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Nutrient impact on the Bocheung watershed by land application of the treated animal waste

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ABSTRACT

Land application of animal waste is the most common and usually the most desirable method of utilizing manure and wastewater because of the value of the nutrients and organic matter. Land application of animal waste should be planned to ensure that the proper amount of nutrients are applied in a manner which does not adversely impact the environment or endanger public health. This study was conducted to defi ne the optimum amount and concentration of animal waste fertilizer considering the watershed impact and public health. A field test bed has been built to perform several loading conditions of animal waste land application. Fromthe field test, the runoff ratio of nutrients such as TN and TP from DM (dried manual) is 29% of surface runoff and 7.0% of groundwater, whereas the one of LF (liquid fertilizer) is 1.5% of surface and 79% of groundwater. In addition, the nitrogen concentration in surface runoff from LF decreases much faster than DF. Using the runoff ratio of nutrients obtained from the field test, SWAT simulations for a real watershed were carried out to evaluate the impact of land application of animal waste on the water environment with the different loading scenarios. Although the different loading scenarios are simulated, very little change in the water qualities in the channel is observed. Thus, most of the nutrients added by DM and LF into the cultivated area seem to disappear or become consumed in the soil and very limited amount of nutrients reaches to the channel. To explore this situation, further research will be necessary.

Keywords: Land application of animal waste; SWAT; Nutrients Manure

1. Introduction

Untreated animal waste significantly affects the water system. For example, rivers may have a high concentration of the organic matters and nutrients. The total flow produced from the animal waste is only 0.6% compared to that from total sewage and wastewater, however the pollution loads affecting the river are 25.8% due to the high concentrations of the nitrogen and phosphorus, which result in the eutrophication and the algal-bloom. Therefore, treatment of the animal waste should be conducted to improve the river's water quality. Swine waste accounts for 60% of animal waste production [1]. The methods to treat the animal waste consist of composting (89.5%), self-disposal (3.0%), recycling services for consignment disposal (2.0%), disposal in public facilities (4.6%), disposed in the ocean (0.9%). In addition, the public treatment facilities for a purification treatment so far would be converted to resourcing facilities for the compost and liquid fertilizer considering the region's characteristics. Cattle farms, sowing farms, Swine Associate Corporation (SAC), and the National Agricultural Cooperative Federation (NACF) would support a center for the compost and liquid fertilizer distribution

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thereby making a progress in resource conservation. Public resource facilities are economically managing the animal waste while effectively recycling the resources by working with the eco friendly agricultural industry. However, it should be practically considered an environmental capacity depending on regions, and injudicious usage of that would result in increased environmental pollution. Even though the concept of the animal waste management is improving by a government policy from simple disposal to fertilizer production, it faces the problem that there are limited numbers of farms that use, supply and transport liquid fertilizers. These problems regularly happen and result in the disharmonious supply and demand of the liquid fertilizer. According to the result of the underground water investigation, over 20% of shallow underground water has been contaminated with nitrate [2]. Thus, domestic farms and soils contain over-nutrition. Supplying an animal liquid fertilizer onto a land would accelerate eutrophication in a lake and increase the nutrition overflowing into a water system.

The main objective of this study is to understand how animal waste affects the water system by analyzing the supply and demand situation of animal wastewater resources in terms of its production and utilizing conditions.

2. Methodology

To accomplish the objectives, two approaches can be made: field test and SWAT simulation. The field test of animal waste land application has been conducted on our test bed, which was recently built for this study. At the test bed, several loading conditions of animal waste land application have been conducted to evaluate its impact on the surrounding water environment. Based on the result from the test bed, SWAT simulations for a real watershed were carried out to evaluate the impact on the downstream water environment. For this purpose, we developed different loading scenarios of animal waste and compared the SWAT simulation results from each scenario in order to establish a better management plan to utilize manure and wastewater from land application of animal waste.

2.1. Field experiments of land application of animal waste

The test area in a field was divided by three regions: Standard (ST) area, dry solid manure (DM) area, and liquid fertilizer (LF) area with the width of 5 m and the length of 10 m, respectively (Fig. 1). The DM is a zone applied with dried cattle manure by surface loading, LF is a zone applied with liquid fertilizer from swine

