Nitrogen recovery from feces and urine in urine diverting composting toilet system

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ABSTRACT

Urine diversion system is applied to the composting toilet by using sawdust as a matrix. Feces are composted in the sawdust matrix and urine is stored in the urine storage unit (USU). It was obtained how much fecal nitrogen was recovered in the sawdust matrix after composting process. Further it was estimated how much urine nitrogen, mainly urea nitrogen, avoided the ammonification during long time storage. These two studies were performed by batch tests in laboratory scale. Finally it was evaluated how much nitrogen can be recovered in the urine diverting composting toilet system (UDCTS) and its result was compared to the recovery rate of nitrogen in conventional style in which faces and urine was treated in the sawdust matrix without separation.

Results show that approximately 35% of fecal nitrogen would be recovered in biologically inert type of organic matter. In the urine storage unit, approximately 65% of urine nitrogen avoided the decomposition to ammonia if urine storage unit was well sealed. Finally approximately 60% of nitrogen from human excreta can be recovered as organic type that included with urea nitrogen in the UDCTS. When inorganic ammonia nitrogen could be counted into the recovered nitrogen, more than 90% of input nitrogen from human excreta might be recovered, while less than 5% of input nitrogen was estimated to recover in the conventional system.

INTRODUCTION

Since toilet waste contains great amount of nutrients [1], unstable organic matter and pathogens, the composting toilet that accepts and treats them is a key technology in the Onsite Wastewater Differentiable Treatment System (OWDTS) [2]. Previous studies have concluded that the composting toilet equipped with the heating and mixing devices performed decomposition and stabilization of organic matter [3] and decay of pathogen from toilet waste in a short time [4] while great amount of power is consumed during the operation mainly for heating process. Since great amount of water mainly from urine

is fed to the composting reactor, the heating process for acceleration of water evaporation is an indispensable process in this system to maintain the aerobic condition in the sawdust matrix. Further it was shown by the practical operation of the toilet that huge amount of nitrogen was lost from the sawdust matrix mainly as ammonia gas [5] which reduce the recovery rate of nitrogen for reuse [6]. Previous studies also showed that volatilization of ammonia from the composting process of livestock manure should be controlled because it contributes to several negative effects to the environment [7].
It is therefore required to study urine diverting composting toilet system (UDCTS). In the UDCTS, feces would be composted in the sawdust matrix as conventional and urine would be stored in urine storage unit (USU). Since sawdust matrix needs to be exchanged at suitable interval, usually once a year, it is assumed that stored urine is also recovered together with the sawdust matrix. Nitrogen contains a unique character due to several gas types (NH_3, N_2, N_2O etc.) among nutrients (N, P, K, etc.) from human excreta. The aim of this study is to show nitrogen recovery rate in the UDCTS: in the composting process of feces and urine storage process.

METHODS

Recovery Rate of Fecal Nitrogen

We performed batch test for composting process of human feces by using experimental devices as shown in Figure 1. In the device, we controlled reaction temperature at 55°C, airflow rate at 100 ml/min (supply of oxygen) and moisture content of composting material around 60% during the tests.

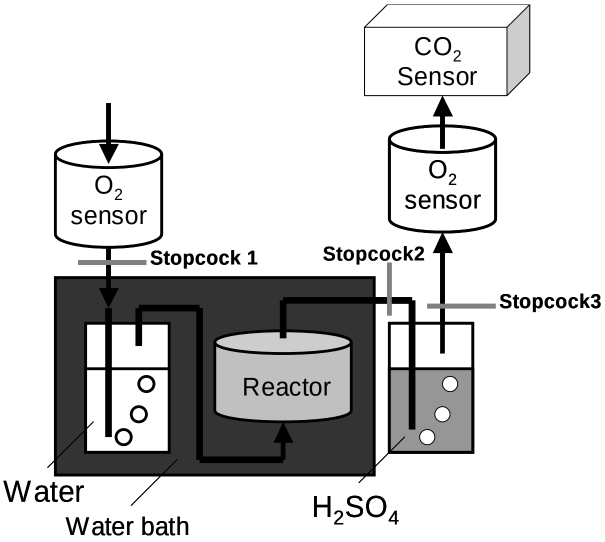

Figure 1. Experimental device for composting process of feces

Feces from young male were collected in plastic vessel and were stored in a refrigerator for a couple of days. Sawdust as a matrix was prepared by composting process in the bioreactor in which only feces had been fed for half a year. Since the sawdust was stored in a freezer until it was used, it was assumed that a character of sawdust as a matrix was uniformed in every batch test. Composting materials for the batch tests were prepared by mixing of feces, the sawdust as a matrix and distilled water to set the initial moisture content on 60%. For batch tests several concentrations of feces in the composting material (FS ratio: Feces sawdust ratio) were prepared between 0 to 20% as shown in Table1.

