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# Implications of $CaCl_2$ application to plants in LID facilities

H. S. Choi, J. S. Hong, F. K. F. Geronimo and L. H. Kim

## ABSTRACT

Low impact development (LID) technologies mimic the natural water cycle through the physico-chemical and biological interactions of plants, filter media and soil, and microorganisms, thereby reducing the release of pollutants. In LID facilities, plants carry out photosynthesis, facilitate microbial growth, and uptake pollutants contained in stormwater runoff. However, de-icers ($CaCl_2$) used to melt snow during winter slow the growth of plants and even increase plant mortality. In addition, de-icers change the soil structure, causing changes in soil content and affecting the growth of plants and microorganisms. Therefore, this study examined the effects of $CaCl_2$ on the resistance of plants, the removal efficiency of non-point source pollutants, and water circulation. The mortality rate of the tree and shrubs caused by $CaCl_2$ was found to be in the order of *Rhododendron indicum* > *Spiraea prunifolia* var. *simpliciflora* > *Metasequoia glyptostroboides*. For herbaceous plants, mortality rate was in the order of *Pratia pedunculata* > *Aquilegia japonica* > *Tagetes erecta* > *Sedum makinoi aurea* > *Hosta longipes* > *Dianthus chinensis* > *Acorus gramineus* > *Liriope platyphylla*. In addition, it was found that the amount of chlorophyll decreases with high concentrations of $CaCl_2$. The findings of this research will be useful for plant selection considering $CaCl_2$ concentrations applied to paved areas during the winter.

**Key words** | $CaCl_2$, LID, plant mortality, plants, water circulation

**H. S. Choi** (corresponding author)
**J. S. Hong**
**F. K. F. Geronimo**
**L. H. Kim**
Department of Civil and Environmental Engineering,
Kongju National University,
275 Budae-dong, Cheonan, Chungnamdo, 31080, South Korea
E-mail: *hyeseon27@kongju.ac.kr*

## INTRODUCTION

Rapid industrialization and urbanization from the mid-20th century onwards have provided goods and spaces essential for human activity. However, the increase in impermeable surfaces such as roads, parking lots and buildings has led to problems such as interference with the natural hydrological cycle, the urban heat island effect, and increased non-point source (NPS) pollutants. Seoul recorded that 47.7% of its surfaces were impermeable in 2010, and most were found to be roads and houses with imperviousness rate of greater than 90% (Seoul Metropolitan Government 2013; Zhou *et al.* 2016). Increased impermeable areas interrupt the natural hydrological cycle by decreasing the underground infiltration rate and increasing surface runoff during heavy rainfall. NPS pollutants are released into water bodies, which causes water pollution and destroys aqua-ecosystems. The resulting decrease in green space and underground infiltration rate has been identified as the cause lower groundwater level and the increased probability of urban flooding.

Low impact development (LID) technologies are being applied to address the above-mentioned urban problems, and have been found to be effective in the restoration of the natural hydrological cycle, flood prevention, provision of habitats for organisms, removal of NPS pollutants and ecosystem restoration. LID refers to the method of efficiently managing stormwater runoff containing NPS pollutants while maintaining natural hydrological functions such as infiltration, subsurface flow and evapotranspiration (MOE 2014; Zhang *et al.* 2016). In general, LID include technologies such as constructed wetlands, vegetative filter strips, bioretention, tree box filters, rain gardens, planters, permeable pavements, green roofs and rainwater harvesting. These technologies achieve ecological, hydrological and environmental effects through interactions with plants, soil, filter media, and microorganisms. In particular, plants play a key role in LID facilities, contributing to the reduction of the heat island effect, reduction of carbon, removal of pollutants, establishment of an ecological environment for microorganisms, and enhanced aesthetics (Kim 2014; Seoul Metropolitan Government 2015). However, it was found recently that the use of de-icers to remove heavy snow during the winter hinders plant growth (Macadam & Parsons 2004; Korea Highway Corporation report 2007). The

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**Table 1** | Plants commonly used in LID technologies

| Classification | Scientific name | Code |
|---|---|---|
| Shrub | *Spiraea prunifolia* var. *simpliciflora* (Nakai) Nakai | SJ |
| | *Rhododendron indicum* (L.) Sweet | RI |
| Tree | *Metasequoia glyptostrobodides* Hu & W.C. Cheng, | MG |
| Herbaceous | *Aquilegia japonica* Nakai & Hara, | AF |
| | *Dianthus chinensis* L. | DL |
| | *Pratia pedunculata* (R.Br.) Benth. | PB |
| | *Acorus gramineus* Aiton, | AS |
| | *Tagetes erecta* L. | TL |
| | *Liriope platyphylla* F.T. Wang & Tang | LP |
| | *Hosta longipes* (Franch. & Sav.) Matsum. | HL |
| | *Sedum makinoi aurea* | SA |

excessive use of de-icers changes the structure of soil particles, causing non-uniformity in soil infiltration and affecting photosynthesis among plants. An elevated salt content in soil accelerates drying, and the crusting of soil hinders germination and root growth. Moreover, excessive salt accelerates the mobility of heavy metals within the soil, and plants are threatened by heavy metal toxicity (Viskari *et al.* 2000; Transportation research board guideline 2007; Dubuque 2010; Shin *et al.* 2010; Oh 2014). While Korea has established guidelines on the use of de-icers, few studies exist on the effects of de-icers on different plants. Therefore this study assesses the effects of $CaCl_2$ de-icer on plants commonly used in LID facilities.