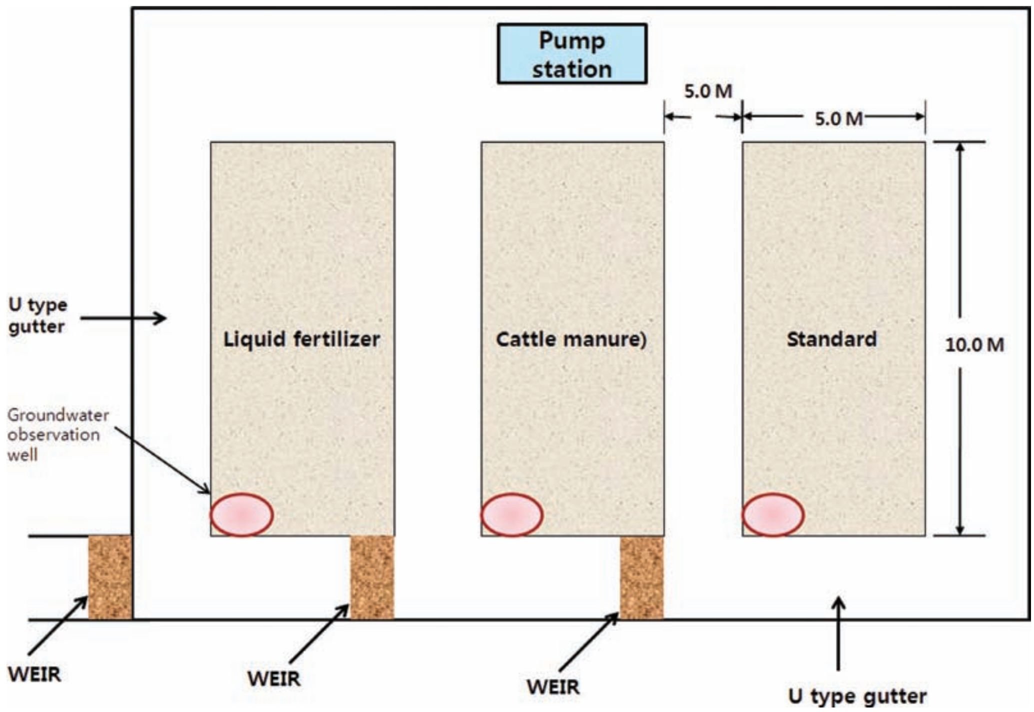

Fig. 1. A plane diagram of the test areas.

manure by spray irrigation and ST is a zone applied with nothing to control. The test areas were constructed with a slope to collect the run-off water at a one point, and the spacing between each test area was 5 m to minimize the influence from another test area (Fig. 2). Several facilities were also constructed at the end of the run-off discharging point. Groundwater wells and weirs were constructed to monitor the groundwater flow and its infiltrate rates, and to check the flow rate of the run-off. Artificial rainfall tests at the intensity of 2–10 mm/h were conducted using the groundwater in the field and which were in a series of sprinklers generally supplied by underground pipes. The input quantities of the DM and LF were determined as 210 kg N/ha/yr by EU standard [3,4]. Based on the standard, therefore, LF of 1200 L and DM of 900 kg were sprayed and dumped onto the test area of 50 m^2 (around 80 L per 3.3 m^2 for liquid fertilizer). The run-off and groundwater samples were collected from each test area depending on the artificial rainfall intensity then analyzed in COD, BOD, TSS, VSS, T-N, T-P, NO3-N, and PO4-P using Standard Methods. The DS and LF were initially sprayed and dumped onto the testing area, and the total artificial rainfall intensity was 1.2 m^2/m^3 through five times in five months.

2.2. SWAT simulation

To explore the impact of the land application of animal waste on water quality in a natural watershed, a SWAT simulation was performed on the Bochung watershed where the test bed site is located.

2.2.1. Description of the study area

The watershed is located in the southwest of Seoul (Fig. 3). It is a typical rural and forest watershed that has a total area of 7020 ha and the rice field and agricultural areas account for 15.6% and 10.2% of the total area, respectively as shown in Table 1. The ratio of the ferti lizer applied land use is approximately 25%. In addition, there is no water treatment plant or other point source of pollutant in the study area. Thus, the land application of the fertilization may be the major source of providing nutrients for the watershed and its streams.

2.2.2. Data acquisition

The following data shown in Table 2 is collected for the analysis. The data period is from 2004 to 2006 except for the channel water quality data, which the period is 2005–2006. The entire data set is collected, verified and

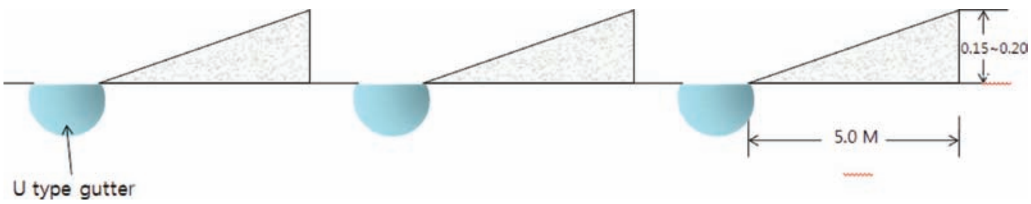

Fig. 2. The cross section figure of the testing field.

