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Analysis on characteristics of SS, N, and P reduction in soil and RBS: Bench scale test

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ABSTRACT

This study quantitatively identified the reduction characteristics and tendency of pollutants without any indoor external disturbance through the manufacturing of RBS (or VFS), which is recognized as one of the main methods to reduce the environmentally-friendly, sustainable non-point pollutants, with a bench scale. With this intention, two kinds of experiments were conducted using the grass soil unit assuming the RBS (or VFS) and the unit is composed of only soil as a contrastive group. The pollutants including SS, T–N, NH_4^+, NO_3^-, T–P and PO_4^- were targeted and their concentration was thus artificially controlled. Through the first 60-min short-term experiment, the outflow forms from the unit, that is, the reduction characteristics of the pollutants according to the surface runoff, intermediate runoff and subsurface runoff, were identified. Through the second long-term experiment, several test conditions conducted in the first experiment were conducted for 720 min and the results were then analyzed in comparison with the results of the first experiment. According to the experiment results, the grass-covered RBS showed a higher pollutant reduction efficiency than the bare soil in short-term runoff. In the case of surface runoff, especially, the reduction efficiency of SS and NH_4^+ was higher by 1.8 times respectively in grass soil than soil. The average reduction efficiency of SS, T–N and T–P in long-term surface runoff showed –8, 2 and 0% respectively in soil unit and 19, 7, and 4% respectively in the grass–soil unit: the reduction efficiency of SS decreased a lot in comparison to the case of short-term runoff while the efficiency of T–N and T–P did not show any significant change. In addition, even though the reduction efficiency of the non-point pollutants of RBS was high, it was difficult to numerically generalize the effect. Especially, the change tendency of SS was nearly linear in the short-term runoff but not linear in the long-term runoff: the severe undulation was clearly shown. On the other hand, T–P and PPO_4^- showed the drastically increased reduction efficiency in the beginning of the runoff in the subsurface and then the situation was continued for a long time duration, so it was identified relatively easily compared to SS. The experiments were conducted as a bench scale under the consistent experiment conditions, so the

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results could be changed in the real field, and the more experiment results need to be accumulated through the consideration of the various parameters in order to generalize the actual reduction efficiency of RBS (or VFS).

Keywords: RBS; VFS; Bench scale; Soil; Grass; SS; T–N; NH_4^+; NO_3^-; T–P; PO_4^-

1. Introduction

Recently, the riparian buffer strip (RBS) or vegetative filtering system (VFS) has been known as BMP, continuously reducible as non-point pollutants such as nutrients, etc. [1]. The main component of RBS or VFS is soil and the impact of the reduction depends on the types of coated plants, sizes (mainly width), the land use patterns in the watershed (components of pollutants that are absorbed into the watershed), rainfall or rainfall patterns, soil type, bacterial habitats, etc. According to previous studies in regard to these matters, various results were thus reported.

Young et al. [2] had investigated the cases for the width of 21.3 m and 27.4 m with the same slope of 4%. A rainulator was used to test the vegetative buffer strips for their ability to control pollution from any feedlot runoff. The cropped buffer strips on a 4% slope reduced the runoff and the total solids transported from a feedlot by 67 and 79%, respectively. The total N and P were reduced by an average of 84% and 83%, respectively. NH_4^+ and PO_4^- were similarly reduced, but the average NO_3^- in the runoff increased because some NO_3^- was gained from the grass and the oat buffer strips.

Dillaha et al. [3] found that 81% and 91% of sediment was removed respectively from 4.6 m and 9.1 m width as the results of the study for the effect of the 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 the soluble nitrogen and phosphorus were not removed effectively, which even showed higher concentrations than the original input concentration. Furthermore, it is reported that the surface runoff from feedlot results in a superior effect of reduction when it is shallow and uniform.

Schwer and Clausen [4] reported regarding pollutant concentration for the effect of reduction from subsurface runoff was better showing a decrease of 92%, 86%, and 83% respectively from the surface runoff while 97%, 92%, and 93 % respectively from subsurface runoff as result of using the grass filter of 2% loam soil, 26 m long, 10.6 m width in the analysis of the effect of reduction of solids of milk house, P, and N for two years. In addition it was reported that the effectiveness of the filter strip treatment is governed by hydraulic loading rate when 2.94 cm/week was maintained using a level lip spreader. It was reported that the nutrient uptake rate by the plants are approximately 2.5%, 15%, etc. in P, and N respectively.

Magette et al. [5] reported, as a result of analyzing the pollutant removal effectiveness in grass VFS formed from a 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 the sediment, rather than the nutrient. At the length of 9.2 m, it showed more removal effectiveness in the case of the sediment. But its removal effectiveness was not so good compared with the initial value input in the case of the nutrient. Furthermore, the comparison between the bare plot and a vegetated plot indicated that as an unvegetated area had increased, VFS performance thus decreased, while as nutrient removals decreased as the number of runoff events increased.

Lowrance et al. [6] reported that RFBS had superior control over polluting substances diffused in NPS (particularly, agricultural watersheds), including sediment, nitrogen and phosphorus. In addition, they found that the slope was the major factor affecting RFBS' ability to eliminate polluting substances and the pollution-reducing effects would improve upon zoning of the area into zone 1 (undisturbed forest), zone 2 (managed forest) and zone 3 (runoff control) from the waterside. In this case, they also recommended deep-rooted trees in zone 1 for biological activities and grass in zone 3 for flow-spreading.

Schumitt et al. [7] reported, in the study on widths of 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 [8] reported, in the study on non-point source controlling using natural riparian wetlands, nitrogen may be primarily removed by denitrification process in the soil as well as the plant uptake, while phosphorus is mainly removed by the precipitation of soil particles.

Omari and Fayyad [9] reported, in the study on domestic wastewater treatment through subsurface flow of constructed wetlands, nitrate nitrogen is reduced by denitrification, plant uptake, and conversion to bacteria cell, but plant uptake and incorporation into bacteria cell mass are relatively small.

Keffla and Ghrabi [10] reported, in the study on nitrogen removal effectiveness using constructed wetlands, both planted and unplanted, that it showed the removals of 27 and 5% for TKN, 19 and 6% for NH_4^+, 4 and 13% for nitrate–nitrite (NO_2^-, NO_3^-) respectively, representing that the removal effectiveness of nitrogen by plant was low. It also reported that even in the wetlands filtration and sediment that is a physical process, the nitrification and denitrification mechanisms that are a chemical/biological process contributed to the removal of nitrogen. Chung et al. [11] reported that SS, T–N, and T–P was reduced at most by 84%, 87% and 98%, respectively, with the RBS of the silt loam covered with 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. They were carried out at an outdoor experiment facility that included grass, reed, shrub, grass and shrub, and natural plant. Also, they reported that the role of woody plants, that is, the uptake by plants was important, so as to remove both NH_4^+ and NO_3^- ion compounds of nitrogen.

As a result of previous studies, RBS appeared to have various reduction effects depending on regional and environmental conditions because the reduction mechanisms were physically, chemically, and biologically complex and complicated [12]. More quantitative analysis was hence required; and this required an indoor experiment of a bench scale that reduced the influence of external factors.

