A Study on Rain Garden System for the First Flush Control of Urban Rainfall Runoff

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도시 초기우수 저감을 위한 생물학적 빗물저류정원에 관한 연구

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ABSTRACT : Rain garden system is an alternative to conventional BMP structures. It is highly applicable to residential uses in community open space and private lots. The rain garden system is very appropriate for treatment of parking lot runoff, roadways where sufficient space accommodates off-line implementation, and pervious area such as golf courses. Rain gardensystem can provide excellent pollutant removal and recharge for the first flush runoff. Optimized rain garden remove SS, metals, N, and P. Specially vegetated rain garden with high density can effectively remove pollutants. In this research, 4 rain gardens were constructed using retaining block wall(1000W X 1500L X 600D(800D)). 2 rain gardens were vegetated with Aster koraiensis, but different middle layer depths(600mm and 800mm), while the others were no vegetation with different middle layer depths(600mm and 800mm). Cross section of rain gardens was comprised of 200 mm top soils(40% sand, 30% silt, 15% clay, 15% organics) and engineered soils(30% top soils, 60% sand, 10% coir fiber) as middle layer soils. The synthetic storm water was used for all testing. The synthetic storm water was based on the average pollution loading taken from runoff water on residential area in Kwanak-gu. Influent and effluent concentrations were compared on an artificial storm by storm basis for all pollutants. Average effluent removal and retention rates of TSS and metals by vegetated systems were more than 93% and 92%(all taken samples of 93% of Zn, 100% of Pb, 89% of Cu and 100% of Cd) with 600mm and 94% and 95%(97% of Zn, 100% of Pb, 100% of Cu and 100% of Cd) with 800mm middle layer depth, respectively. On the other hand, in non-vegetated system, they were approximately 90% and 87% with 600mm and 93% and 90% with 800mm. These results indicate that pollutants from urban first flush runoff should be removed by rain garden system through filtering effect by media and adsorption process by organic matter within soil media and vegetated plants through heavy metal uptake by plants.

Key Words : rain retention garden, first flush runoff, Aster koraiensis

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요약 : 빗물저류정원은 도시초기우수 관리를 위한 가장 보편적인 방법이다. 빗물저류정원은 도시설계에서 많이 적용이 될 뿐 아니라 가정 및 유역단위에서도 적용이 가능한 효율적인 저농도 오염 저감시설이다. 도시초기유출우수의 경우 TSS, 질소, 인 등이 많이 포함되어 있고, 강우시 하천을 따라 방류되게 된다. 이는 하천의 부영양화뿐 아니라 하천 생태계 교란의 원인이 될 수 있다. 본 연구는 분산형 초기우수관리 방법으로 빗물저류정원을 제시하고 있다. 빗물저류정원 실험을 위하여 4개의 빗물저류정원을 제작하였으며 크기는(1000mm W X 1500mm L X 600mm D(800mm D))로 하였다. 2개는 식생(Aster koraiensis)으로 조성되어 있고, 나머진 식생이 대조군으로 식생을 포함하지 않는 상태에서 진행하였다. 하부구조는 200mm 표토(40% sand, 30% silt, 15% clay, 15% organics)와 심토(30% top soils, 60% sand, 10% coir fiber)로 구성되어 있다. 실험에 사용된 강우는 인공강우를 사용하여 제작하였다. 본 연구를 통해 얻은 결과는 600mm 미디어 두께에 식생이 분포된 빗물저류정원에서는 TSS 제거율이 평균 93% 이상이며, 중금속의 경우는 평균 92%(Zn 93%, Pb 100%, Cu 89%, Cd 100%) 이상 제거되는 것으로 보여주고 있다. 또한 800mm 미디어 두께에 식생분포되어 있을때는 TSS 제거율이 평균 94% 이상이며, 중금속의 경우는 평균 95%(Zn 97%, Pb 100%, Cu 100%, Cd 100%) 이상 제거되는 것으로 보여주고 있다. 반면에 식생이 분포되어 있지 않는 경우는 600mm 두께에 90% TSS와 87% 중금속이 제거되며, 800mm 미디어 두께에서는 93% TSS와 90% 중금속이 제거되는 것으로 관찰되었다.

주제어 : 빗물저류정원, 초기유출수, 식생(Aster koraiensis)

Ⅰ. Introduction

Actually, rain garden systems are stormwater best management practices(BMP's) that use filtration to treat stormwater runoff. These systems use vegetation, such as trees, shrubs, and grasses, to remove pollutants from stormwater runoff. In rain garden system, the biological and physico-chemical reaction happen to remove pollutants. Sources of runoff are diverted into the rain garden systems directly as overland flow or through the stormwater drainage system.What that called "Low Impact Development(LID) systems".