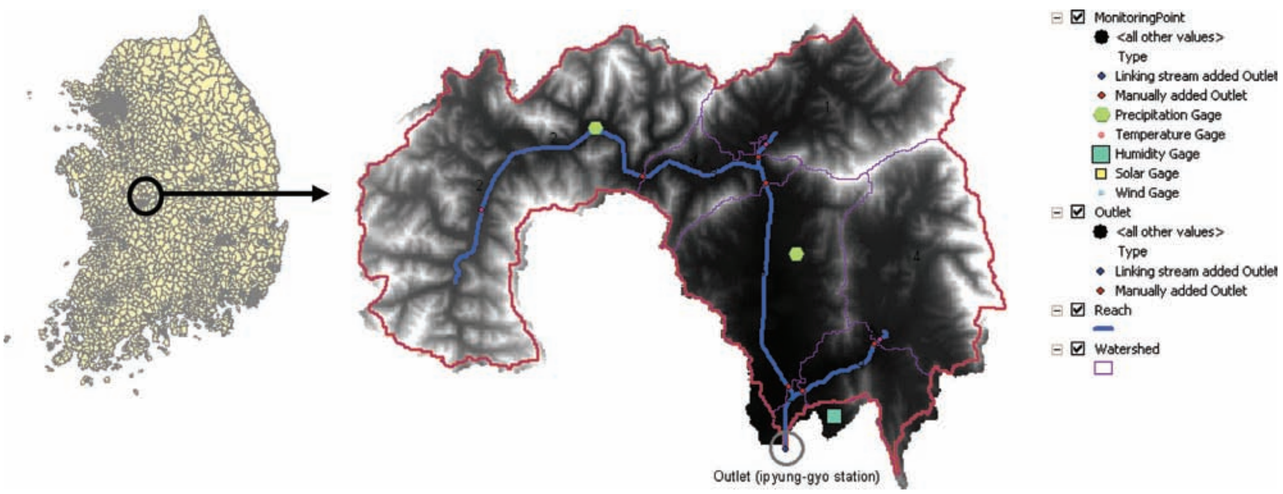

Fig. 3. Streams and outlet of the Bochueng watershed.

Table 1
Land use in the bochueng watershed.

Land use	Area (ha)	Percent
Urban area (including transportation)	217.35	3.1
Rice field	1098.09	15.6
Agricultural land generic (upland field)	714.24	10.2
Forest	4794.93	68.3
Water	80.1	1.1
Etc.	114.84	1.6
Total	7019.55	100.0

Table 2
Data collected for the analysis.

Data Type	Source	Description
DEM	Water Management Information System (WAMIS)	30 m × 30 m resolution (grid. file)
Soil Type	WAMIS	30 m × 30 m resolution (grid. file)
Land use	WAMIS	30 m × 30 m resolution (grid. file)
Stream	WAMIS	shp.file
Observed channel flow	WAMIS	Ipyung-gyo station (Excel file)
Observed channel water quality	Geum river environment research center	Boeun II station
Rainfall	Korea meteorological administration (KMA)	Boeun, Iwon, and Sinham stations (dbf.file)
Max/Min Temp	KMA	Boeun
Wind speed	KMA	Boeun
Humidity	KMA	Boeun
Solar radiation	KMA	Cheongju

Table 3
SWAT fertilizer parameters for "Beef_compost" (60,000 kg/ha/yr applied).

Parameters	Field survey parameters	Converted parameters	Actual mass of nutrient applied (kg/ha/yr)
FMIN	0.002530	0.30360	151.80
FORGN	0.001430	0.17160	85.80
FNH3N	0.001000	0.12000	60.00
FMINP	0.000060	0.00720	3.60
FORGP	0.000354	0.04248	21.24

Table 4
SWAT fertilizer parameters for "Swine_liquefied" (61,720 kg/ha/yr applied).

Parameters	Field survey parameters	Converted parameters	Actual mass applied (kg/ha/yr)
FMIN	0.001450	0.178988	89.49
FORGN	0.001609	0.198615	99.31
FNH3N	0.00100	0.123440	61.72
FMINP	0.00011	0.013578	6.79
FORGP	0.00041	0.050610	25.31

distributed by the Korean government and government funded institutes.

For the fertilizer, the field survey has been performed to obtain the amount, the fertilizer parameters of SWAT of liquid fertilizer and dried manure. 61,720 kg/ha/yr of liquid fertilizer is applied to rice fields and 60,000 kg/ha/yr of dried manure is applied to upland fields. The amount of both fertilizers applied is much greater than the input range of SWAT of which the maximum amount is 500 kg/ha/yr. For this reason, when we added two new fertilizers into the database of SWAT, namely, "Swine_liquefied" and "Beef_compost", the fertilizer parameters for them were converted to satisfy the actual mass balance. The actual fertilizer parameters obtained from the field survey and converted parameters are shown in Tables 3 and 4.

To model the land application of DF and LF, it is assumed that each fertilizer is spread twice every year on December 1st and 15th. For each application, the amount of the fertilizer applied is 225 kg/ha. The 50 kg/ha of the mass difference (i.e. 500 kg/ha − 225 × 2 kg/ha = 50 kg/ha) is accounted for by SWAT's auto fertilization management option.