This study implemented two kinds of indoor experiments as a bench scale. Through the first 60-min short-term experiment, the runoff forms from soil and grass soil, that is, the reduction characteristics of pollutants according to the surface runoff, intermediate runoff and subsurface runoff, were identified. Through the second long-term experiment, the several experiment conditions conducted in the first experiment were conducted for 720 min and the results were then analyzed in comparison with the first experiment results.

2. Methods

The size of the bench-scaled experimental unit was 400 mm (L) × 150 mm (W) × 200 mm (H), and two experimental units made of acrylic were manufactured (Fig. 1). One was filled with only soil and was dubbed Soil (Soil Unit). The other consisted of coated grasses on soil and was named Grass–Soil (Grass–Soil Unit). The Soil unit was filled using within 22–25-mm hardness of the Han River site soil with the measurement of the hardness taken by a Soil Hardness Tester (Model 351, Fujiwara). The structure of the experimental unit was devised to look into the characteristics of lower runoff (outflow A), intermediate runoff (Outflow B), and surface runoff (Outflow C) and each outflow face was manufactured to allow sampling through several minute holes. The flowing structures were same as in Fig. 1. Soil used for the experiment was directly collected at the waterfront of the Han River and had the characteristics of silt loam. Grasses were transplanted by gathering such from the surface of a fernery. The experiment was implemented after the surface of transplanted grasses were washed for 30 min with distilled water. Influent was then smoothly flowed using 10% of slope for the experimental unit. The inflow of samples was adjusted by a micro-flow pump (Masterflex, model 7529-00) and the flow rates were adjusted for each experiment.

The analysis items were SS, T–N, NH_4^+, NO_3^-, T–P, PO_4^- and the analysis was performed with Vacuum Filtration (Glass Fiber Filters, GF/C), Ultraviolet Spectrophotometric Screening Method (SHIMADZU, UV-1601PC), I.C. (Metrohm, 792 Basic IC), I.C. (Metrohm, 792 Basic IC), Ascorbic Acid Method (SHIMADZU, UV-1601PC), I.C. (Metrohm, 792 Basic IC). The measurements were performed with standard methods [13].

2.1. Short term experiment

In this experiment, the prepared artificial samples were used. The concentration of T–N and T–P was adjusted to the boundary of 0.3–17 mg/L and 0.4–6 mg/L with mixing NH_4Cl and KH_2PO_4 to distilled water respectively, and SS to the boundary of 40–120 mg/L. The concentration was adjusted referring to that of stormwater runoff which had been recently examined at the neighboring region. The unit outflow was consistently maintained at 250 mL/min equal to two units. The sampling was conducted 6 times at ten min intervals for 60 min.

2.2. Long-term experiment

In this experiment, the prepared artificial samples were also used, and the sampling method and the con-

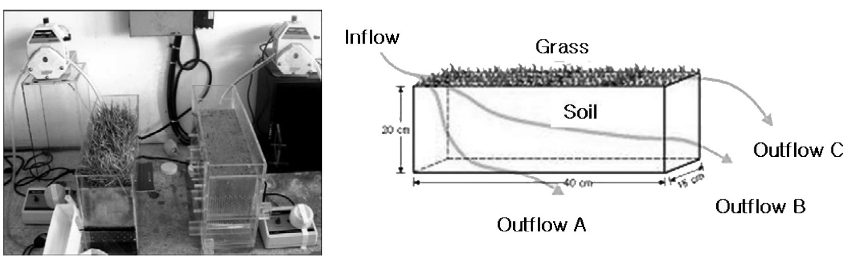


Fig. 1. Schematic description of the RBS bench-scale unit.

centration boundary were equal to the first experiment. The unit outflow of the artificial pollutants was equal to the result of the first experiment at 250 mL/min and the runoff time was 720 min (12 h). The sampling of the runoff was performed 25 times at 30 min intervals. This experiments' purpose was to identify the outflow characteristics of non-point pollutants in the case of a long rainfall time and the test and analysis were conducted focused to the situation that the pollutants flowed out to the rivers through surface and subsurfaces for a long time.

3. Results and discussion

3.1. The reduction characteristics by the pollutant runoff forms in soil and grass soil – short-term experiment and analysis

The concentration of the artificially prepared water input to the two experiments was equal as follows; SS 59.40 mg/L, T–N 12.20 mg/L, NH_4^+ 12.20 mg/L, NO_3^- 0 mg/L, T–P 5.05 mg/L and PO_4^- 5.05 mg/L and the test conditions were maintained well. The concentration of the artificially prepared water was equal between T–N and NH_4^+ and 0 in NO_3^- because the nitrogen water was prepared only with distilled water and NH_4Cl. The concentration of T–P and PO_4^- was also equal because the phosphorus water was prepared only with distilled water and KH_2PO_4 reagent.

The concentration change for 60 min in the experiment unit is shown at Table 1 by each material, runoff form and time course. The reduction efficiency and tendency of pollutants are shown in Fig. 2 and the tendency of reduction efficiency and the reliability of the trend in Figs. 3–4 and Tables 2–3 respectively.

The reduction efficiency and tendency of pollutants were clearly shown by the unit forms (soil and grass soil) and experiment conditions (Fig. 2). The reduction efficiency of T–P and PO_4^- in soil – surface runoff did not show any significant effect, but the rest of the materials had a small reduction effect. SS showed the biggest reduction efficiency of 65% at the passage point of 40 min – the biggest reduction effect of the pollutants in soil – surface runoff. NH_4^+ showed a repetitive increase and decrease in the reduction effect. In grass soil – surface runoff, the reduction effect of SS decreased by 70% for an initial 10 min and then continued to smoothly increase, eventually increasing up to 91%. The reduction effect of NH_4^+ increased up to 84% but showed a repetitive increase

Table 1
The concentration change for 60 min in units (soil and grass soils) by pollutants, runoff form and time course

Time (min)	Soil						Grass soil					
	SS	T–N	NH_4^+	NO_3^-	T–P	PO_4^-	SS	T–N	NH_4^+	NO_3^-	T–P	PO_4^-
Influent	59.40	12.20	12.20	0	5.05	5.05	59.40	12.20	12.20	0	5.05	5.05
	Surface runoff											
10	55.10	10.22	7.21	0.64	5.44	5.33	18.10	14.11	4.00	3.01	5.11	4.95
20	41.20	9.12	6.79	0.75	5.43	5.29	13.00	14.07	3.54	2.94	5.00	4.84
30	25.00	8.56	8.26	0.86	5.46	5.32	8.50	14.83	2.10	2.94	5.00	4.84
40	21.00	9.28	5.98	0.93	5.48	5.48	5.50	14.47	2.75	2.69	4.97	4.85
50	22.00	9.22	8.25	0.85	5.49	5.28	7.50	14.48	1.93	2.69	5.11	5.15
60	23.00	8.40	6.03	0.77	5.46	5.51	6.50	14.45	3.06	2.96	4.93	5.14
	Intermediate runoff											
10		29.55	2.11	1.22	0.12	0.09		2.22	0.08	1.23	0.24	0.10
20		29.35	1.14	1.62	0.14	0.08		2.13	0.05	0.79	0.23	0.09
30		28.06	0.21	2.23	0.18	0.07		1.86	0.15	1.13	0.22	0.09
40		28.23	0.03	2.57	0.43	0.06		1.77	0.26	1.47	0.21	0.08
50		28.57	0.06	2.98	0.31	0.09		3.00	0.10	1.46	0.20	0.14
60		27.90	0.01	2.76	0.26	0.10		3.42	0.05	1.82	0.27	0.15
	Lower runoff											
10		30.11	0.32	1.11	0.32	0.22		3.18	0.10	1.54	0.66	0.51
20		29.11	0.29	1.14	0.35	0.24		3.17	0.11	1.52	0.56	0.41
30		28.95	0.58	1.23	1.07	0.04		3.16	0.34	1.44	0.21	0.16
40		28.95	0.04	1.49	1.61	0.04		5.79	0.17	1.40	0.18	0.12
50		28.57	1.16	2.02	0.15	0.06		4.11	0.10	1.39	0.18	0.12
60		27.75	0.31	1.98	0.40	0.04		2.41	0.02	1.33	0.13	0.10