Table 1. Materials condition.

	FS ratio (%)	Feces (g-dry)	Sawdust (g-dry)
RUN 1	20	18.0	90
RUN 2	5	5.1	103
RUN 3	15	14.1	94
RUN 4	20	17.3	87
RUN 5	20	17.3	87
RUN 6	15	14.1	94
RUN 7	10	9.8	92
RUN 8	2	2.3	102
RUN 9	15	13.3	87

In the batch tests, we measured the oxygen utilization rate (OUR), ammonium nitrogen volatilization rate (ANVR) and CO_2 production rate (CO_2PR) [8]. The OUR was obtained by the differences of oxygen partial pressures between outflow from and inflow to the reactor. The ANVR was obtained by analysis of ammonia in the bottles of sulfuric acid (H_2SO_4) that were exchanged at suitable intervals during the batch tests. To avoid huge amount of leakage of air from the reactor during the exchange of bottles, stopcock1 to 3 were turned off. To complete the aerobic biodegradation of organic matter in feces, every batch test had been continued for two weeks after oxygen consumption (the OUR) in the reactor was approaching to zero.

Mass balance of carbon and nitrogen in the composting material were obtained [9]. The content of nitrogen and carbon in the material of feces and composted material at the end of the batch tests was measured by gas chromatography on an NC analyzer (SUMIGRAPH NC-1000: SHIMADZU CORPORATION) after drying process for 24 hours at 105^{o}C. Dissolved ammonia in the liquid phase of composting material was also measured by following Indophenol method after extraction process [9].

It is very difficult to conduct direct measurement of the fecal contribution to the mass balance of carbon and nitrogen during the composting process. The contributions of composting material (CF+CS) were measured in the batch tests and the contribution of sawdust matrix only (CS) was measured by a same procedure in a pre-batch test. Then fecal contribution (CF) was obtained by a simple subtraction as shown in Figure 2 [9].

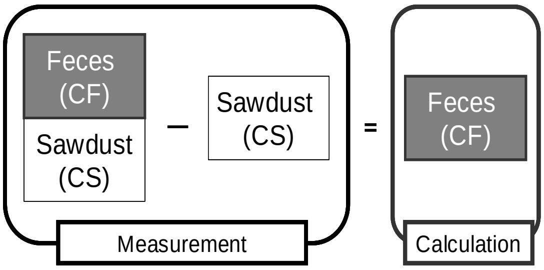

Figure 2. The procedure for calculation of contribution from faeces (CF)

Ammonification in Stored Urine

Since previous reports have already shown that perfect separation of urine from the feces is impossible in a practical situation even in urine diverting toilet bowl [10,11], we performed batch tests of storage process of human urine with fecal contamination. To obtain the lower levels of fecal concentration of 2 g-feces/l-urine, fecal solution was prepared by the addition of distilled water. Fresh feces of 20 g were mixed with 100 ml of distilled water to obtain the fecal solution. When the moisture content of the feces was approximately 88 %, 1.78 ml of the feces solution was fed to 150 ml of the material urine to obtain the 2 g-feces/l-urine [12]. Urine with fecal contamination was poured into the glass bottle that was sealed completely to avoid the leakage of ammonia gas and stored in an incubator at 30 °C (RUN10). During the storage test, pH, urea and ammonia concentrations were measured at suitable intervals for 35 days [12].

RESULTS

Recovery Rate of Fecal Nitrogen

Figure 3 shows the time course of the OUR profiles in every batch tests from RUN1 to RUN8. As we have seen, the levels of OUR increased in first few days and was kept decreasing after peak values. Since they were approaching to zero at the end of the tests, it was therefore assumed that biodegradable organic matter in feces had been decomposed to CO_2 or biologically inert type at the end of the tests.