Table 5
The characteristics of resources from cattle and piggery waste in application area.

Variables	Cattle Waste		Piggery Waste			
	Waste[a]	Dried Manure[a]	Waste[a]	Liquid Fertilizer[a]	Waste[a]	SawdustFermentation[a]
BOD5	38,700	29,600	45,300	3,219	46,300	37,200
CODcr	146,000	125,600	125,400	19.600	173,000	158,600
SS	143,100	176,000	100,500	8,400	117.300	183,000
T-N	7,385	6,310	6,350	1,980	6,290	5,535
T-P	1,540	1,720	1,590	336	1,460	1,110

[a]All units in mg/L.

Table 6
The characteristics of applied liquid fertilizer.

	CODcr	SS	VSS	T-N	T-P
Liquid fertilizer (mg/L)	24,400	18,100	12,300	4,086	408
Dried fanure (mg/kg)	121,300	148,300	112,000-	5,310	2,110

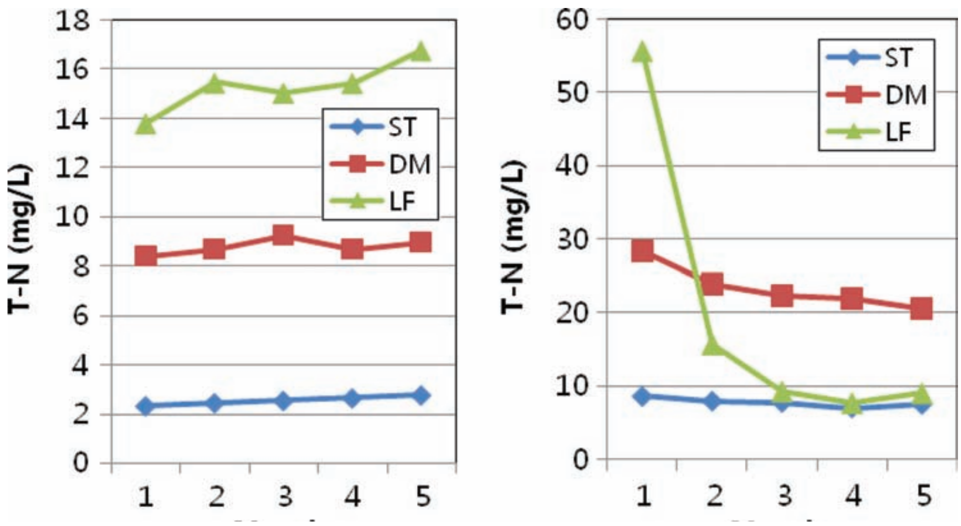

Fig. 4. The variation of T-N concentration in ground water and surface runoff.

3. Result and discussion

3.1. The characteristics of dried manure and liquid fertilizer

Table 5 shows the results analyzed in characteristics of the cattle and piggery waste and manure collected from surveyed farm, depending on the treated form of the wastes. When cattle waste was converted to dried manure, the concentration of the BOD5, CODcr, and T-N decreased to approximately 52%, 26%, and 6%, respectively. However, the concentrations of the SS and T-P increased to approximately 38% and 26%. In the case where piggery waste was converted to LF all the concentrations of the BOD5, CODcr, SS, T-N, and T-P were decreased as 71%, 68%, 99%, 65% and 65%, respectively. When piggery waste was fermented with sawdust, BOD5, CODcr, T-N and T-P were decreased about 33%, 34%, 57%, and 17% and SS were increased to approximately 20%.

3.2. The result of actual field run-off test

The field runoff tests using artificial irrigation with shallow aquifer were conducted. Table 6 shows the characteristics of applied dried manure and liquid fertilizer to a crop field. Figure 4 shows the concentration variation of the total nitrogen in ground water and surface runoff depending on the different waste types. One of the tests was controlled in standard condition. LF had the highest concentrations while the operation around 15 mg/L in ground water compared to the result tested with DM. The concentrations were kept during the operating periods. However, due to the surface runoff, the nitrogen concentration decreases. In the test using LF, in one month the nitrogen concentration drastically dropped by 27% while the test using dried manure decreased gradually. This is a result due to the higher degrading rate from liquid condition to ammonia to nitrate compared to from solid condition (Fig. 5).

3.3. Mass balance of the applied nitrogen

The results of the experiment, which was tested with LF, were analyzed in mass balance to track the nitrogen applied in field. The total applied nitrogen was 4904 g, and that of 1.5% was washed on the surface of the land (surface runoff). 79% of the applied nitrogen was penetrated to the groundwater, and the rest existed in the test area (Table 7). Most of nitrogen applied was detected in ground water in this case because of the characteristics of the LF. The liquid type of the fertilizer could be penetrated to the shallow aquifer in short duration. Therefore, the surface runoff mass was a competitively small amount. In the case of phosphorus analysis, most of P was existed in the field. This was because of soil adsorption of the phosphorus [5]. Phosphorus can easily attach onto the solids and its solubility is low in the LF [6]. In another test with DM, 29% of the total applied nitrogen was detected on the surfaced by runoff and 7.0% of that was penetrated to the ground (Table 8).