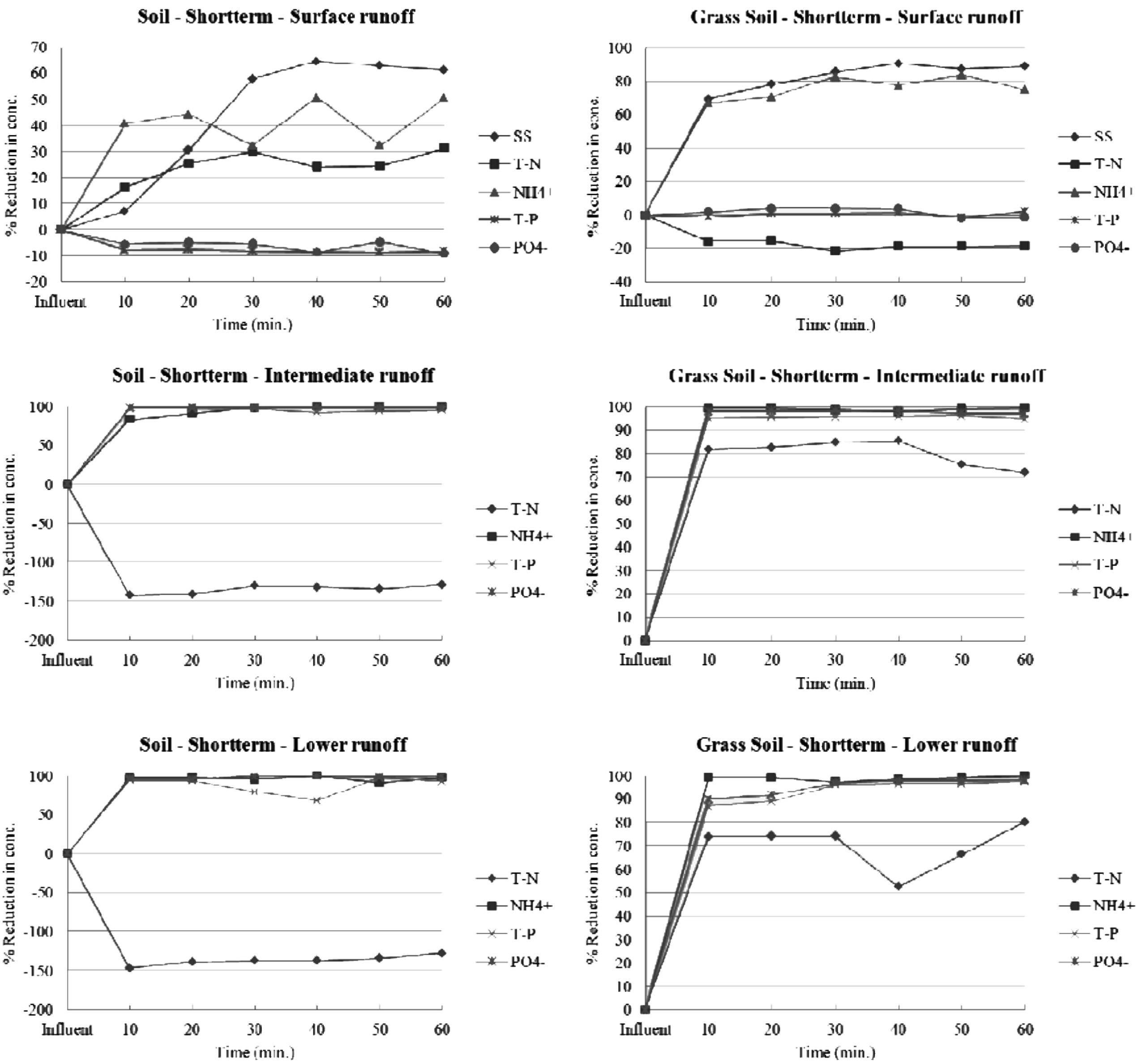


Fig. 2. The reduction efficiency change of unit (soil and grass soil) for 60 min.

and decrease. The rest of the materials did not show a significant reduction effect.

In the surface runoff, the reduction effect of SS was more clearly shown in grass soil than in soil because the physical reduction action, including sedimentation and filtering, is found to work effectively as the sluggish time relatively increased due to the reduced flow speed caused by the grass. The surface runoff concentration of T–N was higher in grass soil because of the effect of the organic-N contained in grass soil and soil surface. The reduction effect of NH_4^+ of ion compound was higher in grass soil. That is because the surface of grass soil has relatively strong negative-charge properties. Accordingly, it is likely that the ion effect actively worked with the positive ion of NH_4^+. This can be confirmed through the observation of the concentration trend of the negative ion of NO_3^- in Fig. 4. In other words, the concentration of NO_3^- was shown higher in grass soil surface than in soil surface.

The average reduction efficiency of NH_4^+, T–P and PO_4^- in soil – intermediate runoff was shown quite high at 95, 95 and 98% respectively. In the case of T–N, however, the average reduction efficiency was shown very low at –135% because of the effect of organic-N and NO_3^- within soil. In grass soil – intermediate runoff, the average reduction efficiency of T–N, NH_4^+, T–P and PO_4^- was shown at 80, 99, 95 and 98% respectively; higher than in the soil unit.