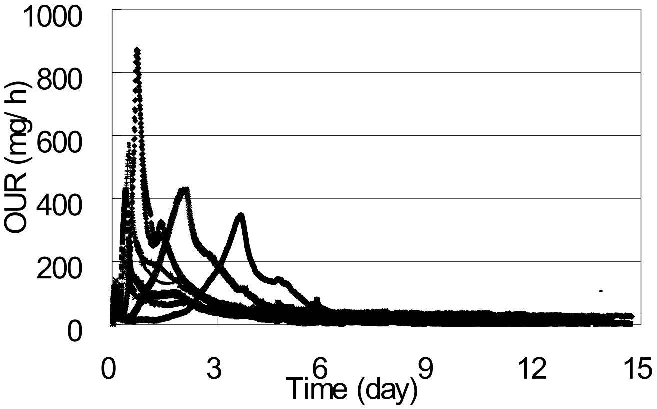

Figure 3. Time course of the OUR in RUN1 to RUN9.

Figure 4 shows the time course of CO_2PR and OUR in RUN1 of 20% of the FS ratio. Since the OUR completely corresponded with CO_2PR, it was therefore concluded that in this study no further oxygen consumption took place, for instance by nitrification, except for CO_2 production by heterotrophic microorganisms. Figure 5.1 shows the production of ammonia nitrogen against the input nitrogen in human feces. As we have seen, approximately 66% of input fecal nitrogen decomposed to ammonia nitrogen during the aerobic biodegradation of feces. Since we were able to neglect the contribution of nitrification, we therefore concluded that the remaining nitrogen could be calculated approximately to 34% of the input nitrogen as organic nitrogen of biologically inert type. Figure 5.2 shows that the organic nitrogen of the inert type remained in the composting material against the input fecal nitrogen. Figure 5.2 supports the calculation result in Figure5.1: 34% of organic nitrogen of the inert type remained in the composting material. In Figure 5.2, data enclosed by a black circle (RUN1) was removed as an irregular value. The results in Figure 5.1 and Figure 5.2 led us to conclude that approximately 66% of fecal nitrogen decomposed to ammonia, while the further 34% remained as organic nitrogen of inert type in the composting material.

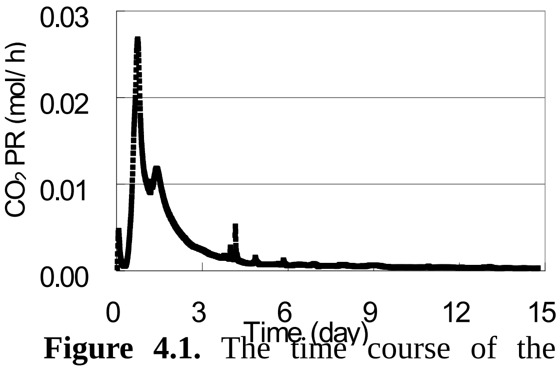

Figure 4.1. The time course of the CO_2PR in RUN1.

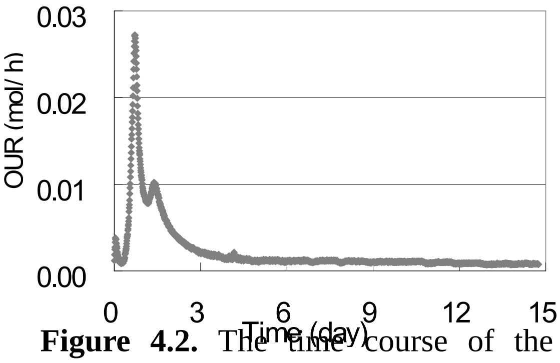

Figure 4.2. The time course of the OUR in RUN1.

Figure 4. The comparison of time course of the OUR with CO_2PR in RUN1

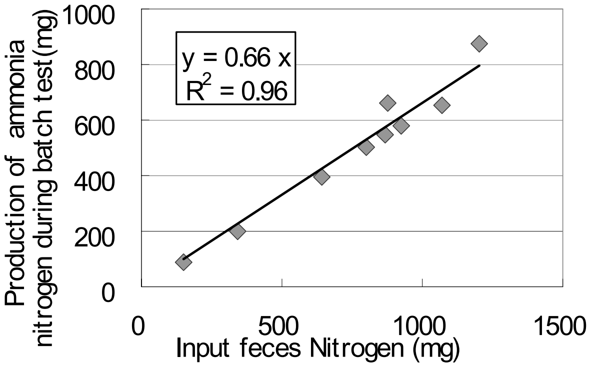

Figure 5.1. Production of ammonia by composting process of feces against input nitrogen in feces.