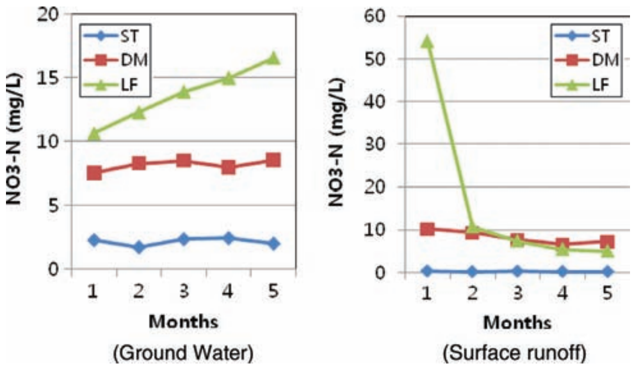

Fig. 5. The variation of nitrate concentration in ground water and surface runoff.

3.4. SWAT calibration results

The SWAT calibration is performed for the period of 2004–2006 and the first year is used as the model initialization (warm-up period). The calibration process consists of two different steps: rainfall-runoff and water quality simulation. While the calibration is performed, the parameters in Table 9 have been adjusted to make a good agreement. Comparing the simulated runoff to the observed stream flow for 2005 and 2006 at Ipyeonggyo station shown in Figs. 6 and 7 performs calibration for rainfall-runoff. Both values of runoff show a good agreement for 2005 and 2006 ($R^2 = 0.77$ and 0.74 and RMSE = 0.174 and 0.173, respectively).

For water quality simulation, we choose TN and TP as the target water quality parameters and calibrate the SWAT input parameters for SWAT to simulate the observed monthly mass of them. The calibration results for TN and TP are shown in Figs. 8 and 9, respectively. In the case of TN, the value of R^2 is 0.686 for the study period.

Table 7
The comparison of liquid fertilizer characteristics between run-off and groundwater.

Resource		Total applied (g)	surface runoff (g)	To ground water (g)	Residual (g)
Liquid fertilizer	COD	29,280	1,054	4,685	23,541
	T-N	4,904	73.56	3,874	956
	T-P	485.4	7.28	39.8	438.3

Table 8
The comparison of cattle manure characteristics between run-off and groundwater.

Resource		Total applied (g)	surface runoff (g)	To Ground water (g)	Residual (g)
Dried manure	COD	109,170	13,646	262	95,262
	T-N	4,779	1,386	335	3,058
	T-P	1,899	550.7	246.9	1,101

Table 9
Calibration results for SWAT parameters selected.

Parameters	Range	Calibration	Description
GW_Delay	All	60	Ground water delay time (days)
AI1	0.07–0.09	0.09	Fraction of algal biomass that is nitrogen (mgN/mg alg.)
AI2	0.01–0.02	0.02	Fraction of algal biomass that is phosphorus (mgN/mg alg.)
NPERCO	0.00–1.00	0.15 (observed)	Nitrate percolation coefficient
PPERCO	10.0–17.5	17.5	Phosphorus percolation coefficient (10 m^3/Mg)
Sol_NO3	All	100	Initial NO3 concentration in the soil layer (mg/kg)
Sol_ORGN	All	5000 (for Rice/Agri. field) 3000 (for others)	Initial organic N concentration in the soil layer (mg/kg)