## RESEARCH METHODS

### Selection of plants for LID assessment

Eleven plant species that are commonly used in LID facilities in South Korea were selected to evaluate the effects of $CaCl_2$, and these are listed in Table 1: two shrubs, one tree, and eight herbaceous plants. More specifically, the deciduous broadleaf shrub, evergreen shrub and deciduous tree were *Spiraea prunifolia* var. *simpliciflora* (Nakai) Nakai, *Rhododendron indicum* (L.) Sweet, and *Metasequoia glyptostroboides* Hu & W.C. Cheng, respectively. The herbaceous plants were mostly perennials: *Acorus gramineus* Aiton, *Aquilegia japonica* Nakai & Hara, *Dianthus chinensis* L., *Pratia pedunculata* (R.Br.) Benth., *Tagetes erecta* L., *Liriope platyphylla* F.T. Wang & Tang, *Sedum makinoi aurea* (SA), and *Hosta longipes* (Franch. & Sav.) Matsum. The plants monitored were 2–3 years old.

### Design of pilot plant

The pilot plant used in this experiment was designed to have a soil depth ranging from 0.3 to 0.8 m. Because woody plants such as SJ, RI, MG, and AS grow rapidly with longer root depth, these plants were planted in pots measuring 1 m (L) × 0.4 m (W) × 0.6 m (H), while AF, DL, PB, and TL herbaceous plants were planted in pots measuring 1 m (L) × 0.4 m (W) × 0.4 m (H) as shown in Figure 1. Soil and sand compatible with LID technologies were used to ensure the restoration of the natural hydrological cycle, provide nutrients for plant growth, and contribute to the removal of pollutants. To ensure high drainage capacity and include sufficient nutrients, sand and original soils were mixed in a ratio of 3:7 (Korea Land & Housing Corporation report 2014).

The surface area of an LID facility should be about 0.5% to 2% of the catchment area (Moon 2015; Yu 2015). The theoretical catchment area used in this study was 40 $m^2$, meaning that the surface area of the LID technology made up only about 1% of the catchment area (CA). In order to assess the effects of $CaCl_2$ on plants, Equation (1) was used to calculate the influent concentration based on the standard de-icer amount (20 g per $m^2$) (Korea Highway Corporation report 2007).

$$\text{Concentration of } CaCl_2(\text{mg/L}) = \frac{CA(m^2) \times CaCl_2(g)}{CA(m^2) \times \dfrac{Rainfall(mm)}{1000}} \quad (1)$$

Table 2 shows the four cases of varying $CaCl_2$ concentrations used in the experiment: 0 mg/L, 500 mg/L, 1,000 mg/L, 1,500 mg/L of $CaCl_2$. 1,000 mg/L is the standard concentration used by the Korea Highway Corporation, and influent water was prepared at 0.5 and 1.5 times the standard concentrations. In addition, sediments collected from roads were passed through sieve No. 100 and added to the influent tapwater to mimic the typical influent concentration of stormwater running off from roads (Sung *et al.* 2009).

### Monitoring and data analysis

Monitoring of plants was conducted from April 2015 to October 2016. The pilot test was conducted once or twice a month in consideration of antecedent dry days (ADD) and plant growth. The influent volume was 10 L, based on a reference rainfall of 20 mm, which is 80% of the accumulated rainfall occurrence frequency in Cheonan.

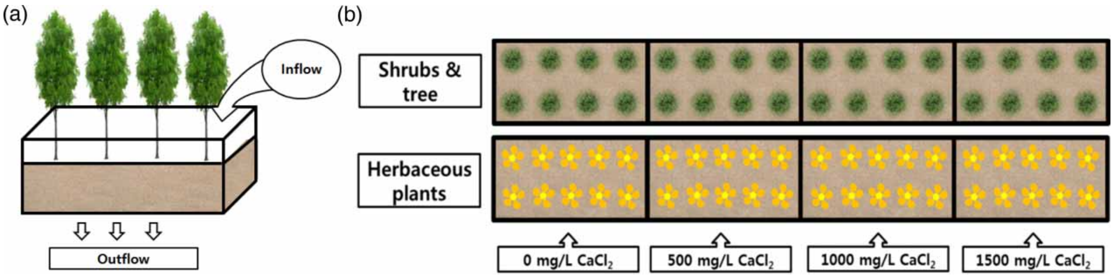


**Figure 1** | Schematic design of the pilot plant; (a) cross section view, (b) plan view.

**Table 2** | Influent concentration per case

| Type | Inflow water concentration | mg/L |
|---|---|---|
| Control | water 10 L + sediment 10 g | 0 |
| Case 1 | water 10 L + sediment 10 g + $CaCl_2$ 5 g | 500 |
| Case 2 | water 10 L + sediment 10 g + $CaCl_2$ 10 g | 1,000 |
| Case 3 | water 10 L + sediment 10 g + $CaCl_2$ 15 g | 1,500 |

As for the outflow, the flow rate was measured at 30-min intervals at 0, 30, 60, 90, and 120 min. The samples collected up to 120 min of outflow were sampled and analyzed using *Standard Methods for the Examination of Water and Wastewater* (APHA/AWWA/WEF 2005). To assess the effects of $CaCl_2$ on plants, the rate of mortality was investigated twice a month. As shown in Equations (2) and (3), the dry matter (DM) and root/shoot (R/S) ratio of plants were calculated to evaluate plant activity. A chlorophyll-measuring instrument (SPAD-502) was used to determine the amount of chlorophyll per unit area of plant. Each plant was sampled every season and separated into shoots and roots. Dry weight (DW) was measured after drying at 50 °C until no further changes in weight were observed (Kalra 1998).

