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The reduction of nutrients by riparian silty soil and sandy soil: Comparison and analysis

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ABSTRACT

RBS (or VFS) is a facility that reduces non-point source pollutants with a sustainable reduction effect and an excellent visual impact. Now that RBS is located in streamsides, and it is distributed by various sandy soils and sands, which have been deposited over long periods of time owing to the hydraulic dynamics of rivers. In this study, we manufactured three types of bench-scaled units to compare and analyze the effect of the reduction of nutrients in silts and sands. Then, we investigated the reduction of T-N, NH_4^+, NO_3^-, NO_2^-, T-P, and PO_4^- using silt (SILT), sand (SAND), and mixed silt and sand (SILT + SAND) units. The influent water was comprised of reagent and distilled water and quantitative data was acquired with stable indoor experimental conditions. As a result, silts were 2 times better than sands in reducing nutrients. Silts had better effects in reducing nitrogen and showed a 79% reduction rate for NH_4^+ through the adsorbtion in soils due to ion effects. However, the reduction rate of T-N was not as high as that of NH_4^+ was. The reduction rate of the phosphorus was 99% in SILT and it did not change over time. However, this was not good in sands, and the reduction rate had actually decreased over time. This study verified that soils with fine particles had a better reduction rate for nutrients and only soils significantly had reduced the nutrients. However, because fine soils impoverished permeability, additional studies were required in order to build the actual RBS.

Keywords: RBS (or VFS); Bench scale; Unit; Silt; Sand; Soil; Permeability

1. Introduction

Eco-friendly pollution reduction methods are cost-effective for construction and management, constantly effective, and provide good visual impacts and reduction efficiencies. It has been reported that one of the eco-friendly methods, riparian buffer strip (RBS) or vegetative filter strip (VFS), was mainly comprised of soil and plants was prominent for non-point pollutants such as SS, nitrogen (N), phosphorus (P), etc. RBS is adjacent to water bodies (streams or lakes, wetlands) and therefore it may exert unique ecosystem effects, such as the function of stabiliz-

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ing bank erosion and biotope functions, etc. in addition [1–5]. However, because the reduction mechanism of pollutants was very complicated in physical, chemical, and biological ways, improving the efficiency of the reduction systems and equipment requires a quantitative analysis for each component.

Dillaha et al. [6] found that 81 % and 91% of sediment was removed respectively from 4.6 m and 9.1 m width as a result of studying the effect of reduction of sediment, T-N, T-P, soluble N and P using rainfall simulation and grass VFS of silt loam soil. In addition, T-N showed 58 and 69%, and T-P showed 64 and 74% in their removal efficiencies respectively, but soluble nitrogen and phosphorus were not removed effectively, which even showed higher than the input concentration. Furthermore, it is reported that surface runoff from feedlot results in an excellent effect of reduction when it is shallow and uniform.

Magette et al. [7] reported, as result of analyzing pollutant removal effectiveness in grass VFS formed from sandy loam soil, TSS, T-N, and T-P were reduced by 66, 0, and 27% at the length of 4.6 m, which indicates it is more effective for removing sediments than nutrients. At the length of 9.2 m, it showed more removal effectiveness in the case of sediment. But its removal effectiveness was as effective as compared with the initial value input in the case of nutrients. Furthermore, the comparison between bare plots and vegetated plots indicated that as unvegetated area had increased VFS performance decreased, while as nutrient removals decreased as the number of runoff events had increased.

Schumitt et al. [8] reported, in the study on width 7.5 and 15 m, fine textured-soil, 6–7% slop using vegetated filter strip and simulated runoff event, 76–93% of sediment, 55–79% of T-P, 24–48 % of nitrate, 19–43 % of dissolved P, 5–43% of herbicide such as atrazine contained in runoff were reduced. In the case of grass with 2-year-old and 25-year-old among a variety of plants used for vegetation, 25-year-old was reported to have better filter performance.

Mitsch [9] reported, in the study on non-point source controlling using natural riparian wetlands, nitrogen may be mainly removed by denitrification process in soil as well as plant uptake, while phosphorus is mainly removed by precipitation of soil particles.

Keffla and Ghrabi [10] reported, in the study on nitrogen removal effectiveness using constructed wetlands that were planted and unplanted, showed the removals of 27 and 5% for TKN, 19 and 6% for NH_4^+, 4 and 13% for NO_2^-, NO_3^-, respectively. It represented that the removal effectiveness of nitrogen by plant was ultimately low.