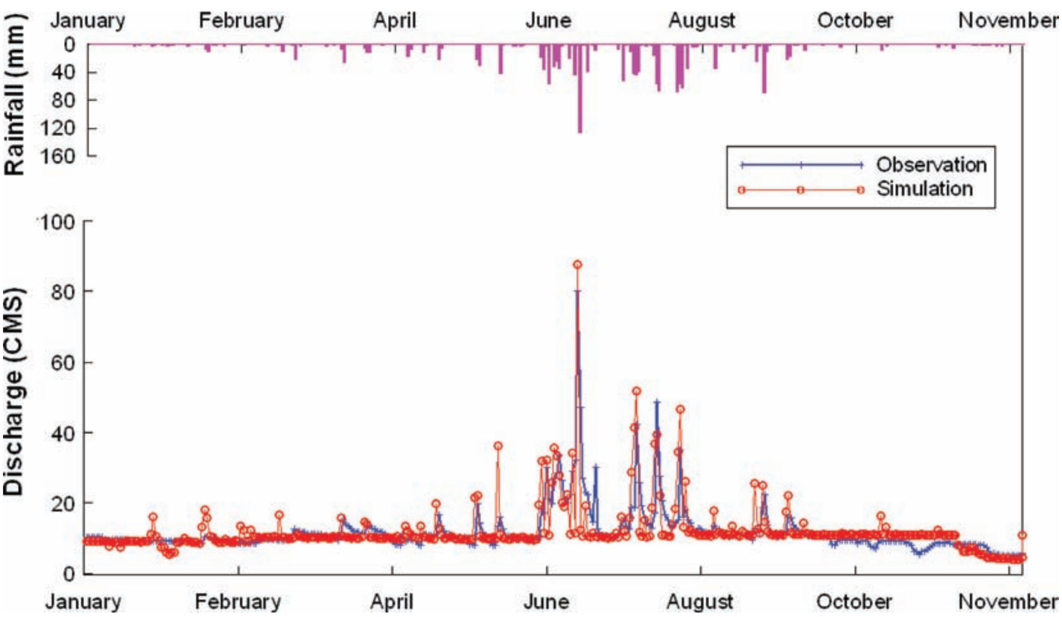

Fig. 6. Observed and simulated daily stream flows at Ipyeong-gyo station (2005).

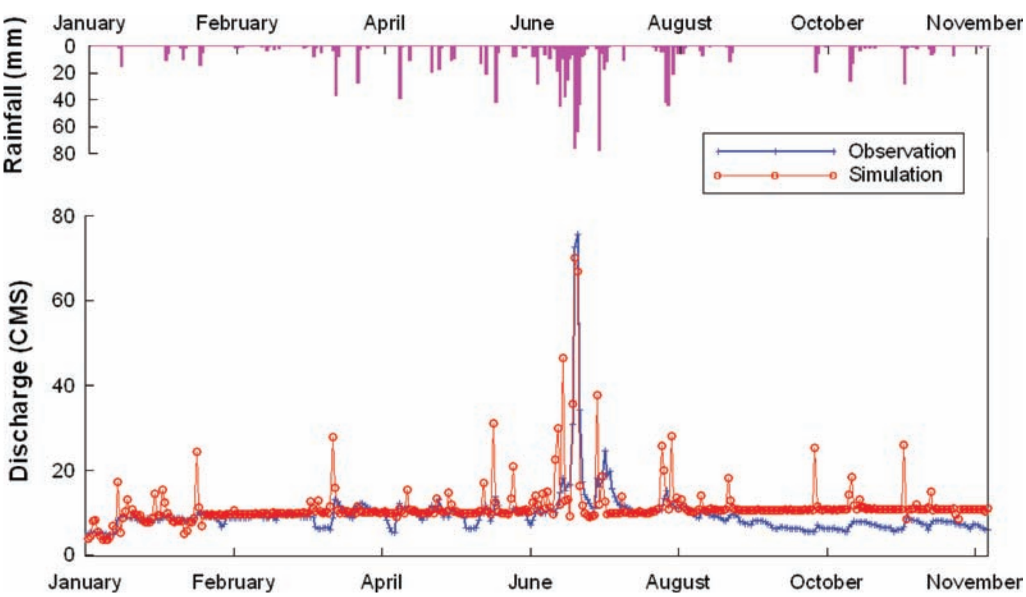

Fig. 7. Observed and simulated daily stream flows for at Ipyeong-gyo station (2006).

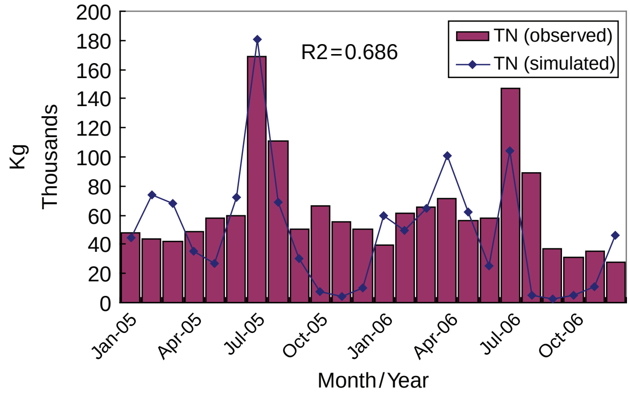

Fig. 8. Comparison result the monthly mass of the observed TN to the simulated TN.

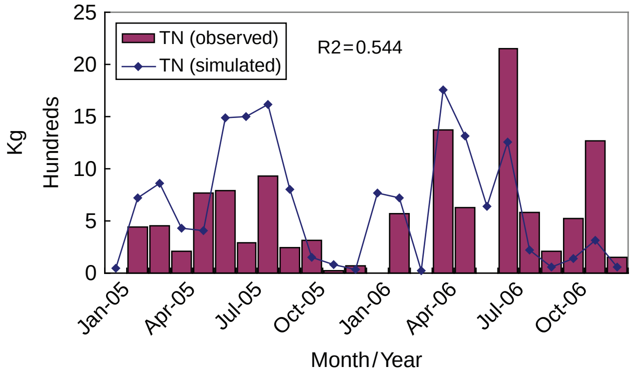

Fig. 9. Comparison result the monthly mass of the observed TP and the simulated TP.