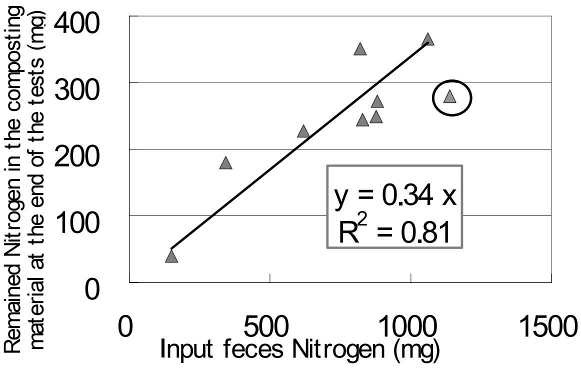

Figure 5.2. Nitrogen in composting material remaining as inert type against input nitrogen in feces.

Figure 5. Nitrogen transformation to ammonia or organic nitrogen as inert type during the composting process of feces

Ammonification in Stored Urine

Figure 6 shows the time course of the nitrogen components in the stored urine (RUN10) at 30°C. As we have seen, we obtained the hydrolysis of urea 20 days after the beginning of the test. After 20 days the hydrolysis stopped even though a certain amount of urea still remained. We obtained the constant value of the sum up of the ammonia and urea during the batch test.

Figure 7 shows the time course of the ammonification rate in the batch test at 30°C. In Figure 7 the ammonification rate rapidly increased for up to 2.3 days and dropped to zero by the end of the test. Approximately 65% of total nitrogen remained as organic type that included with urea after 35 days storage. Since ammonification rate had kept decreasing and reached zero after 27.6 days, it was assumed that stored urine with fecal contamination (RUN10) contained an effect of inhibition on the ammonification.

The effects of the molecular type of ammonia ($NH_{3(aq)}$)on the activity of microorganisms have already been reported in areas of anaerobic digestion for wastewater treatment [13]. According to this report, a concentration of more than 1500mg/l of ammonia nitrogen at pH of more than 7.4 inhibits the activity of bacteria. The corresponding concentration of $NH_{3(aq)}$ was calculated as 33 to 102mg/l. Figure8 shows the time course of the ammonification rate and the concentration of $NH_{3(aq)}$ in the batch test. As we have seen, the ammonification rate significantly kept decreasing after the concentration of $NH_{3(aq)}$ had increased more than 137mg/l, which value was obtained at 2.4 days. Finally the ammonification rate reached approximately 0g-N/day after 27.6 days when urea was still more than half of the initial concentration as shown in Figure 6. It might thus be possible to say that the ammonification rate was affected by the concentration of $NH_{3(aq)}$ during storage of urine.

While further more studies are required to evaluate the inhibition factor for ammonification in stored urine, it can be seen that at least 65% of nitrogen in urine could avoid ammonification for 35 days and then the rate of ammonification had approached to zero after 27.6 days if the USU was sealed well.

