

## Groundwater Pollution by Cattle Slurry Stored in Unlined Lagoon

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### Abstract

The influence of dairy wastes stored in an unlined lagoon on the total nitrogen concentration of shallow groundwater was investigated in western Hokkaido. The lagoon was constructed in a meadow consisting of an Andosol with a high water table. Increase of the total nitrogen concentration in groundwater was observed at a distance of 75 m from the lagoon within 4 days after a low concentration dairy slurry was loaded into the lagoon. At a distance of 15 m from the lagoon, higher total nitrogen concentration was still observed 85 days after slurry loading. These facts clearly indicate that groundwater contamination by cattle slurry stored in the unlined lagoon occurs very quickly and persists for a very long period of time.

**Discipline:** Agricultural environment

**Additional key words:** nitrogen leaching, Andosols

### Introduction

In Japan, the largest dairy farming areas are located in the eastern and the northern parts of Hokkaido. The farms are getting larger and the number of dairy cattle is increasing in these areas. Dairy wastes were usually separated into solid and liquid materials. However, increasing volume of dairy wastes recently has tended to be handled as slurry. Slurry is sometimes stored in unlined earthen pits, namely lagoons, for economic reasons. Lagoons have already been used in more concentrated animal industries such as swine production in Japan.

Obviously, the utilization of such lagoons is associated with the risk of groundwater contamination. Ozaki et al.<sup>(6)</sup> observed an increase in the concentration of nitrate in shallow groundwater at a distance of 50 m from a swine waste lagoon. Shimura and Tabuchi<sup>(8)</sup> pointed out that the nitrate concentration of the river increased in proportion to the livestock density of the catchments where

lagoons are used.

On the other hand, there are conflicting reports on the influence of lagoons<sup>(1,3)</sup> because the infiltration rates of slurry vary depending on the experimental conditions<sup>(2,7)</sup>. In a test conducted under drastic conditions, using a 2 ha lagoon filled with relatively dilute beef cattle manure, Miller et al.<sup>(5)</sup> observed the rapid self-sealing of the lagoon within 2 weeks. They concluded that the lagoon had no effect on the downstream groundwater quality. However, Cullley and Phillips<sup>(3)</sup> concluded that lagoons were not effectively sealed in an experiment covering a 5-year period using 3 lagoons constructed in areas with different soil types.

In this study, the objective was to examine the risk of utilizing an unlined lagoon. Influence of dairy wastes stored in a lagoon on the total nitrogen concentration of shallow groundwater was investigated. In order to observe the influence clearly, an experiment was conducted under drastic but possible conditions in actual farms. In the experimental design, special attention was paid to both areal expansion

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and temporal changes of groundwater contamination. Detailed process of contamination is described and its magnitude was analyzed.

## Materials and methods

### 1) Site description

The experiment was conducted at Hokkaido National Agricultural Experiment Station, Sapporo (43°0'N., 141°24'E.). A cylindrical lagoon, 10 m i.d. × 1.8 m depth, was excavated in a meadow in June 1995. The experimental field was located on a gentle slope on Tsukisamu terrace. Inclination of the slope was 1.7° (Fig. 1).

The soil belonged to Cumulic Andosols<sup>9)</sup>. Tsukisamu terrace is composed of the Tsukisamu clay Formation of Late Pleistocene, covered with volcanic ashes. Soil survey revealed that volcanic ashes could be divided into a humus accumulation layer and Eniwa loamy layer. A transitional layer was observed beneath the Eniwa loamy layer. The upper part of the Tsukisamu clay Formation was divided into 3 layers based on structural differences, namely upper, middle and lower Tsukisamu clay layers (Fig. 2). Based on properties such as texture of soil layers or spurting out of groundwater, the transitional layer and middle Tsukisamu clay layer were considered to be the main paths of groundwater flow, although their hydraulic conductivity was not appreciably different from that of the Eniwa loamy

layer. Lower Tsukisamu clay layer was an impermeable layer, whose hydraulic conductivity was the lowest. Middle Tsukisamu clay layer was an aquifer because it was underlain by an impermeable layer.