Being 0.5 higher it means SWAT can simulate the monthly runoff trend of TN. In particular it shows that the annual peak of TN, which occurs in July, and the runoff for the dry period, from January to April can be properly simulated by SWAT. However, the simulation results of TN are not good enough to be compared with that of the stream flow. The most discrepancy between the observed and simulated is found in the period between October and December or after harvest. During this period, the observed mass of TN maintains the certain level, which is higher than 20 tons/month while the simulated mass of TN, is less than 5 tons/month. While considering this fact, with the statistical result and the overall comparison between the observed and simulated results of TN, the prediction of TN runoff by different fertilizer loading conditions is possible.

In case of TP, the value of R^2 is 0.544 for the study period which is a little higher than 0.5. In 2005, the values of TP simulated are generally higher than that of the observed while those are lower than that of the observed in 2006. Although the annual peak concentration and overall annual runoff trend of TP may not be accurately simulated by SWAT, we come up with a different conclusion for TP since the amount of TP emitted from this area is very small. If the monthly mass of TP is converted into the concentration, its range is 0.02–0.001 mg/L, which is much low to be measured accurately. Thus, the amount of TP emitted may not have much influence on the water quality in the local channel. For this reason, the current calibration results can be used to simulate the different loading condition of the DM and LF.

3.5. Simulation of different DM and LF loading conditions

With calibration parameters of SWAT, the impact of treated animal waste fertilizer (DM and LF) applied to cultivated areas on water quality of the channel is explored. For this purpose, three different DM and LF loading conditions are assumed and those are

- CASE 1: 60 tons/ha/yr (current condition)
- CASE 2: 30 tons/ha/yr
- CASE 3: 1 tons/ha/yr

CASE 1 is the current condition representing that the possible maximum amount of treated animal waste is applied to cultivated areas. Compared to CASE 1, CASE 2 and 3 are introduced to explore the fact that the water quality will be improved by reducing the amount of treated animal waste that is applied to cultivated areas. Figures 10 and 11 show the simulation results for TN and TP from the three cases, respectively. Surprisingly, the runoff amount of TN and TP from each CASE is very similar. It means that additional amounts of nutrients supplied by DM and LF are not delivered to the channel and most of them disappear or become consumed by the soil. To verify this hypothesis, we look at the monthly values of the variables representing the nutrient physical status in the soil and find that the monthly values of "F-MN", "A-MN", and "A-SN" change significantly depending on the amount of DM and LF applied. The definition of those variables is explained in Table 10.

An example of the monthly values of such variables is shown in Table 11. The results from Table 11 show one rice cultivating HRU out of the 75 HRUs while showing the same outcome of as the others. For January, "A-SN" is significantly increased then drastically decreased after January and "F-MN" is increased in proportion to the amount of DM and LF applied. It implies that additional amount of TN from DM and LF of CASE 1 and 2 turns into "A-SN" or "F-MN" while it remains in the soil until it is consumed or disappeared. It is also why the runoff of TN to the channel does not change regardless of the amount of DM and LF applied. Although it does show where the additional amounts of TN are located, the detailed physical and soil-chemical processes are not understood." To explain why this phenomenon occurs in the soil, further research is necessary.

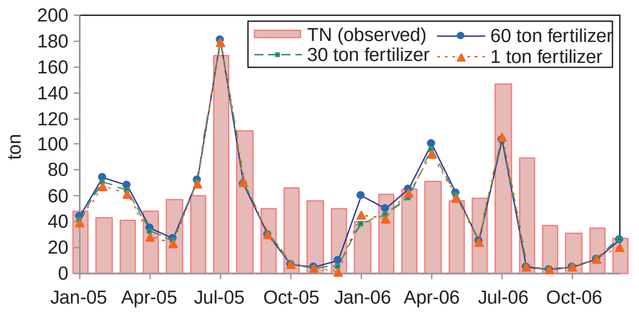

Fig. 10. Comparison results for the different loading conditions of TN.

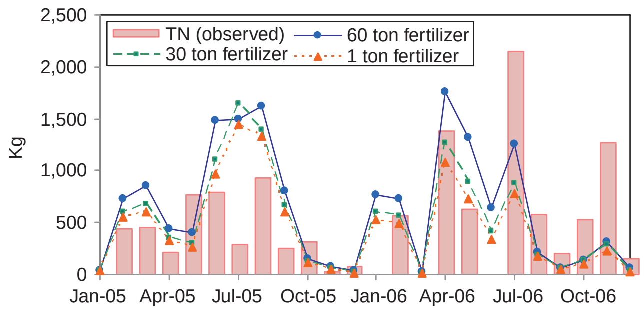

Fig. 11. Comparison results for the different loading conditions of TP.

