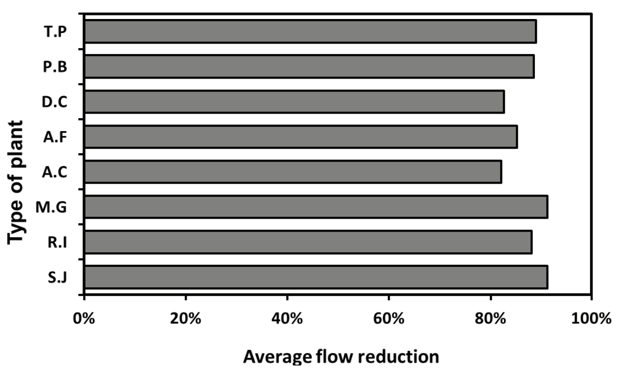


Fig. 4. Average flow reduction by plants and soil media.

was because of the physical adsorption to the soil media.

4. The flow reduction by the pilot plant was in the range from 80% to 90%, depending on the kinds of plants. Dawn redwood showed the largest water retention caused by the void expansion due to the high rate of photosynthesis and root growth. China pink, having shallow roots, showed the smallest water retention in the soil.

Acknowledgements

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