$$\text{DM (Dry matter, \%)} = \frac{\textit{Dry weight (DW)}}{\textit{Fresh weight (FW)}} \times 100 \quad (2)$$

$$\text{R/S (root/shoot ratio)} = \frac{\textit{Root dry weight}}{\textit{Shoot dry weight}} \times 100 \quad (3)$$

## RESULTS AND DISCUSSION

### Monitoring and data analysis

Figure 2 shows the monthly mortality rate of plants in relation to $CaCl_2$ concentration. In the year 2015, SJ, MG, RI, AF, DL, AS, PB, and TL plants were analysed while LP, SA, and HL were reselected and replanted for analysis in the year 2016 due to the death of some plants such as AS, PB and TL.

SJ had a higher mortality rate when the concentration of $CaCl_2$ was greater than 1,000 mg/L, and less than 40% at a concentration below 500 mg/L. The mortality rate of RI increased with $CaCl_2$ concentration, indicating that plant growth is influenced by $CaCl_2$. It is apparent that when water availability is restricted by salinity, all the factors which regulate or influence water absorption and water loss by plants contribute in some way to salt tolerance (Hayward & Bernstein 1958; Navarro *et al.* 2000; Kaya *et al.* 2002). MG was observed to have higher mortality at 1,500 mg/L $CaCl_2$ concentration, but showed a lower mortality rate of 17.5% compared to SJ and RI. Among the three types of trees and shrubs, MG showed the greatest tolerance to $CaCl_2$.

An analysis of the monthly mortality rates for the eight types of herbaceous plants showed that AS had the lowest mortality rate of 5%. Depending on the plant growing season, AF showed a high mortality rate after July. The longer sunshine exposure of 7.2 hours in the summer of 2015 caused PB to have a rapid increase in mortality rate. Both TL and DL had mortality rates of about 20% at the highest concentration of 1,500 mg/L, but very low mortality rates at lower concentrations. These species were rated as having a high tolerance to $CaCl_2$. LP was observed to have high growth despite $CaCl_2$ application. Meanwhile, some of SA died due to heavy rainfall (greater than 300 mm) in July 2016. HL mostly died after August. The relatively high mortality rate of plants which were not exposed to $CaCl_2$ indicated that plant death was caused not only by $CaCl_2$ but also was related to annual plant life cycle. The mortality of herbaceous plants in relation to $CaCl_2$ concentration was in the order of PB > AF > TL > SA > HL > DL > AS > LP. In particular, herbaceous plants have shallow roots that caused them to be more easily exposed to $CaCl_2$. As such, these plants were more affected by high concentrations of $CaCl_2$ than the shrubs and trees.