Chung et al. [11] reported that SS, T-N, and T-P respectively reduced at most 84%, 87% and 98% with the RBS of silt loam covered with local vegetation and the reduction rates were improved with the constant increase of width. The width of the pilot RBS was 20 m and the experiment took into consideration rainfall conditions and soil properties. The experiments were carried out at an outdoor experiment facility including grass, reed, shrub (pussy-willows), grass and shrub (pussy-willows), and natural (local dominant) plant. Also, they reported that the role of woody plants, that is, uptake by plants was important, so as to remove the ion compounds of nitrogen such as NH_4^+ and NO_3^-.

According to previous studies, the reduction effects of RBS (VFS) for non-point source pollutants showed many differences over environmental and experimental conditions, but it clearly reduced the non-point source pollutants. Therefore, RBS (VFS) is effective for reducing nutrients and is gradually recognized as sustainable BMP [12]. Soil existing in nature supports vegetation, plays roles of ion interaction, a habitat for bacteria, filtering pollutants, etc and its functions may depend on the types of soils. This study quantitatively compared and analyzed the reduction of nutritive substances by sandy soil and sand distributed on the streamside. Waterfronts, particularly the streamside of alluvial rivers are characterized by various sandy soils and sands which have been deposited over long periods owing to the hydraulic dynamics of rivers. It is also the most effective zone, which can block the non-point pollutants that flow in from watersheds.

2. Methods

The three same experimental units were manufactured of cylindrical acryl with a 5-mm thickness. The size of the experimental unit was a 150-mm diameter; 450-mm height, 100-mm pore-sheet height from the bottom, and a 5-mm pore and a pore space for collecting samples (runoff water) through soils. The experimental units were comprised of three types, silt unit (SILT) sand (SAND), and a silt + sand unit (SILT + SAND) (Fig. 1). SILT was filled using within 22–25-mm hardness of the Han River site silts with the measurement of the hardness with a Soil Hardness Tester (Model 351, Fujiwara). Silts and sands used in this study were collected at the waterfront of alluvial river, the Han River and they were not artificially washed in order to preserve the natural properties of the soils. Samples were flowed into the top of the experimental units and influent samples were naturally penetrated over time. A microflow pump (Masterflex model 7529-00) adjusted the inflow and flow rates of samples and it was operated for one hour with 500 ml/min of inflow. Runoff water passing through soils was respectively sampled for 0–30 min and 30–60 min at the lower part of the experimental units and were then analyzed. Nutrients and its ion compounds were analyzed and the analysis items were T-N, NH_4^+, NO_3^-, NO_2^-, T-P, and PO_4^-. The influent concentration was 30 mg/L for N and 5 mg/L for P, and the concentration was adjusted using NH_4Cl and KH_2PO_4. Also, we used distilled water for all experiments. The analysis was performed with an Ultraviolet Spectrophotometric Screening Method

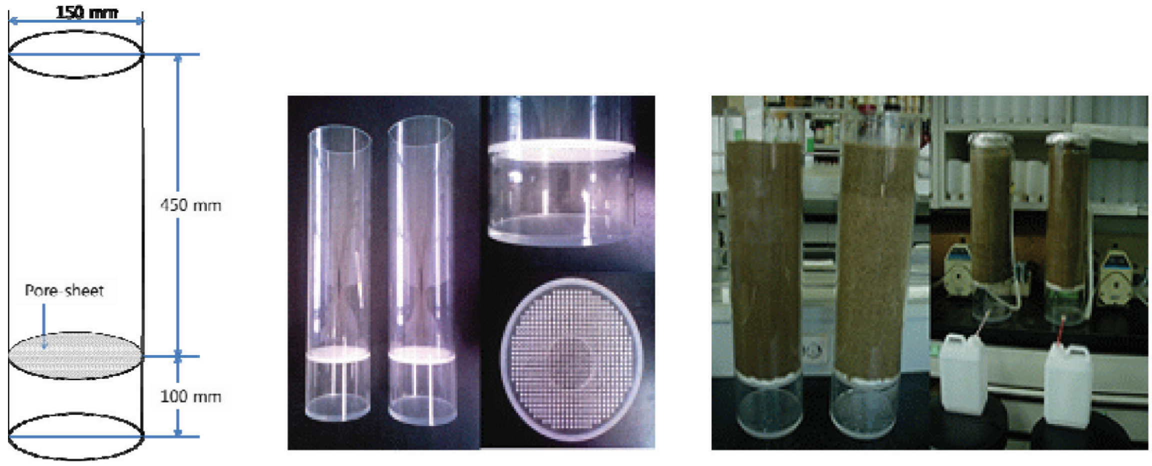

Fig. 1. Schematic description of the test unit.