Actually, the first flush from initial runoff on urban area filters through the vegetation and soil within the rain garden. This filtered runoff flow into the under-drain systems such as rainwater storage tank and infiltrate into the underground. Rain garden systems have several advantages which provide a variety of pollutants removal process such as filtration, plants uptake and adsorption. These means that rain garden system is multiple removal reactors.

Many researchers refer to rain garden and bioretention systems as BMP structures(Lee and Han, 2009; Wossink and Hunt, 2003; Davis et al., 2001; Hsieh and Davis, 2005b; Erickson et al., 2007). Wossink and Hunt(2003) reported that bioretention and rain garden system is more cost effective than other BMPs structure.

Initial studies of these systems documented that it provide considerable potential to removal of TSS and metals by chemical adsorption and precipitation(Davis et al., 2001).

For TN removal and retention, Denman et al.(2006) and Breen et al.(2004) noted the difference of TN removal and retention is

Source: Department of Civil and Environmental Engr., University of Maryland

Figure 1. Picture of rain garden

attributed to the presence of vegetation. Fletcher et al.(2007) and Henderson et al.(2006, 2007) indicated that the presence of vegetation had potential effect to promote N removal and retention from an extensive column study comparing nutrient retention in a variety of media and plant species.

For TP removal and retention, Hsieh and Davis(2005a) reported TP retention is up to more than 80% from the column study in the short term. On the other hand, long term study was shown as 65% TP retention. Also, there is no declining trend for TP removal. In contrast to these findings, Hunt et al.(2006) and Dietz and Clausen(2005) reported that TP effluent concentration is higher than inflow TP concentration due to be attribute to media with little organic matter. Hsieh et al.(2007) investigated the effect of a P loading retention with different soil media mixtures varying from 30 to 70% soil. Initial TP retention was 100% in the sand media. However, according to extend contact time, TP retention would be reduced. Henderson et al.(2007) compared retention in vegetated and non vegetated mesocosm. The results indicated the presence of vegetation had a pronounced effect to promote P retention.

For metals, Davis et al.(2003) and Hunt et al.(2006) perform column study and field test. A few studies that were performed on column tests to remove pathogenic bacteria reported (Dietz and Clausen 2005; Hunt et al., 2006; Heasom et al., 2006).

II. Materials and Methods

1. Rain Garden Design

The experiments were performed for 6 months in 2008. The 4 rain garden systems were constructed using retaining block wall. Cross section of rain gardens was composed of 200mm top soils, engineered soils as middle layer and underlain facility as bottom layer. Figure 2. shows engineered soil specification.

The rain garden consists of top layer and middle layer. The total frame was constructed by retaining block wall. The bottom layer was underlain by geotextile blanket, pea stone and PVC pipe. 2 rain gardens were planted with Aster koraiensiss. The rain garden were constructed from 1.0 m W × 1.5m L × 0.6m(0.8m) D as block retaining wall. Figure 3. is illustrated.