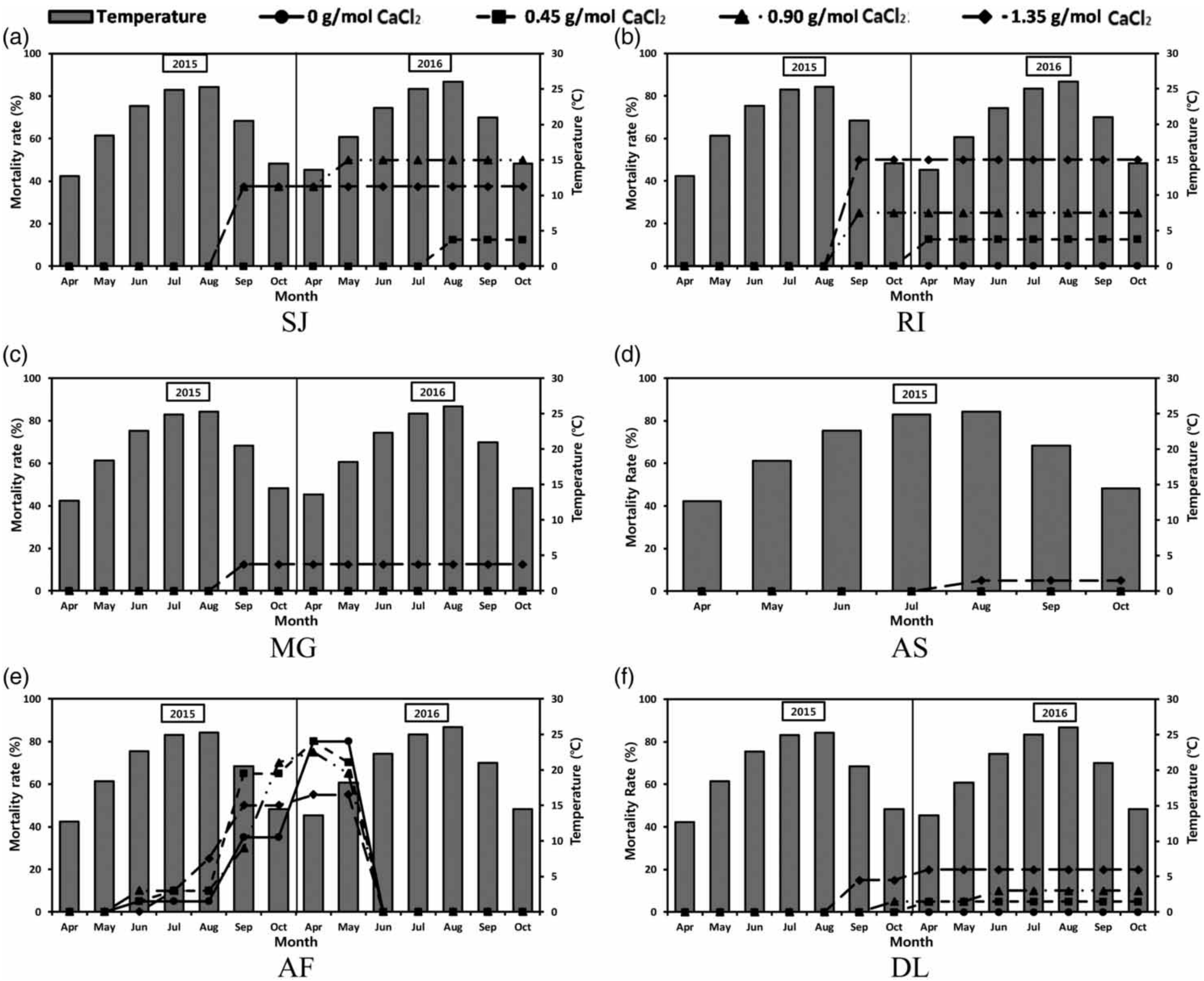


**Figure 2** | Monthly mortality rate of plant species. (*Continued*.)

## Monthly rate of dry matter and R/S ratio

The change in moisture is an index that provides information on plant water stress (Han 2009; Shishi *et al.* 2015). Plants experience greater water stress when the water content in the soil decreases. Table 3 shows the plant biomass and DW of shoots, the biomass weight and DW of roots, the DM rate, and the root/shoot (R/S) ratio in relation to $CaCl_2$ concentration. The DM for the SJ control was 19.5% lower compared to the experimental group in which 1,500 mg/L $CaCl_2$ was applied, with a DM content of about 67.1%. RI had a DM rate of 79.0% for the control group, but 71.8% for the experimental group after exposure to a high concentration (1,500 mg/L) of $CaCl_2$. The R/S ratio decreased by 56% from 2.40 to 1.35 for SJ, and by 65% from 2.87 to 1.89 for RI. MG, on the other hand, was unaffected in terms of DM rate and R/S ratio. The DM rate and R/S ratio were analyzed for the eight types of herbaceous plants in relation to $CaCl_2$ concentration. AS was identified as the most affected herbaceous plant by $CaCl_2$ application, whereas the DM rates of AF, DL, PB, TL, and SA were unaffected. High concentrations of $CaCl_2$ influenced the DM rates of LP and HL. The R/S ratio decreased for AF and TL but remained largely unaffected for DL, PB, and LP. The roots were more influenced by $CaCl_2$ compared to shoots in the case of trees and shrubs (SJ, RI) and herbaceous plants (AS, AF, TL, and HL), which saw a decrease in the R/S ratio. $CaCl_2$ has a greater impact on the roots of herbaceous plants than trees and shrubs because calcium chloride causes membrane decay