### 2) Operation

One hundred two tons of dilute dairy cattle slurry, with a concentration of 0.8 gN/L total nitrogen, were loaded into the lagoon on June 14, 1995. Since the slurry was rapidly depleted within a few days, additional 23 t were applied on June 21, 1995 in order to keep sufficient loads of slurry.

Groundwater samples were collected from 38 monitoring wells surrounding the lagoon during the period of June 8 and September 7, 1995 (Fig. 1). Thereafter, the lagoon was overflowed by heavy rainfall, and groundwater sampling was discontinued. Sampling of groundwater was carried out almost every day in the first week after slurry loading, and every 1 or 2 weeks, thereafter. A polyvinyl chloride pipe 26 mm in diameter was used as monitoring well. The pipe was perforated in the lower part up to 60 cm from the bottom, and was set at a 2 m depth from the soil surface (Fig. 3).

### 3) Analysis

Total nitrogen concentration of the groundwater samples was analyzed chromatographically after potassium peroxosulfide degradation<sup>4)</sup>. Samples contained a large amount of suspended solids, and they were

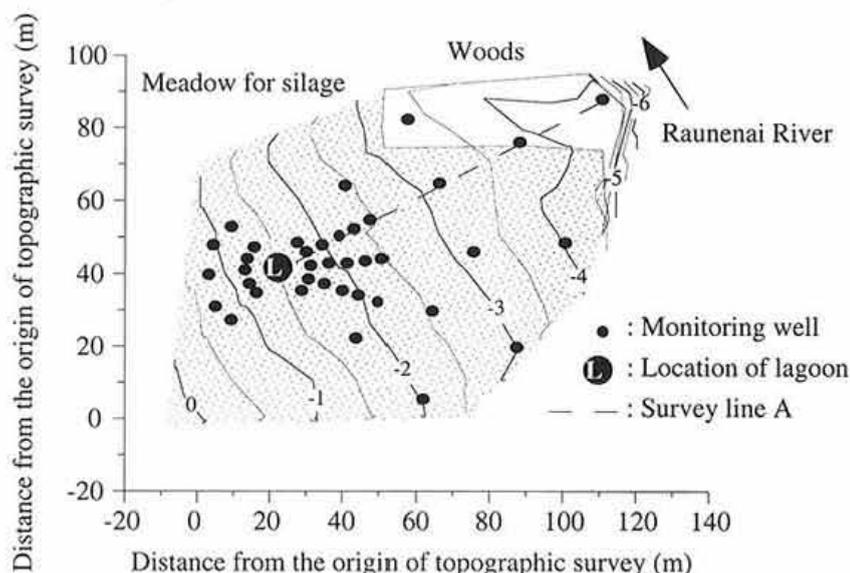


Fig. 1. Contour map of experimental site  
Contour lines are indicated with relative altitude values to the origin of the survey (m).

allowed to stand for a week before analysis in order to induce the precipitation of the suspended solids. Nevertheless, the groundwater samples could not be analyzed by ion chromatography because of the residual suspension.

Soil samples were analyzed for water soluble inorganic ions. Analysis was carried out using 0.45 μm filtrate of water : soil = 5 : 1 extracts by ion chromatography (DX-AQ, Nippon Dionex K. K., Osaka, Japan). Results were expressed as ion concentrations in soil water.

**Results**

*1) Effect of slurry application on total nitrogen concentration of shallow groundwater*

Highly contaminated groundwater was observed immediately after the first slurry loading. Contami-

nation spread rapidly. Expansion of contaminated groundwater occurred mainly along the slope inclination (Fig. 4). After 9 days of the first loading, the contaminated area decreased. However, contamination still persisted at 85 days after the first loading in the vicinity of the lagoon.