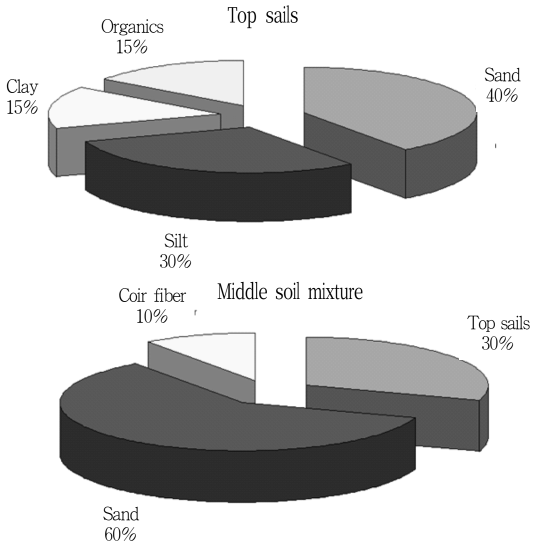

Figure 2. Engineered soil specification

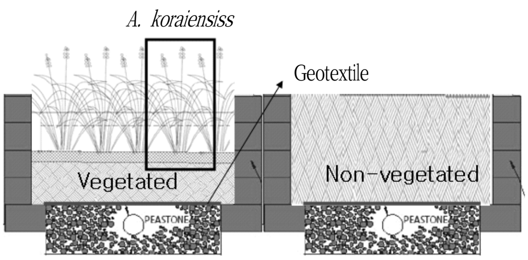

Figure 3. Experimental set-up

2. Experimental Procedure

Several papers were suggested following similar method(Lee and Han, 2009). A weekly dosing with stormwater commenced from May 2008 to September 2008 for 18 weeks. Stormwater(50L) has been dosed to stable condition every twice a week for 3 weeks before the sampling campaign began. 15 sampling runs have been undertaken to every week after 3rd week performing. 50L(approximately 10L~100L) is determined by harvested runoff volume which is collected in urban catchment area of 124m^2.

Synthetic stormwater runoff was applied. Synthetic stormwater runoff was prepared using tap water that was left to stand at room temperature for 24h to dechlorinate. Syntheic runoff water were manipulated following similar method(Lee and Han, 2009). For TSS, sediment slurry was used. For Cu, $CuSO_4$ was applied. Also, $PbNO_3$, Zinc Chloride and $Cd(NO_3)_2$ was used for Pb, Zn and Cd. It is made based on the runoff monitoring data on the residential area(37°28′41.39″N, 126°57′09.18″E) in Kwanak-gu, Seoul.

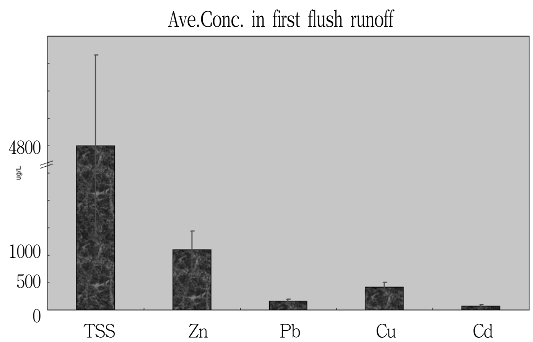

Figure 4. Ave. pollutant concentrations within first flush on residential area on Kwanak-gu, Seoul, South Korea

Figure 4 was obtained from 15 rainfall events in study area. The first flushing time was defined from starting time to collect harvested runoff within 30 minutes.

3. Analysis

Samples are collected and analyzed for TSS and metals in KIST-Gangneung accredited laboratory. TSS method is performed according to the standard method(APHA et al., 1995). For metals analysis, influent/effluent sample are digested with concentrated trace metal grade HNO_3(Fisher Scientific) and diluted for metal analysis(APHA et al., 1995). For the investigation of metals, soil samples are analyzed with an Inductively Coupled Plasma Optical Emission Spectrometer(ICP-OES) according to reported Xueli and Allen(2007).

III. Results and Discussion

1. Removal efficiencies of Total Suspended Solids(TSS)

Figure 5 shows that TSS is effectively reduced by rain garden system in vegetation condition.

Table 1. The removal rate of TSS

Inflow TSS (mg/L)	Vegetated		Barren	
	60cm depth	80cm depth	60cm depth	80cm depth
480[1)]	91%[2)]	94%[2)]	87%[2)]	92%[2)]

1) average TSS inflow concentration
2) The removal rate

Removal efficiency of TSS concentration in the 4th week is 83% with 60cm media depth and 81% with 80cm media depth respectively, removal efficiency is more than 90% from 8th week in vegetated condition with all different soil media. There are significant interactions between establishment time and vegetation. However, there are no significant between in different middle layers for removing TSS. While figure 6 shows that removal efficiency is more than 90% from 10th week in non-vegetated condition. It explains how