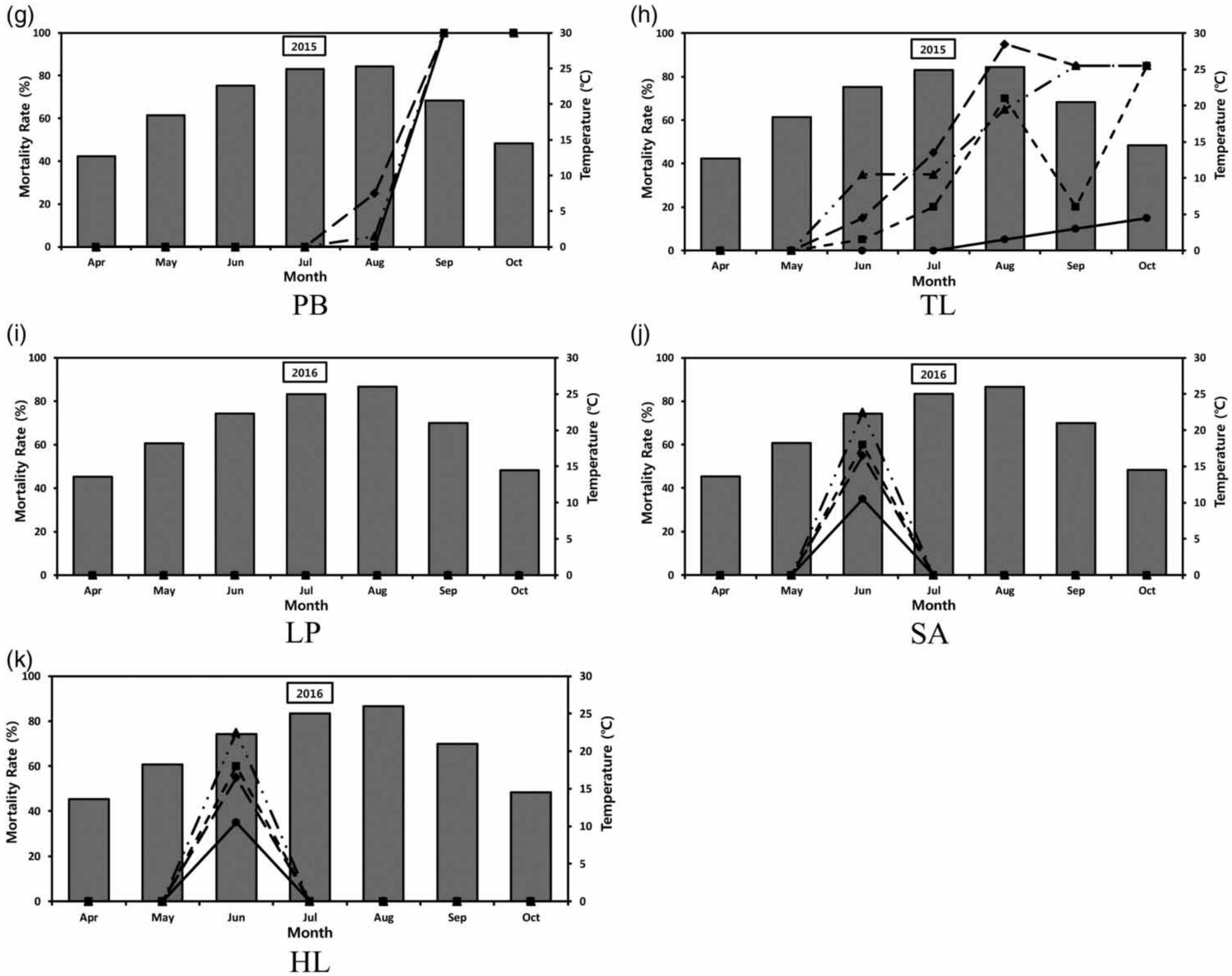


**Figure 2** | Continued.

of plants, suppression of nitrogen uptake and disruption of ion transport, resulting in plant death (Cerda & Martinez 1988; Cachorro *et al.* 1994; Shen *et al.* 1994; Tuna *et al.* 2007).

## Changes in chlorophyll with $CaCl_2$

Figure 3 shows the changes in the amount of chlorophyll per unit area for the control group (0 mg/L) and experimental group before and after the introduction of $CaCl_2$ (1,500 mg/L) in spring and summer. In spring, the amount of chlorophyll decreased by 0.4 to 8.6 μg/cm$^2$ after the introduction of $CaCl_2$. For SJ and RI, the amount of chlorophyll increased by 0.5 μg/cm$^2$ for the control group, but was observed to have a greater increase in chlorophyll for the experimental group of about 1.0 to 8.6 μg/cm$^2$ when exposed to a high concentration of $CaCl_2$. The amount of chlorophyll decreased for AF, DL, and HL when $CaCl_2$ was introduced at a concentration of 1,500 mg/L, indicating that $CaCl_2$ has an influence on the amount of chlorophyll. In summer (July), when plants were observed to have the highest growth, SJ, MG and DL showed an increase in chlorophyll regardless of the concentration of $CaCl_2$. However, RI, LP, AF, and HL exhibited a decrease in chlorophyll in relation to the introduction of $CaCl_2$. From the higher concentration of chlorophyll per unit area in spring compared to summer, it can be observed that the concentration of chlorophyll is affected not only by the concentration of $CaCl_2$ but by environmental factors, specifically sunlight and rainfall. The rate of photosynthesis varies according to the genetic difference

**Table 3** | Plant dry matter content and root/shoot ratio per species

| Species | Concentration (mg/L) | Shoots FW | Shoots DW | Roots FW | Roots DW | DM (%) | R/S |
|---|---|---|---|---|---|---|---|
| SJ | 0 | 51.4 | 39.8 | 75.1 | 67.1 | 82.6 | 2.4 |
| | 1,500 | 47.8 | 35.7 | 61.7 | 56 | 67.1 | 1.35 |
| RI | 0 | 99 | 75.3 | 183.7 | 145.4 | 79.0 | 2.87 |
| | 1,500 | 71.2 | 57.7 | 110.5 | 87.5 | 71.8 | 1.89 |
| MG | 0 | 123 | 55.6 | 88.6 | 66.9 | 61.7 | 1.55 |
| | 1,500 | 107.3 | 87.5 | 116.3 | 106.3 | 81.3 | 1.82 |
| AS | 0 | 72.7 | 26.7 | 59.2 | 24.8 | 53.0 | 2.09 |
| | 1,500 | 26.6 | 16 | 33.2 | 24.8 | 41.0 | 1.33 |
| AF | 0 | 62.2 | 21.1 | 25.4 | 14.6 | 62.9 | 1.14 |
| | 1,500 | 7.6 | 7.6 | 13.9 | 9.9 | 69.9 | 0.66 |
| DL | 0 | 40.1 | 15.8 | 34.7 | 16.7 | 56.1 | 0.60 |
| | 1,500 | 36.8 | 23.6 | 37.7 | 24.4 | 59.7 | 0.90 |
| PB | 0 | 133.4 | 24 | 47.6 | 24 | 66.4 | 0.90 |
| | 1,500 | 7.4 | 7.0 | 30.7 | 14.1 | 81.7 | 1.00 |
| TL | 0 | 31.7 | 15.1 | 17.9 | 11.7 | 62.3 | 0.80 |
| | 1,500 | 27.1 | 20.1 | 16.2 | 8.3 | 71.7 | 0.20 |
| LP | 0 | 10.1 | 8.6 | 18.2 | 11.8 | 72.0 | 1.37 |
| | 1,500 | 16.5 | 7.3 | 22.9 | 14 | 54.1 | 1.90 |
| SA | 0 | 77.5 | 16.4 | – | – | 21.2 | – |
| | 1,500 | 78.2 | 29.4 | – | – | 37.6 | – |
| HL | 0 | 25.5 | 13.5 | 27.1 | 17.9 | 59.6 | 1.33 |
| | 1,500 | 31.2 | 17.1 | 29.1 | 13.5 | 50.7 | 0.79 |

of plant species and the rate of photosynthesis is only useful as a selection criterion for salt tolerance in those species in which there is a close relationship between photosynthesis and growth under salt stress (Lakshmi *et al.* 1996; Tezara *et al.* 2002; Burman *et al.* 2003).