(SHIMADZU, UV-1601PC) for T-N, I.C. (Metrohm, 792 Basic IC) for NH_4^+, NO_3^- and NO_2^-, Ascorbic Acid Method (SHIMADZU, UV-1601PC) for T-P, and I.C. (Metrohm, 792 Basic IC) for PO_4^-. The measurements were performed with standard methods [13].

3. Results and discussion

The experimental conditions were well maintained and the study showed meaningful results. The results are presented in Table 1.

3.1. Result 1: Reduction characteristics of the nitrogen over each unit

The nitrogen was reduced at all three units. In SILT, NH_4^+, NO_2^-, NO_3^-, and T-N were 3.53, 0.01, 2.88, and 17.17 mg/L at 30 min, respectively and 8.8, 0.02, 1.59, and 23.46 mg/L at 60 min, respectively. 88% of NH_4^+ was reduced at 30 min compared to the influent concentration and 43% of T-N was reduced. However, after 60 min, NH_4^+ and T-N were reduced 71% and 22%, respectively, and the reduction efficiency had lowered. Although influent concentrations of NO_2^- and NO_3^- were 0, NO_2^- was increased from 0.01 mg/L to 0.02 mg/L and NO_3^- was somewhat decreased from 2.88 mg/L to 1.59 mg/L. In SAND, NH_4^+, NO_2^-, NO_3^-, and T-N were 10.8, 0, 0.93, and 23.18 mg/L at 30 min, respectively and 15.17, 0.01, 1.37, 26.7 mg/L at 60 min, respectively. NH_4^+ and T-N were respectively reduced by 64% and 23% at 30 min compared to the influent concentration. However, at 60 min, NH_4^+ and T-N were reduced by 49% and 11% respectively, and the reduction efficiency was rather lowered. NO_2^- was increased from 0 mg/L to 0.01 mg/L and NO_3^- was increased from 0.93 mg/L to 1.37 mg/L. In SILT + SAND, NH_4^+, NO_2^-, NO_3^-, and T-N were 4.29, 0, 2.27, and 19.56 mg/L at 30 min, respectively and 10.4, 0.01, 3.59, 23.93 mg/L at 60 min, respectively. NH_4^+ and T-N were respectively reduced by 86% and 35% after 30 min compared to the influent concentration. However, after 60 min, NH_4^+ and T-N were reduced by 65% and 20% respectively, and the reduction efficiency was rather lowered. Even though influent concentrations of NO_2^- and NO_3^- were 0, NO_2^- was increased from 0.01 mg/L to 0.02 mg/L and NO_3^- was

Table 1
Concentration of the pollutants over the units

		Concentration (mg/L)					
		Silt		Sand		Silt + Sand	
Items	Input	30 min	1 h	30 min	1 h	30 min	1 h
NH_4^+	30	3.53	8.80	10.80	15.17	4.29	10.40
NO_2^-	—	0.01	0.02	0.00	0.01	0.00	0.01
NO_3^-	—	2.88	1.59	0.93	1.37	2.27	3.59
T-N	30	17.17	23.46	23.18	26.70	19.56	23.93
PO_4^-	5	0.05	0.04	3.60	4.15	1.06	0.81
T-P	5	0.04	0.03	3.66	4.54	1.09	0.81

somewhat decreased from 2.27 mg/L to 3.59 mg/L with the lapse of time.