In intermediate runoff, the inflow permeates into the surface through the two unit surfaces and then directly contacts the soil particles. Accordingly, PO_4^- and T–P showed a negative charge in the pollutants but the two

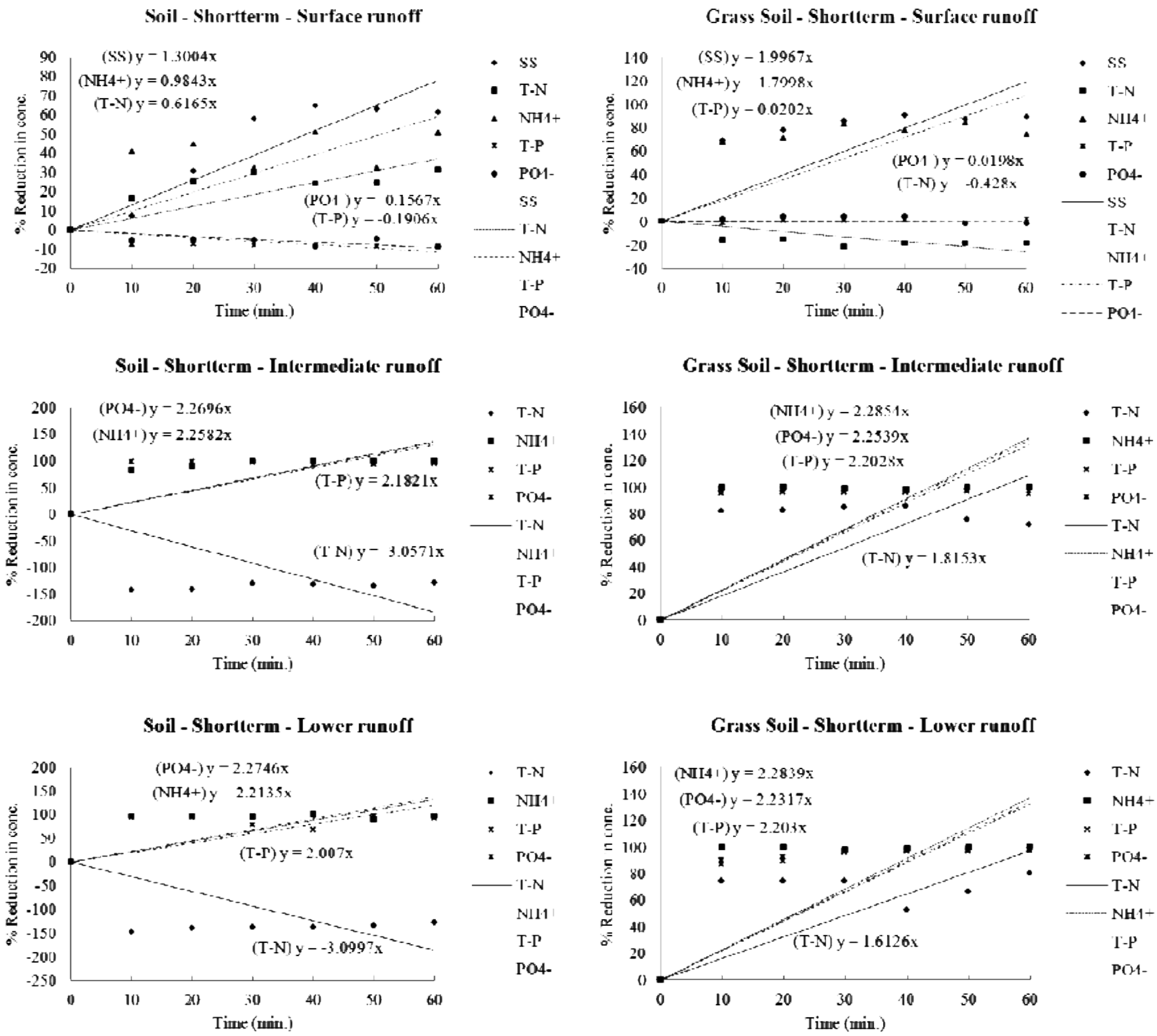


Fig. 3. The reduction efficiency trend of unit (soil and grass soil) for 60 min.

units showed the clear reduction efficiency due to the properties of the specific adsorption to soil. In the case of T–N, however, the two units were comprised of the same soil but the reduction effect was shown higher in the surface of the grass soil unit. This is because the effect originated from grass root — the ability to cohere soil, organic materials and other particles — was high.

The pollutant reduction effect in soil – lower runoff did not show a large difference compared to the intermediate runoff. Then, T–P showed a level of 68% in the 40-min passage point of runoff; the temporary reduced phenomenon compared to the average of 87%. Comparing to the movement of PO_4^-, however, it is judged that the temporary decrease of T–P had originated from the experimental error rather than some other factors. The case of grass soil – lower runoff did not show a big difference from the intermediate runoff. T–N, however, showed a temporary decrease of the reduction efficiency in the 40–50-min passage point. Through reviewing on the movement of NH4+ and NO3– (Fig. 4), or the soluble materials composing T–N, the linkage with the temporary decrease reason of T–N reduction efficiency could not be found. If it is assumed that the effect was caused by organic-N, it is judged that the temporarily increased concentration of organic-N at the grass root had an effect on the lower runoff. It is presumed that the organic-N, which was condensed to part of the root, was temporarily removed by runoff.

According to the results with regards to the observed reduction tendency of pollutants as above, the reduction efficiency of the grass soil unit was generally shown higher and clearer than in the soil unit. Especially, SS showed

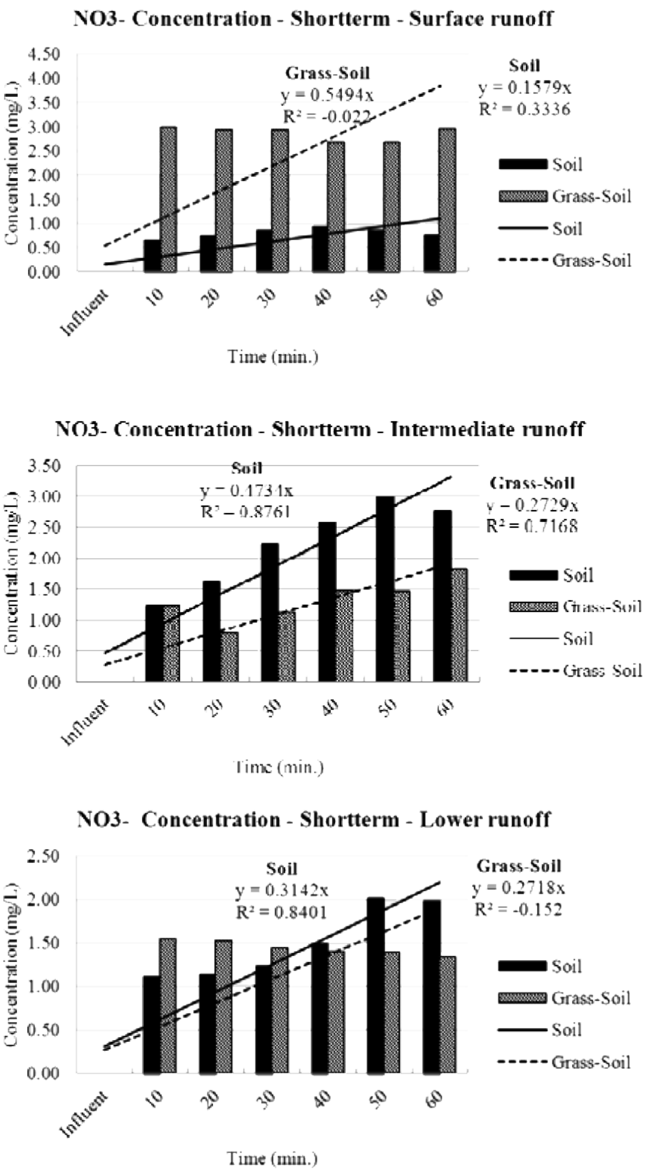


Fig. 4. The concentration change trend of NO_3^- in unit (soil and grass soil) for 60 min.

the reduction tendency in surface runoff of grass soil and NH_4^+, T–P and PO_4^- showed clearly the reduction tendency in intermediate runoff and lower runoff of the two units. When it comes to NO_3^- with the inflow concentration of 0, it was observed that the element hidden within soil rose for the initial 10 min and then there was not any significant concentration change for 60 min. In addition, the repetitive phenomenon of the increase and decrease in the reduction efficiency was observed depending on the runoff types in this experiment. Through the second 720-min long-term runoff experiment, it was partially confirmed if the change tendency was temporary or regular dependent on the time course.