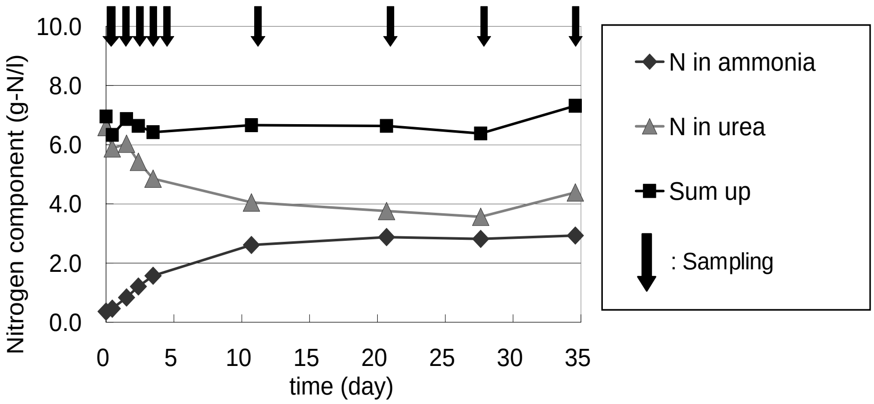

Figure 6. Time course of nitrogen components in stored urine

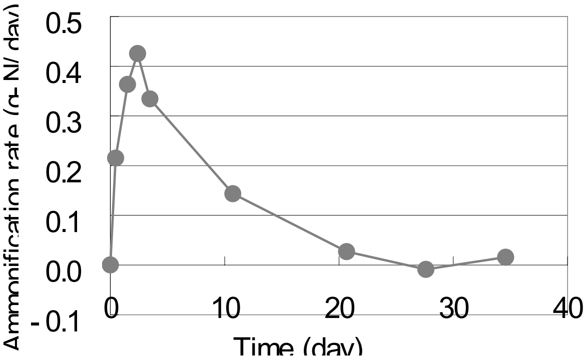

Figure 7. Ammonification rate during the urine storage

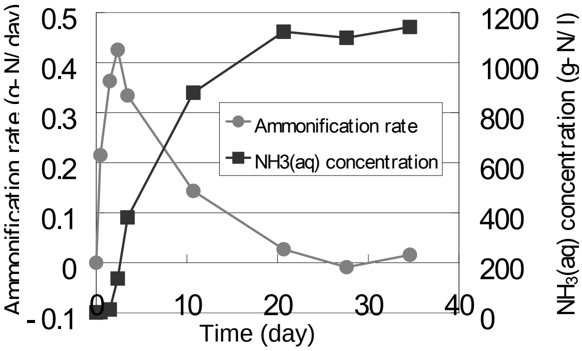

Figure 8. The comparison of the ammonification rate to $NH_{3(aq)}$ concentration in stored urine

DISCUSSION AND CONCLUSION

Previous study has already shown nitrogen recovery rate in a practical operation in which feces and urine had been treated in the sawdust matrix for 28 days (without urine diversion). Approximately 80% of input nitrogen from feces and urine had been lost in the operation mainly because of ammonia volatilization [5]. A simple approximation was obtained by the trend of input and accumulation of nitrogen in 28 days operation. The approximation would have given an estimation of the nitrogen loss to 97% if the operation had continued for a year.

According to our analytical results of feces and urine, nitrogen content of urine and feces are17g-N/l-urine and 0.07g-N/g-dry-feces [9]. In general, daily amount of urine and feces are 1.0 l-urine/day and 150 g-feces/day [14]. Since content of dry matter in feces was obtained around 20%, daily amount of dry matter of feces should be 30g-dry/day. The quantity of nitrogen from human excreta can therefore be summarized as shown in Table 2. As seen in Table 2, 6.2 kg-N/person/year (urine) and 0.77 kg-N/person/year (feces) were obtained.

Table 2. Summary of mass and nitrogen in human excreta

	Urine		Feces	
Total Mass	1	L/year/day	0.03*	kg-dry/day
	365	L/year	11**	kg-dry/year
Nitrogen	0.017	kg-N/day	0.002	kg-N/day
	6.2	kg-N/ year	0.77	kg-N/year

* Quantity of raw matter is 0.15 kg/day.
** Quantity of raw matter is 55kg/year.

By using results obtained by batch tests in "Recovery rate of fecal nitrogen" and "Ammonification in stored urine", the recovery rates of nitrogen in a year operation were estimated as shown in Table 3. In the result of the batch tests, remaining ammonia nitrogen in the sawdust matrix after composting process of human excreta was around 1 mg-N/g-dry.

Table 3. Comparison of nitrogen recovery rates estimated in a year operation

	Conventional style		UDCTS	
	Urine	Feces	Urine	Feces
Input nitrogen	6.2	0.77	6.2	0.77
Lost nitrogen during operation	6.2	0.50	0**	0.50
Residual ammonia-N	0*	0*	2.2	0*
Residual other types-N		0.27	4.0	0.27

Unit: kg/person/year

*Since ammonia-N remaining in the sawdust matrix should be much smaller than the total input nitrogen from urine or feces, it was assumed that residual ammonia-N could be negligible.

**It was assumed that emission of ammonia gas would be negligible if the USU was sealed well.

Approximately 5 kg-dry of sawdust is required in the composting toilet for one person. Then maximum ammonia remaining in the composting material should be 5g-N/composting-reactor at maximum. The quantity of ammonia remained in the composting material was therefore negligible. It could be calculated that all of nitrogen from urine would be volatilized as ammonia and totally approximately 6.7 kg of nitrogen that was approximately 96.0 % of total input nitrogen would be lost in the conventional style without urine diversion. It supported the 97 % of nitrogen loss estimated by the practical operation.

It was therefore concluded that the lost nitrogen by volatilization of ammonia from the composting material could be decreased in the treatment of human excreta from 6.7 kg to 0.5 kg, from 96.0 % to 7.8%, of total input nitrogen when the urine diversion is applied into the composting toilet system and the USU is well sealed.

In the UDCTS, approximately 4.0 kg of nitrogen that was approximately 65 % in urine could avoid ammonification in the USU and all of nitrogen would be recovered while almost all nitrogen from urine would be lost from the composting material by the volatilization of ammonia without urine diversion. Approximately 0.27 kg of nitrogen that was approximately 35 % of fecal nitrogen transformed to organic nitrogen of inert type after composting process while its 65 % of nitrogen (0.5kg) transformed to ammonia during the composting process.

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