3.2. Result 2: Reduction characteristics of the phosphorus over each unit

The phosphorus was significantly reduced in all three units. In SILT, PO_4^- and T-P were 0.05 and 0.04 mg/L at 30 min respectively, and 0.04 and 0.03 mg/L at 60 min respectively. Both of PO_4^- and T-P were reduced by 99% at 30 min compared to influent concentration and the reduction efficiency of 90% had not changed at 60 min. In SAND, PO_4^- and T-P were 3.6 and 3.66 mg/L at 30 min respectively, and 4.15 and 4.54 mg/L at 60 min, respectively. The reduction efficiency of the phosphorus in the SAND was lower than in SILT. Compared to influent concentration, both of PO_4^- and T-P was respectively reduced by 28% and 27% at 30 min and respectively by 17% and 9% at 60 min. The reduction efficiency at 60 min was lower than one at 30 min. In SILT + SAND, PO_4^- and T-P were 1.06 and 1.09 mg/L at 30 min respectively, and both PO_4^- and T-P were 0.81 mg/L at 60 min. The reduction efficiency of the phosphorus in SILT + SAND was lower than that of the one in SILT and higher than the one in SAND. Compared to influent concentration, both PO_4^- and T-P in SILT + SAND were respectively reduced to 79% and 78% at 30 min and they both were respectively at 84% at 60 min. The reduction efficiency of the phosphorus had somewhat increased over time.

3.3. Discussion: Reduction characteristics of the nutrients over each unit

The reduction efficiency of the nutrients in the three units was on average 57%, the nitrogen was 48% and the phosphorus was 67%. The average reduction rates of NH_4^+, T-N, and T-P were 71%, 26%, and 66%, respectively and NH_4^+ and PO_4^- were most effectively reduced. The reduction changes of the nitrogen and the phosphorus were as follows. Fig. 2 shows the reduction of NH_4^+ over units. The reduction of NH_4^+ was the highest value, 88% at 30 min in SILT and it was the lowest value, 49% at 1 h in SAND. The main reduction mechanism of NH_4^+ is in general nitrification and absorption into soils. NH_4^+ was greatly reduced and the main reduction reason was considered to be the absorption into soils. If the nitrification happened, the concentration of NO_2^- and NO_3^- converted from NH_4^+ would significantly increase, but, it was not observed or it was as very small as to avoid detection. The influent nitrogen was the substance that formed with NH4Cl added to the distilled water in the preparation process of the influent water. Accordingly, NO_2^- and NO_3^- did not theoretically exist directly after the influent water was prepared, and the natural conversion of NH_4^+ is very rare with the elapse of only a few. Therefore, it was assumed that the NO_2^- and NO_3^- that was detected in the runoff water were originally contained in the natural soil. That is, it was analyzed that NH_4^+ was generally adsorbed into soils with an anionic attribute. In addition, because the anionic attribute of silts were strong and the area of fine particles, one of silts contacted with NH_4^+ were large, the reduction of NH_4^+ in SILT was the highest. The reduction efficiency was SILT > SILT + SAND > SAND (Fig. 2). Fig. 3 shows the reduction efficiency of T-N. Although the influent concentration of T-N was the same as with NH_4^+, the outflow concentration was significantly higher; the reduction efficiency of T-N was relatively lower than NH_4^+. Furthermore, supposing that T-N should be the sum of NH_4^+, NO_3^- and NO_2^-, it did not show such in the analysis of the runoff water. Because the nitrogen, especially organic nitrogen potentially existed

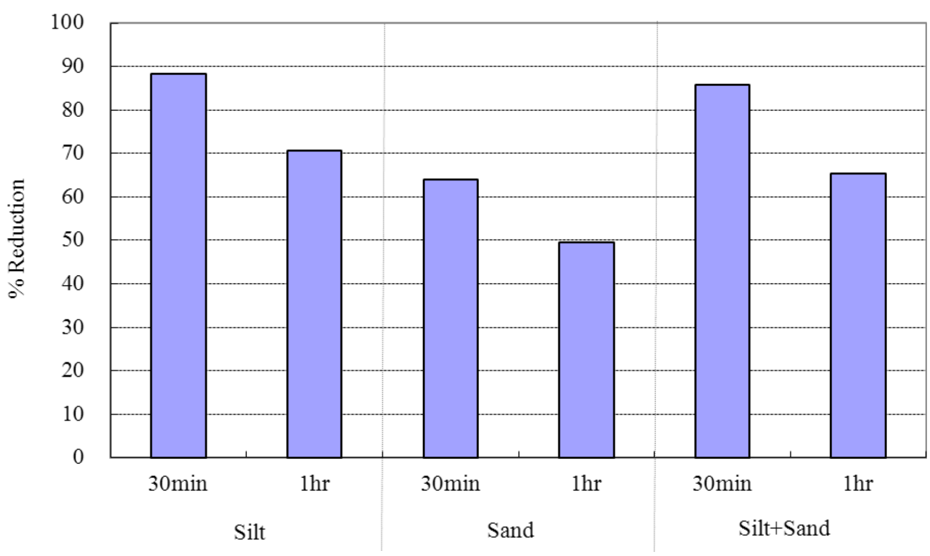

Fig. 2. Reduction rate of NH_4^+ over units and time.