According to the 60-min short-term experiment through using the measured data in order to quantitatively confirm the tendency and reliability of the reduction efficiency, each equation was identified (Figs. 3–4). The slope value a of each trendline in the equation showed numerically the reduction efficiency trend of each pollutant, so the bigger the value, the clearer the reduction trend (Table 2). In addition, the linear coefficient R^2 showed how the change trend is near to linear, so the nearer to 1 the coefficient, the clearer the relationship to the passed time (Table 3). Because the NO_3^- value was calculated by concentration, however, it is impossible to perform a direct numerical comparison to other materials. With regard to a value, NH_4^+ in grass soil – intermediate runoff showed the highest value at 2.29 and was followed by NH_4^+ in grass soil – lower runoff at 2.28. On the other hand, PO_4^- in intermediate runoff – lower runoff of soil and grass soil was shown at 2.23–2.27 and T–P at 2.01–2.20 – relatively high. SS was shown at 2.00 in grass soil – surface runoff, which expressed numerically well the relatively huge reduction trend compared to 1.30 in soil – surface runoff. In the case of a low slope value a, T–N showed –3.06 and 3.10 in soil – intermediate runoff and soil – lower runoff respectively.

The R^2 value was proportional to the time passage with SS showing highly at 0.82 in soil – surface runoff, so it was clearly determined that the reduction effect increased gradually. Next, PO_4^- was shown at 0.35 in soil – surface runoff, so it was found that the reduction efficiency had decreased over time (a = –0.16). On the other hand, NO_3^- calculated with concentration change was shown at 0.88 and 0.72 in intermediate runoff of soil and grass soil, respectively – relatively high linear coefficients. Accordingly, it was found that the concentration increased consistently for 60 min over time. The R^2 values of the other items were shown low overall, so the runoff time and reduction efficiency within 60 min showed a week interrelation. T–N, NH_4^+ and T–P showed the range of –0.56–0.31 in intermediate runoff – lower runoff of soil and grass soil.

According to the 60-min short-term experiment result, the increase trend of the reduction efficiency was shown highest in the surface runoff of grass soil – SS and the trend pattern was close to a linear form. In the intermediate runoff and lower runoff, the increasing trend of reduction efficiency of T–N, NH_4^+, T–P and PO_4^- and the decreasing trend of NO_3^- reduction efficiency in grass soil was shown clearly. In addition, the trend pattern was very linear and the reduction efficiency showed the drastic change within the initial 20 min and thereafter a relative consistent pattern until the 60 min-passage.

3.2. Reduction characteristics in the time of the 12-h long-term runoff of pollutants

In this experiment, the first experiment results were analyzed through a 720-min long-term experiment with several experiment conditions. The items analyzed in

Table 2
Reduction efficiency trend of pollutants in unit (soil and grass soil) for 60 min (NO_3^- was calculated based on concentration)

Slope (a; $y = ax$)	SS	T–N	NH_4^+	NO_3^-	T–P	PO_4^-
Surface runoff						
Soil	1.30	0.62	0.98	0.16	–0.19	–0.16
Grass soil	2.00	–0.43	1.80	0.55	0.02	0.02
Intermediate runoff						
Soil		–3.06	2.26	0.47	2.18	2.27
Grass soil		1.82	2.29	0.27	2.20	2.25
Lower runoff						
Soil		–3.10	2.21	0.31	2.01	2.27
Grass soil		1.61	2.28	0.27	2.20	2.23

Table 3
Reduction efficiency trend reliability of pollutants in unit (soil and grass soil) for 60 min (NO_3^- was calculated based on concentration)

Linear coefficient (R^2)	SS	T–N	NH_4^+	NO_3^-	T–P	PO_4^-
Surface runoff						
Soil	0.82	0.31	–0.12	0.33	–0.15	0.35
Grass soil	0.08	–0.03	–0.08	–0.02	0.17	–0.27
Intermediate runoff						
Soil		–0.51	–0.02	0.88	–0.43	–0.35
Grass soil		–0.56	–0.35	0.72	–0.35	–0.37
Lower runoff						
Soil		–0.55	–0.39	0.84	–0.33	–0.27
Grass soil		–0.36	–0.33	–0.15	–0.13	–0.18

this experiment were SS, T–N and T–P in unit (soil and grass soil) and T–N, NH_4^+, NO_3^-, T–P and PO_4^- in grass soil – lower runoff. The pollutant concentration changes in the experiment condition are shown in Tables 4–5. In the experiment, very interesting results were identified. Fig. 5 shows the reduction efficiency change characteristics in the surface runoff of soil and grass soil. On the other hand, their reduction efficiency trends are shown in Fig. 6.

The analysis results of SS, T–N and T–P in unit (soil and grass soil) surface runoff are as follows:

SS showed a consistent reduction efficiency change tendency in soil for 720 min, while grass soil showed the wide-range reduction efficiency with positive and negative directions and the periodical repetition – vastly different results from the short-term experiment ones. The final reduction efficiency after the 720 min-passage in grass soil was 76% and showed a huge change width between the highest 77% and the lowest — 70%. The average reduction efficiency of SS in grass soil was 19%; higher than –8% in soil and much lower than 83% in grass soil. In addition, the increasing trend of the reduction efficiency was very linear in the short-term experiment but just contrary in the long-term experiment. Those results were due to the reduction mechanism of SS was likely to be mostly dependent on sedimentation, attachment and filtering. In other words, when SS was gradually attached and accumulated to grass and then reached a certain limit, it was likely to outflow out at the moment and the phenomenon was likely to repeat itself. In this experiment, these cycles occurred three times for 720 min and the cycles were observed in 150–180-min intervals (Fig. 5). The example suggested that SS reduction efficiency in grass soil — surface was very different depending on the runoff duration and concentration measurement timing. On the other hand, when it comes to the SS reduction efficiency trend for 720 min, the slope values in soil and grass soil were –0.016 and 0.0618 respectively – higher in grass soil (Fig. 6).