## Changes in soil infiltration rate with $CaCl_2$

A higher calcium chloride concentration accelerates the coagulation of soil particles, which leads to a higher permeation coefficient and influences the water content. In addition, soil exhibits hydrophobic properties, resulting in increased cations and facilitating acidification. When the water content in soil decreases, the soil becomes non-uniform and causes problems for plant growth (Transportation Research Board guideline 2007). Figure 4 shows the change of soil infiltration rate in relation to the concentration of $CaCl_2$. The control group (0 mg/L) showed an infiltration rate of 2.8–12.2 mm/h after 30 min but was later decreased to 0.7–2.6 mm/h at 60 min. At a high concentration (1,500 mg/L), the infiltration velocity was 2.5–8.1 mm/h at 30 min, and 0.60–3.0 mm/h at 60 min. The initial infiltration rate of approximately 50 mm/h decreased to 0.15–3 mm/h at the end of the experiment. This can be attributed to the influent being introduced using the pulse input method, such that the saturation of the soil drops after a certain period. If the influent is introduced continuously, a higher and more stable infiltration rate can be achieved. The concentration of $CaCl_2$ is likely to have influenced the infiltration rate as the soil was sufficiently drained,

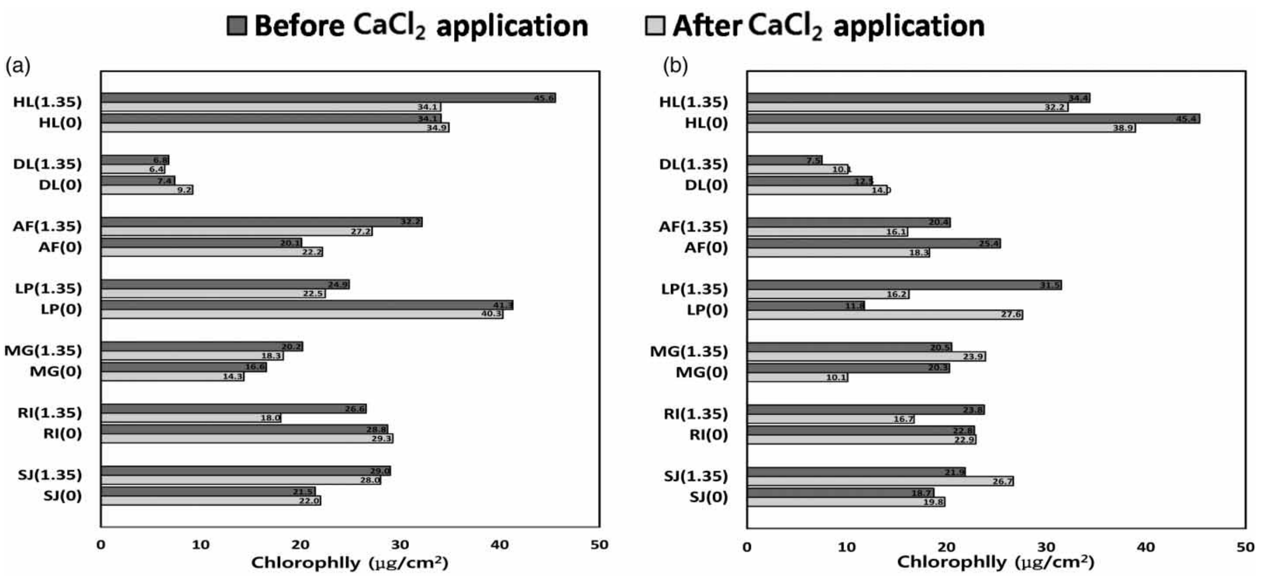


**Figure 3** | Changes in chlorophyll content with respect to $CaCl_2$ application: (a) spring, (b) summer.

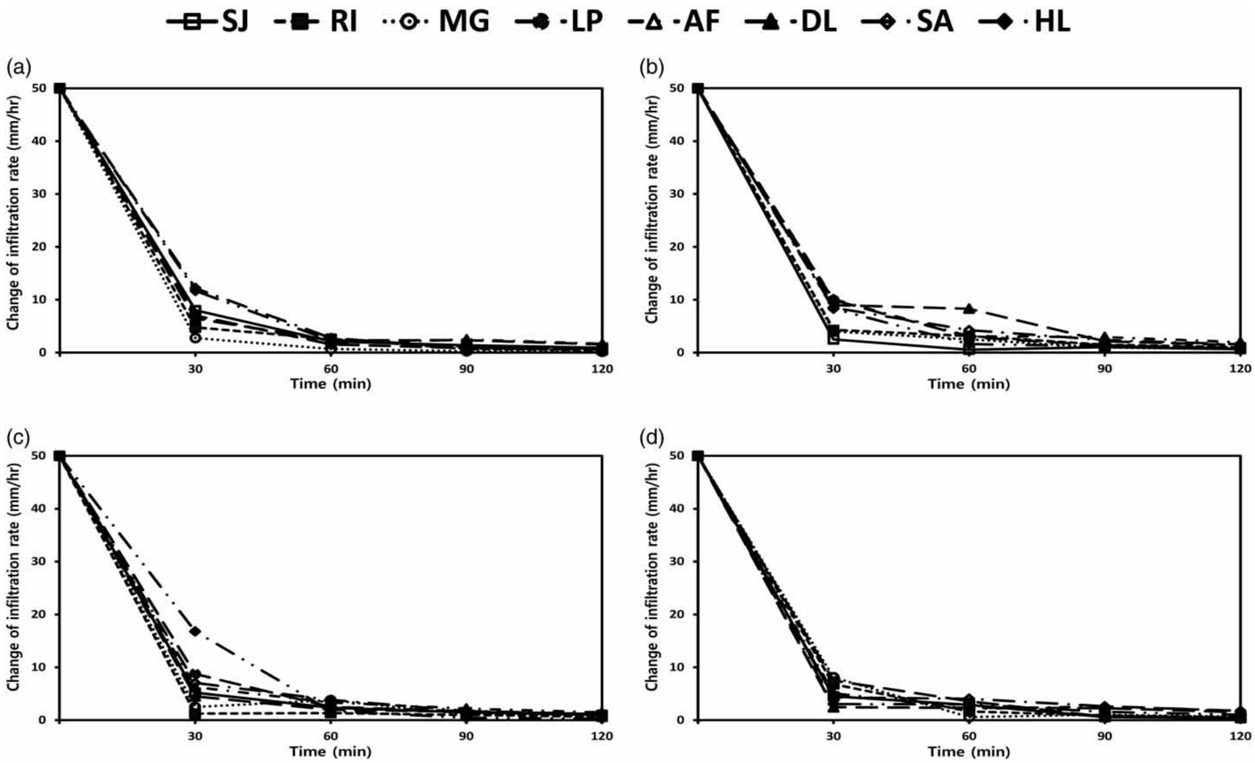


**Figure 4** | Changes in soil infiltration rate with respect to $CaCl_2$ concentrations. (a) 0 mg/L $CaCl_2$, (b) 500 mg/L $CaCl_2$, (c) 1000 mg/L $CaCl_2$, (d) 1500 mg/L $CaCl_2$.

providing a high drainage capacity. By plant species, herbaceous plants exhibited faster declines in infiltration rate compared to the tree and shrubs. This finding was attributed to the roots of plants and the activity of roots in relation to $CaCl_2$. In general, all species showed similar infiltration rates at 60–90 min because the soil saturation dropped with rapid drainage up to 60 min. Since it is essential for LID facilities to maintain an adequate level of water content within 3 days of the end of heavy rain, the change of infiltration constant in relation to $CaCl_2$ and type of plants can be used to calculate the adequate infiltration rate.