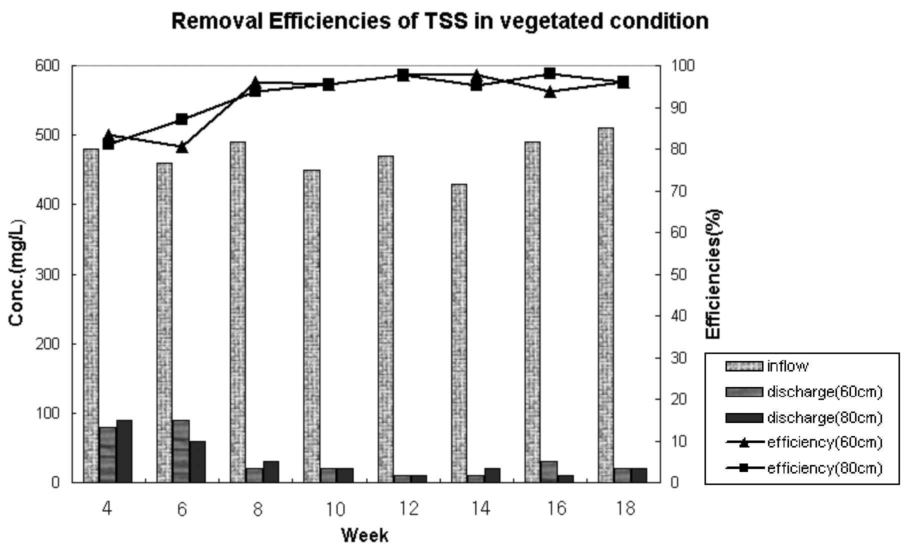

Figure 5. Influence of two type of middle layer depth on reduction in TSS over time in vegetation condition

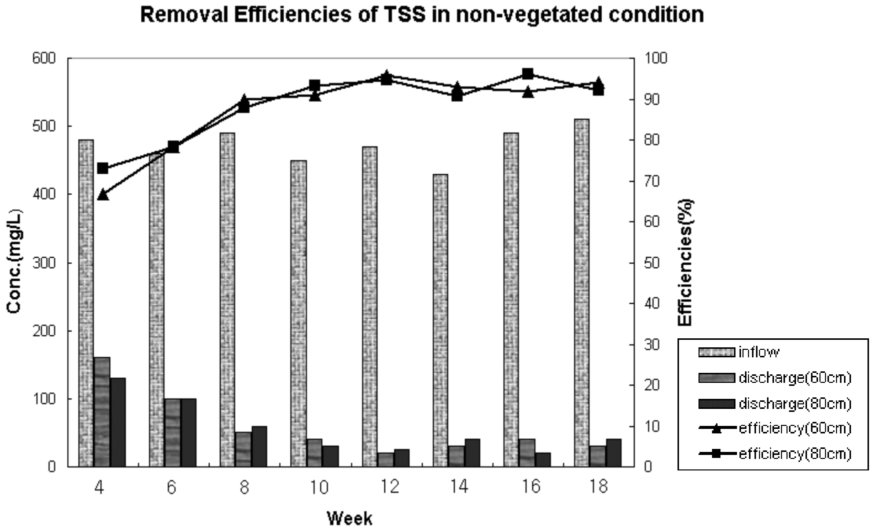

Figure 6. Influence of two type of middle layer depth on reduction in TSS over time in non-vegetation condition

vegetated condition is so effective in filtering out by root zone networks. Also, below 90% efficiency indicates that suspended solids flow out from soil-based media due to be unstable plant establishment by 8th week. With respect to efficiency of TSS concentration in non-vegetation condition(Figure 6), removals of TSS have below 90% efficiency until 10th week. These indicate that there is a significant establishment time of rain garden. Until 8-10 weeks, it shows that soils with proportions of smaller particle sizes including silts and clay have been prone to flow out.

2. Removal Efficiencies of Metal

Metal concentrations are also very effectively removed by media depth and vegetation condition, which is not surprising, given the high and low level of metal removal.

Table 2. The removal rate of Metal

Inflow Zn (ug/L)	Vegetated		Barren	
	60cm depth	80cm depth	60cm depth	80cm depth
1200[1)]	93%[2)]	97%[2)]	78%[2)]	89%[2)]
Inflow Cu (ug/L)	Vegetated		Barren	
	60cm depth	80cm depth	60cm depth	80cm depth
450[1)]	89%[2)]	100%[2)]	85%[2)]	91%[2)]
Inflow Pb (ug/L)	Vegetated		Barren	
	60cm depth	80cm depth	60cm depth	80cm depth
230[1)]	100%[2)]	100%[2)]	100%[2)]	100%[2)]
Inflow Cd (ug/L)	Vegetated		Barren	
	60cm depth	80cm depth	60cm depth	80cm depth
100[1)]	100%[2)]	100%[2)]	100%[2)]	100%[2)]

1) average TSS inflow concentration
2) The removal rate

There is an overall average removal

efficiency(μ) with vegetation condition and 60cm depth for all taken samples of 93% of Zn, 100% of Pb, 89% of Cu and 100% of Cd.

On the other hand, in 80cm depth media with vegetation condition, overall average removal efficiencies are 97% of Zn, 100% of Pb, 100% of Cu and 100% of Cd. These show that metals are adsorbed to media based soils with including the organic matters(Figure 7).