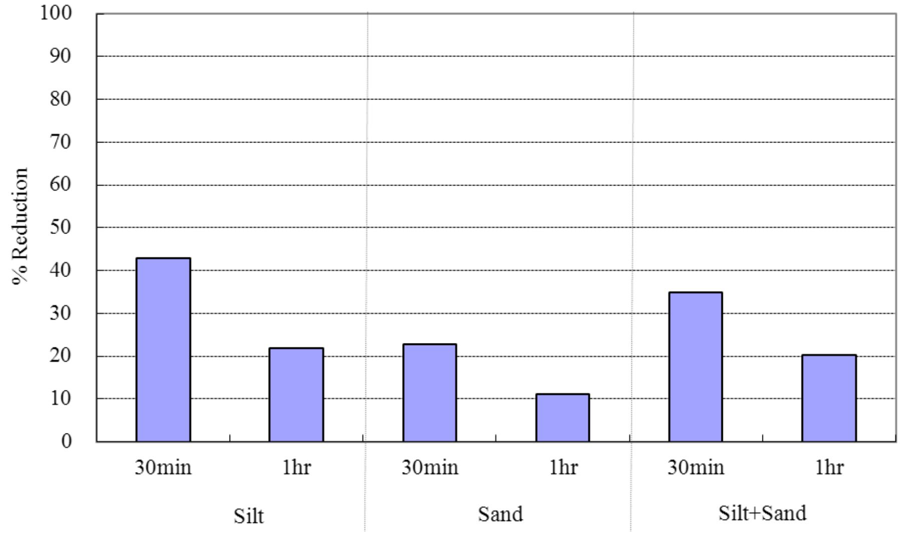

Fig. 3. Reduction rate of T-N over units and time.

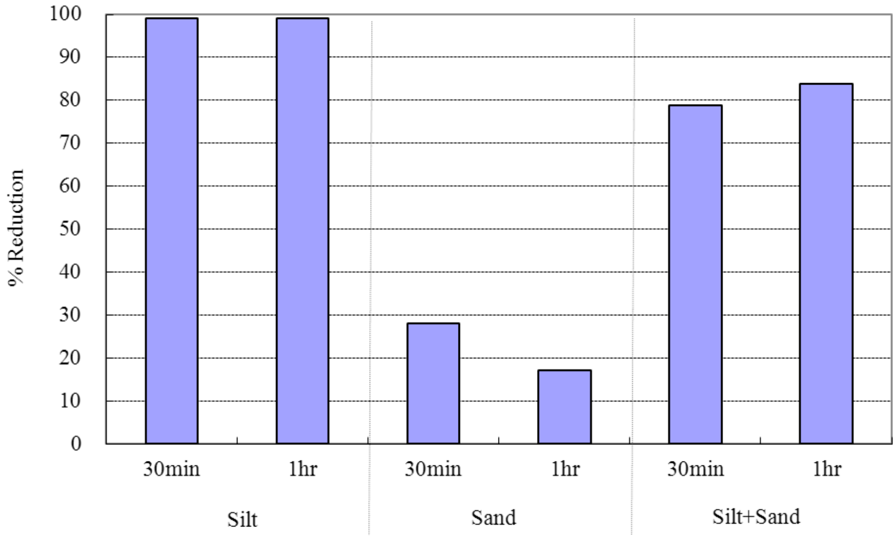

Fig. 4. Reduction rate of PO4- over units and time.

in natural soils, it was considered to have been flown out with runoff water. The reduction efficiency of T-N was SILT > SILT + SAND > SAND.