The reduction efficiency of T–N did not show a significant change in soil but the slight increase and decrease with a parabola shape for 720 min in grass soil (Fig. 5). The average reduction efficiency was shown at 2 and 7% in soil and grass soil respectively — higher in grass soil. With regards to the reduction tendency, the slope values

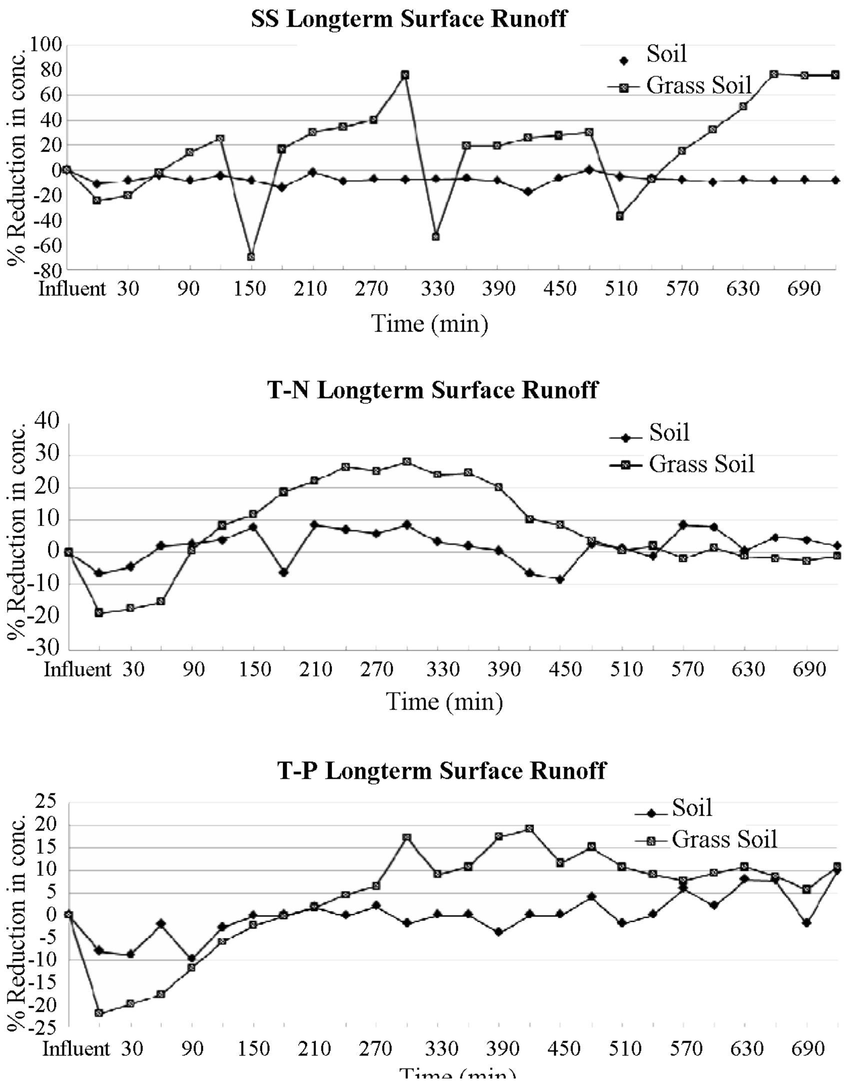


Fig. 5. Reduction efficiency change of SS, T–N and T–P for 720 min in unit (soil and grass soil) surface runoff.

were 0.0049 and 0.0139 in soil and grass soil respectively — a very slight increasing trend (Fig. 6). Grass soil showed negative reduction efficiency in the 60-min short-term experiment but in the case of the 720-min duration of runoff, it showed a slight increase of reduction efficiency.

The reduction efficiency tendency of T–P also showed slightly high in grass soil (Fig. 5). In the long-term experiment, the average reduction efficiencies for 720 min were 0 and 4% in soil and grass soil respectively, without large difference and after the 720-min passage, the final reduction efficiencies were 10 and 11% without any difference as well.

Through the 720-min experiment in unit (soil and grass soil) surface runoff, SS showed repetitive increases and decreases, and T–N and T–P did not show any significant reduction efficiency.

The analysis results of T–N, NH_4^+, NO_3^-, T–P and PO_4^- in grass soil – lower runoff are as follows (Fig. 7):

The reduction efficiency of T–N decreased by –159% after 30 min and then gradually increased to 76% after 720 min. The slope value was relatively low as 0.0651 but the reduction efficiency was entirely under the increasing tendency. That is presumably because NO_3^- and organic-N originally contained in soil have continually decreased. Fig. 8 shows the concentration change tendency of NO_3^-, the concentration reached the top in the time of the 20–30 min passage of initial runoff and thereafter decreased gradually — a change pattern similar to T–N. The reduction efficiency tendency of NH_4^+, T–P and PO_4^- was very similar to the 60-min short-term experiment. That is, it showed a very high reduction efficiency of over 90% for the initial 20 min and afterwards continuous reduction efficiency until the 720-min passage. That is presumably because of the ion action with the negative charge nature of NH_4^+ and soil and the specific adsorption of phosphorus and soil like the 60-min short-term