## CONCLUSIONS

Plants are widely used in LID technologies because they establish natural water circulation based on undercurrent, infiltration, and evapotranspiration. However, de-icers ($CaCl_2$) used to melt snow during the winter change the soil content and affect the growth of plants. This study assessed the effects of $CaCl_2$ application to plants in LID technologies. Based on the results, the following conclusions were drawn.

1. The mortality rates of the tree and shrubs in relation to the application of $CaCl_2$ was in the order RI > SJ > MG, while that of herbaceous plants was in the order PB > AF > TL > SA > HL > DL > AS > LP. Herbaceous plants have shallow roots that caused more exposure to $CaCl_2$ and they were therefore more affected by high concentrations of $CaCl_2$ compared to the tree and shrubs.
2. An evaluation of plant activity (DM rate, R/S ratio and amount of chlorophyll) showed a decrease in the amount of chlorophyll when exposed to a high concentration of $CaCl_2$. This finding indicated that the amount of chlorophyll is significantly influenced by $CaCl_2$. Compared to herbaceous plants, the tree and, shrubs were found to have a higher tolerance to $CaCl_2$.
3. Both the DM rate and R/S ratio were found to decrease at increasing $CaCl_2$ concentrations for AS, SJ and RI. On the other hand, it was found that the DM rate and R/S ratio of MG, DL, SA and PB were not affected by the change in $CaCl_2$ concentration. The DM rate of LP and HL decreased with increasing $CaCl_2$ concentrations.

Lastly, only the R/S ratio decreased for AF and TL at increasing $CaCl_2$ concentrations.

4. The control group (0 mg/L) showed an infiltration rate of 2.8–12.2 mm/h after 30 min, which later decreased to 0.7–2.6 mm/h at 60 min. At a high concentration (1,500 mg/L), the infiltration velocity was 2.5–8.1 mm/h at 30 min, and 0.60–3.0 mm/h at 60 min. The infiltration velocity was similar regardless of $CaCl_2$ concentration and plant species after 60–90 min because of the decline in soil saturation arising from rapid drainage up to 60 min.

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## REFERENCES

APHA (American Public Health Association), AWWA (American Water Works Association) & WEF (Water Environment Federation) 2005 *Standard Methods for the Examination of Water and Wastewater*, 21st edn. American Public Health Association, Washington, DC.

Burman, U., Garg, B. K. & Kathju, S. 2003 Water relations, photosynthesis and nitrogen metabolism of Indian mustard (*Brassica juncea* Czern & Coss) grown under salt and water stress. *Journal of Plant Biology–New Delhi* **30** (1), 55–60.

Cachorro, P., Ortiz, A. & Cerda, A. 1994 Implications of calcium nutrition on the response of *Phaseolus vulgaris* L. to salinity. *Plant Soil* **159**, 205–212.