The phosphorus showed better reduction efficiencies than nitrogen. The reduction rate of PO_4^- was 99% at 30 min and it was very effectively reduced (Fig. 4). It appeared as the same result at 60 min and the impact of the reduction was consistent. However, the reduction efficiency of SAND at 30 and 60 min were respectively 28% and 17%. The reduction impact and the consistency were much lower than SILT. The reduction efficiency of PO_4^- was SILT > SILT + SAND > SAND. It was assumed that PO_4^-–ion compound was well-adsorbed in the soil through the attribute of phosphorus, specific adsorption. T-P also was reduced in SILT quite well (Fig. 5). The reduction rate was 99% and it was same as with PO_4^-. The effect was constant for 60 min. However, the reduction efficiency of SAND at 30 and 60 min were respectively 27% and 9%. The reduction impact and the consistency were much lower as with PO_4^-. The influent water used for the reduction experiment of the phosphorus was artificially prepared using the distilled water and KH_2PO_4. Therefore, the initial concentration of PO_4^- and T-P before inflow was theoretically the same. In general, the phosphorus attaches to soils and sediment very well, and it does not displace itself even with leaching. Therefore, it

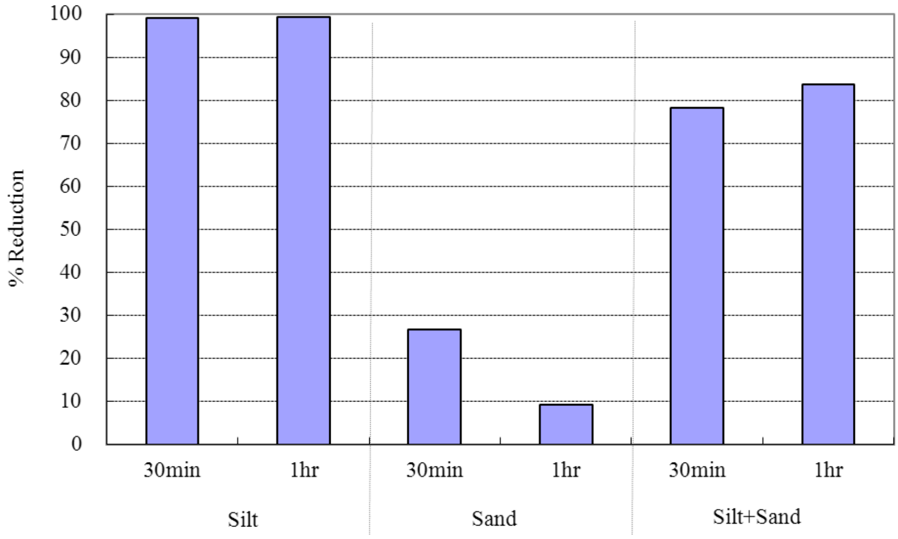

Fig. 5. Reduction rate of T-P over units and time.

was analyzed that the nitrogen was absorbed into the silt well and the effect was relatively consistent because the large area of silts was contacted owing to fine particles.

4. Conclusions

In the study, we manufactured the bench-scaled three kinds of units using silts and sands and then performed the experiments and analyses for determining the reduction characteristics of nitrogen and phosphorus. With these results, we reached the following conclusions:

1. The reduction efficiencies of the three units for T-N, NH_4^+, T-P and PO_4^- proved more effective in the order of SILT > SILT + SAND > SAND. However, the results may differ over compaction and the various properties of soils for other regions because this study was carried out using an indoor experiment.
2. The nitrogen was reduced to 56% in SILT and to 37% in SAND. Therefore, SILT was better than SAND. NH_4^+ and T-P at SILT were 79% and 32% respectively. It explained better absorption of the nitrogen with soils due to positive ion compounds. However, the runoff of T-N could be increased by inorganic N that potentially exists in soils.
3. The phosphorus was reduced to 99% in SILT and to 20% in SAND. Again, SILT was better than SAND. Even though PO_4^- and T-P at SILT were constantly reduced with the elapse of time, they were reduced to more than 50% at SAND. As a result, the phosphorus was better absorbed into soils than the nitrogen and moreover, it was constantly reduced.
4. In the study, the soils themselves can reduce the considerable quantity of the nutrients such as T-N, NH_4^+, T-P, and PO_4^- by ionic interaction, physically fixed particles, habitat for bacteria, etc. The finer the soils are, the better the reduction effect. However, it was assumed that the anionic compounds, such as $NO_3^-$and NO_2^-, were emitted through a minus charge attribute of the natural soils without being adsorbed in soils. On the other hand, PO_4^- had been significantly removed by a specific adsorption even though it had a minus charge attribute.

In the study, we mostly compared and analyzed the reduction characteristics of pollutants under the indoor special conditions by sampling soils in certain area. Therefore, for real RBS (or VFS), additional studies are required considering regional particularity and analyzing the permeability of soils.

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