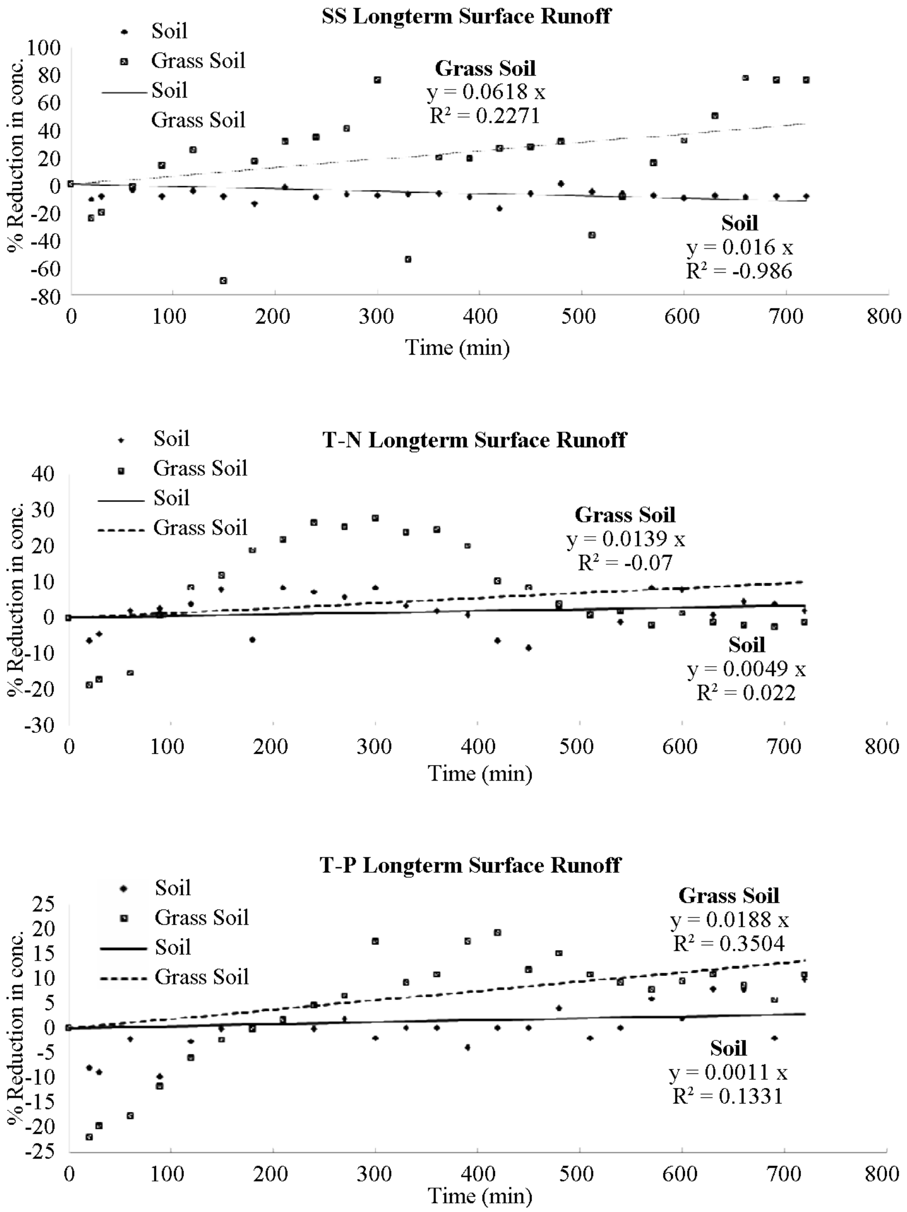


Fig. 6. Reduction efficiency trend of SS, T–N and T–P for 720 min in unit (soil and grass soil) surface runoff.

experiment. In addition, it was found that these actions were clearly sustained for the 720-min long-term through these experimental examples. In the case of NO_3^-, the inflow water was prepared only with NH_4Cl reagent and distilled water, so there was no NO_3^- in the initial inflow. Accordingly, it was impossible to directly compare the reduction efficiency calculation to the other materials. In addition, the concentration of NO_3^- detected at the time of runoff can usually be considered to be hidden in the soil. Accordingly, in this analysis, like the above 60-min short-term experiment, the change pattern was grasped and compared not by the reduction efficiency but by the concentration change. In the 720-min long-term experiment, the concentration of NO_3^- reached up to 4.34 mg/L after the initial 20 min in grass soil – lower runoff and thereafter decreased gradually over time to the lowest concentration of 0.38 mg/L after 720 min. The concentration change can be said to be an increasing trend as the slope value of 0.2104 including 0 min (inflow time). In the concentration change until the 720 min passage after the 20 min passage excluding 0 min (inflow time), however, the distinct continuous decreasing trend was shown.

The changer tendency for 0–60 min in this 720-min long-term experiment should theoretically be equal to the 60-min short-term experiment, but different cases were observed in some conditions. That is presumably because the unit was used in the long-term experiment after the short-term experiment and some substances remained

Table 4
Concentration change of SS, T–N and T–P for 720 min in unit (soil and grass soil) surface runoff

Time (min)	SS		T–N		T–P	
	Soil	Grass soil	Soil	Grass soil	Soil	Grass soil
Influent	44.20	44.20	15.50	15.50	5.10	5.10
	Surface runoff					
20	49.00	55.00	16.50	18.40	5.51	6.21
30	48.00	53.20	16.20	18.20	5.55	6.11
60	46.00	45.00	15.20	17.90	5.21	6.00
90	48.00	38.10	15.10	15.40	5.60	5.70
120	46.20	33.00	14.90	14.22	5.24	5.40
150	47.90	75.10	14.30	13.70	5.11	5.22
180	50.40	36.70	16.45	12.60	5.10	5.11
210	45.10	30.70	14.20	12.10	5.01	5.01
240	48.20	29.10	14.40	11.40	5.11	4.87
270	47.50	26.40	14.60	11.60	5.00	4.77
300	47.60	10.54	14.20	11.20	5.20	4.22
330	47.50	68.10	15.00	11.80	5.10	4.64
360	47.20	35.70	15.20	11.70	5.10	4.55
390	48.10	35.80	15.40	12.40	5.30	4.21
420	52.10	32.70	16.50	13.90	5.10	4.12
450	47.10	31.90	16.80	14.20	5.10	4.51
480	44.20	30.70	15.10	14.90	4.90	4.33
510	46.50	60.43	15.30	15.40	5.20	4.55
540	47.20	47.80	15.70	15.20	5.10	4.64
570	47.60	37.60	14.20	15.80	4.80	4.71
600	48.40	30.10	14.30	15.30	5.00	4.62
630	47.60	22.10	15.40	15.70	4.70	4.55
660	48.10	10.20	14.80	15.80	4.71	4.66
690	47.80	10.70	14.90	15.90	5.20	4.81
720	48.00	10.60	15.20	15.70	4.60	4.55

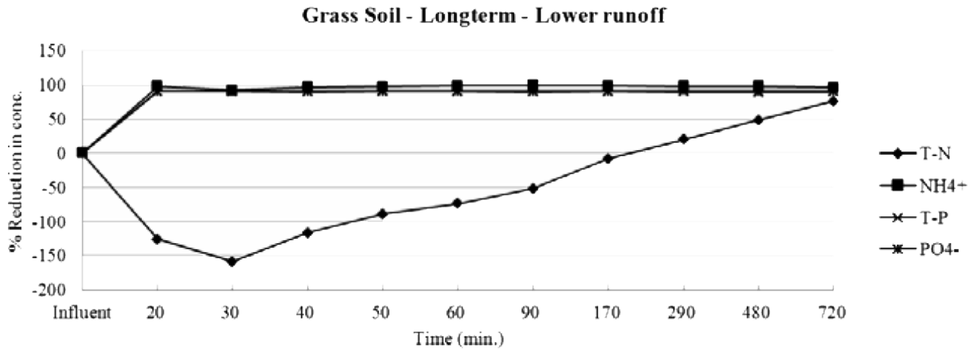
Table 5
Concentration change of pollutants for 720 min in grass soil – lower runoff

Time (min)	Grass soil				
	T–N	NH_4^+	NO_3^-	T–P	PO_4^-
Influent	13.35	13.35	0.00	5.52	5.52
	Lower runoff				
20	30.16	0.25	4.34	0.50	0.49
30	34.53	1.03	3.50	0.51	0.51
40	28.94	0.41	3.07	0.54	0.50
50	25.22	0.33	2.67	0.48	0.50
60	23.18	0.17	2.44	0.51	0.51
90	20.32	0.13	2.12	0.54	0.51
170	14.48	0.14	1.44	0.52	0.51
290	10.68	0.28	1.04	0.55	0.49
480	6.85	0.22	0.71	0.58	0.51
720	3.16	0.52	0.38	0.53	0.50

in the unit in the short-term experiment. The time of 720 min in the long-term experiment is long — 12 times more compared to the time of the 60 min of the short-term experiment. The reduction efficiency for the 12 h showed the repetition with a regular cycle, an insignificant change and a smooth change pattern. Accordingly, it is judged that the remained concentration did not have a significant effect on the long reduction tendency.