In general, removal efficiency of metals without vegetation is lower than with vegetation (Figure 8). For μ_{Zn}, 93% with 60cm and 97% with 80cm in vegetated condition are a much higher than 78% with 60cm and 89% with 80cm in non-vegetation condition. These results suggest that Aster koraiensiss is to promote Zn

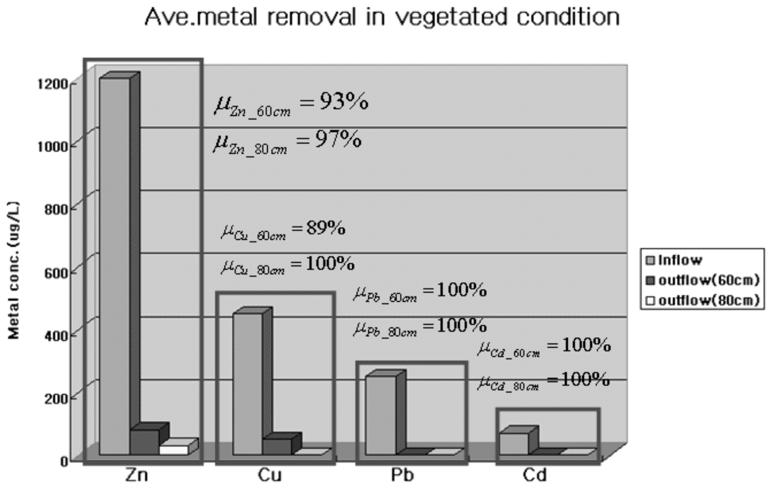

Figure 7. Influence of two type of media depth on reduction in vegetation condition

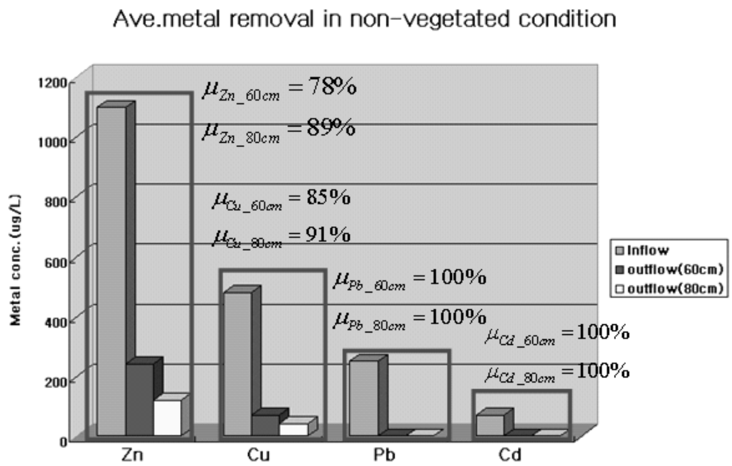

Figure 8. Influence of two type of media depth on reduction in non-vegetation condition

uptake as well as soil based media including organic matter has a significant influence on metal sorption performance.

Ⅳ. Conclusion

The results show that rain garden systems can be very effective for removing TSS and metals from urban first flush runoff. A small scale rain garden study for treatment of urban first flush runoff shows that more than 90% of input TSS is removed within 2 type of soil media depth(60cm and 80cm) in vegetation condition after 8th week. Meanwhile, in non-vegetation condition, more than 90% of TSS removal efficiency is after 10th week. These results suggest that dense root network of Aster koraiensiss does not have a good TSS retention performance. In case of metal removal, rain garden system is promising technology to urban first flush runoff. Metal concentrations are also effectively reduced where high concentrations of metals are expected on urban first flush runoff. The organic matter content of the rain garden media can be increased for high adsorption capacity. An important finding is that Aster koraiensiss enhances the Zn uptake. However, the current findings are not in broad agreement. Further research is being undertaken to investigate spatial distribution of metals between the different tissue types in Aster koraiensiss. In the relationship between TSS and metal concentration, the removal rate of TSS is in proportion in metal removal. The reason is seen that is removed because metal ion is adsorbed to TSS. But, we were judged that some metal was kept by ionic state or brought from soil media.

At last, we should make basic concept about first flush and its pattern, even though the 30 min. from first flush was chosen. In this study area, 30 min. was a critical time point for the concentration of runoff water quality. But it was a case for this study area and 50L synthetic rainfall amount. Therefore, in the further study, we will progress. Also, experimental analysis for other water quality will be performed, even though the main contaminated sources were heavy metals and TSS.

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