Cerda, A. & Martinez, V. 1988 Nitrogen fertilization under saline conditions in tomato and cucumber plants. *Journal of Horticultural Science* **63** (3), 451–458.

Dubuque, C. 2010 De-icers for driveways and sidewalks. *Telegraph Herald*, 14 November, E7.

Han, S. H. 2009 *Ecohydrological Analysis on Soil Water and Plant Water Stress*. Master's thesis, Pukyong National University, Busan, South Korea.

Hayward, H. E. & Bernstein, L. 1958 Plant-growth relationships on salt-affected soils. *The Botanical Review* **24** (8–10), 584–635.

Kalra, T. P. 1998 *Handbook of Reference Methods for Plant Analysis*. Soil and Plant Analysis Council, Inc., CRC Press, Boca Raton, Florida, USA.

Kaya, C., Kirnak, H., Higgs, D. & Saltali, K. 2002 Supplementary calcium enhances plant growth and fruit yield in strawberry cultivars grown at high (NaCl) salinity. *Scientia Horticulturae* **93** (1), 65–74.

Kim, L. H. 2014 GSI for nonpoint source management, 2014 Water Ecosystem Conservation Joint Conference: Ecological River Restoration and Nonpoint Source Management, Jeju.

Korea Highway Corporation 2007 *Effect and Control of Chloride Salt on Concrete Structures and Environment with Different Type of Deicing Agent*.

Korea Land & Housing Corporation 2014 *Development of Design Decision Support System for Non-Point Reduction Facility: Design Method and Optimum Method*.

Lakshmi, A., Ramanjulu, S., Veeranjaneyulu, K. & Sudhakar, C. 1996 Effect of NaCl on photosynthesis parameters in two cultivars of mulberry. *Photosynthetica* **32**, 285–289.

Macadam, J. & Parsons, S. A. 2004 Calcium carbonate scale control, effect of material and inhibitors. *Water Science and Technology* **49** (2), 153–159.

Ministry of Environment (MOE) 2014 *Installation, Management and Operation Manual of Nonpoint Pollution Control Facility*.

Moon, S. Y. 2015 *Development and Performance Assessment of an Infiltration Planter for Roof Runoff Management*. Master's thesis, Kongju National University, Cheonan City, South Korea.

Navarro, J. M., Martinez, V. & Carvajal, M. 2000 Ammonium, bicarbonate and calcium effects on tomato plants grown under saline conditions. *Plant Sci.* **157**, 89–96.

Oh, S. H. 2014 *Toxicity Effect of Chloride Deicing Agent on Small Fishes (Oryzias sinensis, Pseudorasbora parva)*. Master's thesis, Hanyang University, Seoul, South Korea.

Seoul Metropolitan Government 2013 *Seoul Metropolitan City Stormwater Management Plan*.

Seoul Metropolitan Government 2015 *Water Circulation Effect Analysis and Infrastructure Construction Technology Development Research Service Report*.

Shen, Z., Shen, Q., Liang, Y. & Liu, Y. 1994 Effect of nitrogen on the growth and photo-synthetic activity of salt stressed barley. *Journal of Plant Nutrition* **17** (5), 787–799.

Shin, S. S., Park, S. D. & Kim, H. S. 2010 Effects of calcium chloride and eco-friendly deicer on the plant growth. *Journal of the Korean Society of Environmental Engineers* **32** (5), 487–498.

Shishi, L., Peng, Y., Du, W., Le, Y. & Li, L. 2015 Remote estimation of leaf and canopy water content in winter wheat with different vertical distribution of water-related properties. *Remote Sens.* **7**, 4626–4650.

Sung, J. H., Je, S. M., Kim, S. H. & Kim, Y. K. 2009 Effect of calcium chloride ($CaCl_2$) on the characteristics of photosynthetic apparatus, stomatal conductance, and fluorescence image of the leaves of *Cornus kousa*. *Korean Journal of Agricultural and Forest Meteorology* **11** (4), 143–150.

Tezara, W., Mitchell, V., Driscoll, S. P. & Lawlor, D. W. 2002 Effects of water deficit and its interaction with $CO_2$ supply on the biochemistry and physiology of photosynthesis in sunflower. *Journal of Experimental Botany* **53** (375), 1781–1791.

Transportation research board 2007 *Guidelines for the Selection of Snow and Ice Control Materials to Mitigate Environmental Impacts*.

Tuna, A. L., Kaya, C., Ashraf, M., Altunlu, H., Yokas, I. & Yagmur, B. 2007 The effects of calcium sulphate on growth, membrane stability and nutrient uptake of tomato plants grown under salt stress. *Environmental and Experimental Botany* **59** (2), 173–178.

Viskari, E. L. & Karenlampi, L. 2000 Roadside Scots pine as an indicator of deicing salt use – a comparative study from two consecutive winters. *Water Air Soil Pollution* **122**, 405–409.

Yu, K. K. 2015 *Development and Performance Assessment of A Bioretention Technology Treating Urban Stormwater Runoff*. Master's thesis, Kongju National University, Cheonan City, South Korea.

Zhang, K., Che, W., Zhang, W. & Zhao, Y. 2016 Discussion about initial runoff and volume capture ratio of annual rainfall. *Water Science and Technology* **74** (8), 1764--1772.

Zhou, Q., Ren, Y., Xu, M., Han, N. & Wang, H. 2016 Adaptation to urbanization impacts on drainage in the city of Hohhot, China. *Water Science and Technology* **73** (1), 167–175.

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