4. Conclusion

This study conducted the 60-min short-term and the 720-min long-term experiment in the door bench scale unit, where the experimental conditions could be controlled, in order to quantitatively identify the reduction characteristics of RBS non-point pollutants. Soil type and grass-soil (RBS assumed) were used in the experiment unit and the experimental conditions were applied equally to the two units. According to the results analyzed



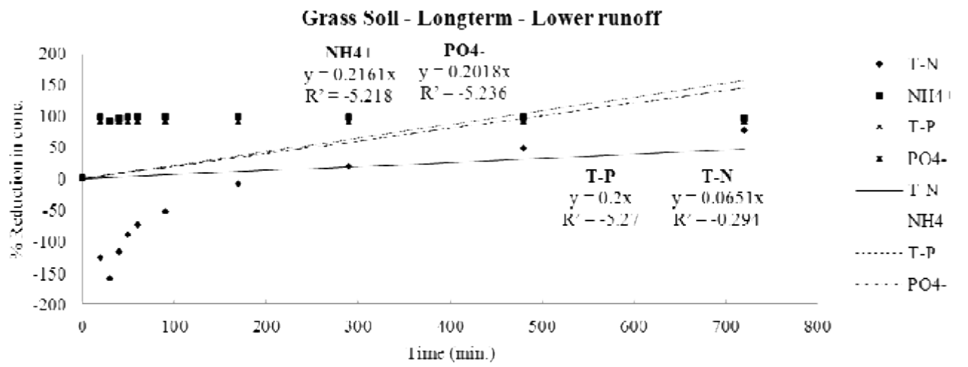


Fig. 7. Reduction efficiency (above) and trend (below) of pollutants for 720 min in grass soil – lower runoff.

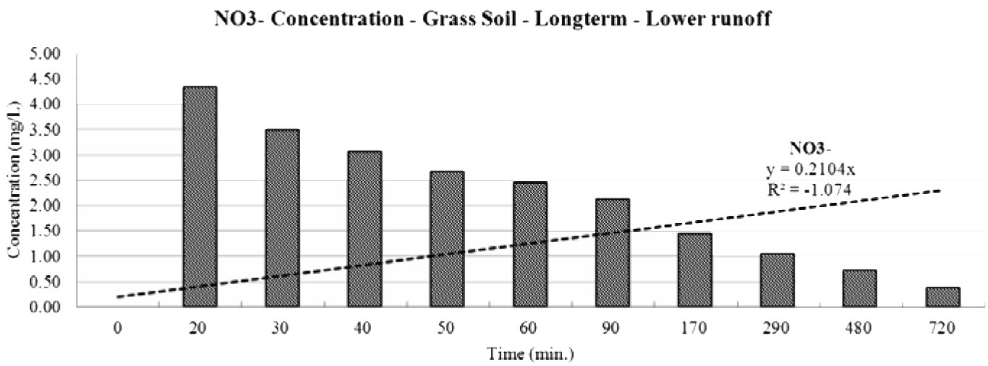


Fig. 8. Concentration change and trend of for NO_3^- 720 min in grass soil – lower runoff.

through application of several conditions to this experiment, the following results were identified:

1. In short-term runoff, the grass-covered RBS showed the higher pollutant reduction efficiency than bare soil and in surface runoff, SS and in subsurface runoff, T–N, especially, showed the relatively very clear reduction effect. In surface runoff, the average reduction efficiencies of SS, T–N, NH_4^+, T–P and PO_4^- were shown at 47, 25, 42, –8 and –5% in soil unit and 83, –18, 76, 1 and 2% in grass–soil unit, respectively; excellent in grass–soil unit excluding NH_4^+. On the other hand, in the lower runoff of subsurface, T–N, NH_4^+, T–P and PO_4^- showed –137, 96, 87 and 98% in soil unit and 70, 99, 94 and 95% in grass–soil unit, respectively; showing little effect of grass, and T–N showed a clear effect of grass. Give the average concentration of NO_3^-, it was found that it rose less in the subsurface of the grass–soil unit than in the soil unit.

2. In the long-term runoff, the pollutant reduction effect of RBS and bare soil was shown differently from the short-term runoff. The average reduction efficiency of SS, T–N and T–P in surface runoff showed –8, 2 and 0% respectively in soil unit and 19, 7, and 4% respectively in the grass–soil unit: the reduction efficiency of SS decreased a lot as compared to the case of short-term runoff

while the efficiency of T–N and T–P did not show any significant change. In the lower runoff of the subsurface, T–N, NH_4^+, T–P and PO_4^- of the grass soil unit showed –48, 97, 90 and 91% respectively – a slight difference from the short-term runoff except T–N. On the other hand, the NO_3^- concentration-decreasing trend in the lower runoff of the grass–soil unit was shown clearer than the short-term runoff.

3. Even though the reduction efficiency of non-point pollutants of RBS was high, it was hard to numerically generalize the effect. Especially, the reduction efficiency of SS in grass soil – short term – surface runoff showed 89% at the 60-min passage; the lowest at 70% and the highest at 91% and the change tendency comparatively close to linear. In grass soil – long term – surface runoff, however, the reduction efficiency of SS showed 76% at the 720-min passage; the lowest at 70% and the highest at 77% for 720 min and a non-linear change pattern. In addition, the reduction efficiency showed a pattern with repetitive increases and decreases over time. Accordingly, that means that the reduction efficiency was shown extremely dependent on the runoff duration time and the concentration measurement timing. On the other hand, T–P and PO_4^- showed the drastically increased reduction efficiency in the beginning of the runoff in the subsurface and then the situation continued for a long time, so it was identified relatively easily as compared to SS.

4. In the case of nitrogen, it was found that $NH_4^+$is very sensitive to the negative charge of soil and T–N containing organic-N and NO_3^- is influenced by grass root action. In the grass soil – short-term experiment, the average reduction efficiency of T–N showed –18% in surface runoff, 80% in intermediate runoff and 70% in lower runoff; the reduction efficiency change after the passage of the plant root was clearly confirmed but the reduction efficiency improvement in subsurface runoff of soil unit was not found. This phenomenon was similar to the average concentration change pattern by the runoff depth of NO_3^-. On the other hand, it was confirmed that the concentration of T–N could temporarily increase by the removal of the organic-N that had condensed in grass root. The movement of nitrogen was unstable in surface runoff but stable in the subsurface runoff.

5. In the case of phosphorus, the reduction effect is excellent in the subsurface runoff of soil regardless of grass and is sustained for a long time. The reduction effect through the specific adsorption of phosphorus was confirmed commonly through both the short-term and the long-term experiment. It was found that the reduction efficiency over 90% was showed both in the soil unit and the grass–soil unit between the initial 10–20 min of subsurface runoff. In addition, it was confirmed that the efficiency was sustained stably for 720 min in the grass–soil unit. The reduction efficiency of phosphorus was nearly observed in surface runoff but its movement was a slightly stable compared to nitrogen.

The experiments in this study were conducted indoors in order to identify the reduction characteristics of RBS (or VFS) pollutants under the consistent experiment conditions without external disturbances. Accordingly, the results could be different according to soil kinds, rainfall pattern and pollutant load depending on local areas. In addition, in order to generalize the RBS (or VFS) reduction efficiency, the accumulation of many experiment results considering various parameters is needed.

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