Table 10
The definition of "F-MN", "A-MN", and "A-SN".

Variable name	Description (SWAT user's manual and technical documents)
F-MN	Fresh organic to mineral N (kg N/ha). Mineralization of nitrogen from the fresh residue pool to the nitrate (80%) pool and active organic nitrogen (20%) pool during the time step. A positive value denotes a net gain in the nitrate and active organic pools from the fresh organic pool while a negative value denotes a net gain in the fresh organic pool from the nitrate and active organic pools
A-MN	Active organic to mineral N (kg N/ha). Movement of nitrogen from the active organic pool to the nitrate pool during the time step.
A-SN	Active organic to stable organic N (kg N/ha). Movement of nitrogen from the active organic pool to the stable organic pool during the time step.

Table 11
An example of the monthly values of those variables (rice field).

RICE field	1 ton			30 tons			60 tons		
	F-MN	A-MN	A-SN	F-MN	A-MN	A-SN	F-MN	A-MN	A-SN
Jan-05	0.04	0.32	–17.16	1.00	0.33	872.02	2.00	0.34	872.09
Feb-05	0.09	0.39	–0.10	2.44	0.41	0.02	4.88	0.44	0.15
Mar-05	0.19	0.69	–0.17	4.99	0.76	0.18	9.97	0.83	0.54
Apr-05	0.12	0.79	–0.17	3.31	0.87	0.17	6.62	0.95	0.52
May-05	0.09	1.15	–0.19	2.46	1.27	0.16	4.91	1.39	0.52
Jun-05	0.05	1.51	–0.20	1.24	1.66	0.13	2.47	1.82	0.47
Jul-05	0.01	1.68	–0.23	0.40	1.84	0.09	0.79	2.00	0.43
Aug-05	0.00	1.70	–0.25	0.11	1.85	0.05	0.21	2.01	0.37
Sep-05	0.06	1.34	–0.26	0.09	1.46	0.02	0.11	1.59	0.32
Oct-05	0.04	0.83	–0.28	0.04	0.89	0.00	0.05	0.97	0.30
Nov-05	0.02	0.65	–0.28	0.02	0.71	–0.01	0.02	0.76	0.27
Dec-05	0.03	0.32	–0.15	0.86	0.34	–0.08	1.72	0.35	0.00
Jan-06	0.15	0.44	–16.35	4.22	0.49	853.40	8.43	0.54	854.06
Feb-06	0.15	0.48	–0.21	4.37	0.55	0.16	8.74	0.62	0.55
Mar-06	0.17	0.67	–0.29	4.86	0.79	0.33	9.71	0.91	0.96
Apr-06	0.10	0.69	–0.29	2.97	0.81	0.30	5.94	0.94	0.92
May-06	0.08	1.05	–0.30	2.39	1.24	0.30	4.78	1.43	0.92
Jun-06	0.04	1.39	–0.31	1.27	1.64	0.26	2.54	1.90	0.85
Jul-06	0.02	1.64	–0.33	0.43	1.90	0.24	0.86	2.17	0.82
Aug-06	0.01	1.65	–0.35	0.13	1.92	0.20	0.27	2.20	0.77
Sep-06	2.01	1.14	–0.36	2.33	1.33	0.17	2.72	1.53	0.71
Oct-06	3.31	0.90	–0.37	3.79	1.05	0.16	4.30	1.20	0.72
Nov-06	1.96	0.64	–0.36	2.00	0.75	0.15	2.06	0.85	0.68
Dec-06	1.69	0.64	–0.36	9.05	0.79	0.42	16.16	0.94	1.22

4. Conclusion

Five months of field runoff study was conducted to determine an optimum application level of dried and liquefied animal waste for crop field. From the nitrogen mass balance, the total applied nitrogen of 1.5% was washed as surface runoff and 79% of the applied nitrogen was penetrated to the groundwater. The liquid type of the fertilizer cannot be penetrated to the shallow aquifer in short duration. In another test with DM, 29% of the total applied nitrogen was detected on the surface by runoff, and 7.0% of that was penetrated to the ground.

Based on the field data obtained from the experiment and hydrologic and geographic watershed data, SWAT simulations were performed. The rainfall-runoff calibration was performed, followed by the water quality calibration for TN and TP for 2005–2006. After the calibration, the observed and simulated stream flows show a good agreement compared to the water quality results.

With three different loading conditions, TN and TP reached to the channel remains in the same amount. The additional amount of TN and TP turned into the active or mineral organic and eventually were consumed or disappeared in the soil. Unfortunately, the detail processes involved in this phenomenon cannot be explained in this study. As a conclusion, the treated animal waste applied to the cultivated areas may not have significant impact on the water quality in the channel. However, further research is required to understand the physical and soil-chemical processes, which remove or consume the additional nutrients in the cultivated areas.

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