In order to analyze the temporal changes of the total nitrogen concentration in detail, data of 8 monitoring points on line A (Fig. 1) are shown in Table 1. Based on the background level, 1.2 mgN/L at most, the data over 2 mgN/L were considered to indicate the contamination of groundwater by the slurry (depicted in shadowed boxes). On the next day of the first slurry loading, the total nitrogen concentration exceeded the background level at a distance of 50 m from the lagoon. On the 4th day, 75 m point was also contaminated. After 9 days, the concentration decreased at most of the

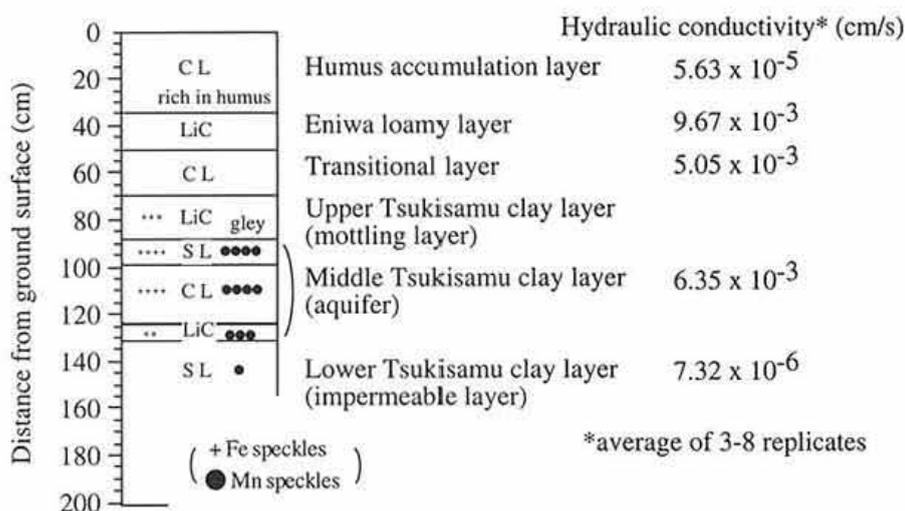


Fig. 2. Soil profile at the location of the lagoon

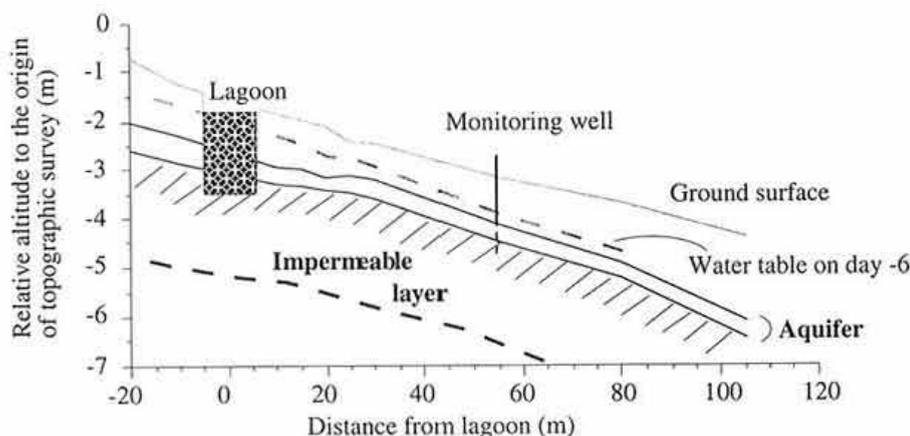


Fig. 3. Profile of survey line along the slope

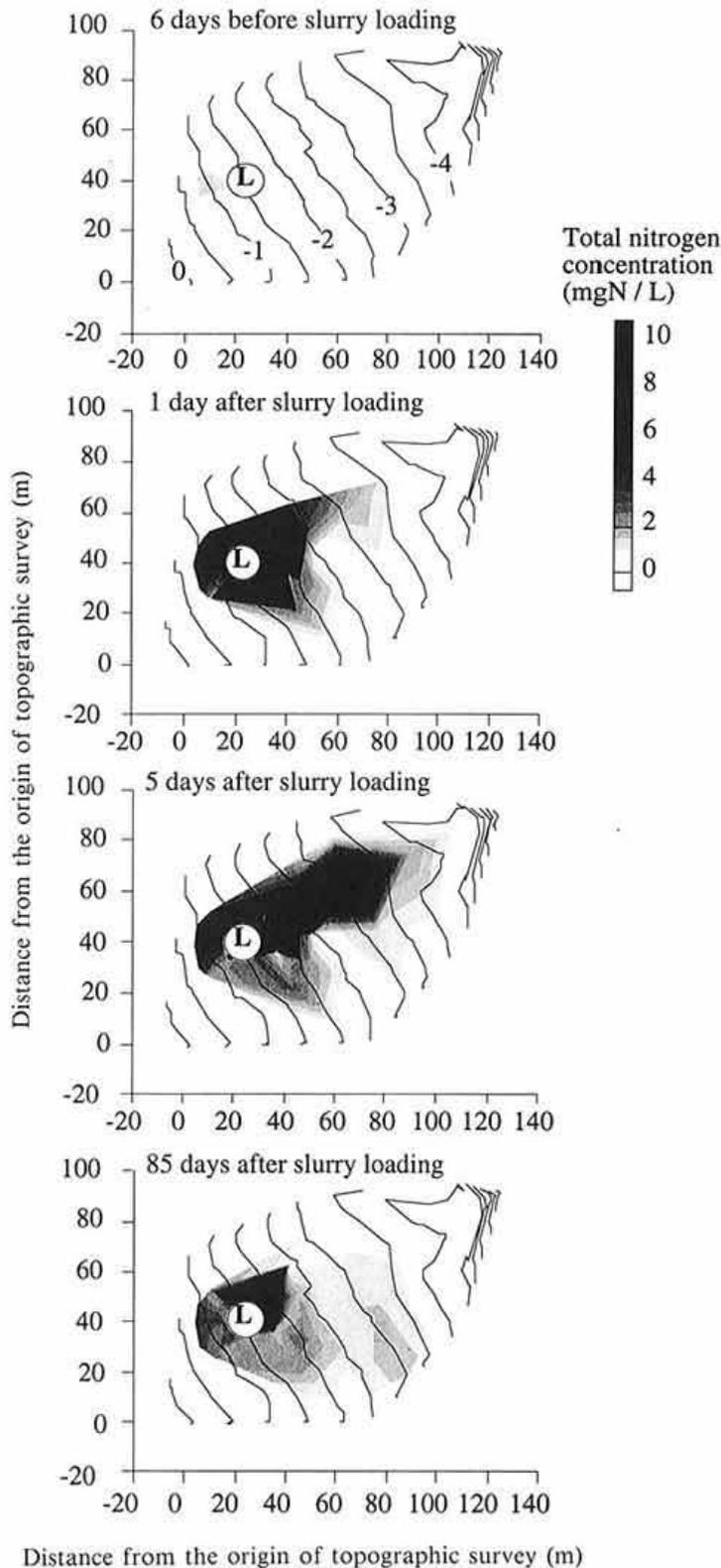


Fig. 4. Expansion of groundwater containing a high concentration of total nitrogen

monitoring points. However, contamination still persisted at 85 days after the first loading at 15 m point.

## 2) Contamination path

After monitoring of the total nitrogen concentration in the groundwater, the slurry was removed and the surrounding soils were analyzed for water-extractable inorganic ions.

In order to analyze the running path of contaminated groundwater, soil samples were collected from every 20 cm layer at 5 sites on line A (Fig. 1). Influence of slurry was obvious at 5 m point down the lagoon (Fig. 5). Ammonium, potassium and chloride were mainly detected in the middle Tsukisamu clay layer. This fact corresponded to the observation that the middle Tsukisamu clay layer was an aquifer, suggesting that most of the contaminated water moved through this aquifer. Interestingly, the nitrate distribution was very different for unknown reasons.

Downward seepage of slurry was examined using soils beneath the bottom of the lagoon. Ammonium, potassium, nitrate and sulfate were mainly distributed within a 20 cm area under the bottom. Chloride was detected slightly deeper, but most part remained within the 50 cm zone (Fig. 6). These facts indicate that downward seepage of the slurry was negligible in this study compared to the horizontal expansion of the contamination.

## Discussion

We examined the influence of slurry stored in an unlined lagoon on the total nitrogen concentration of groundwater. Experimental conditions were drastic. The lagoon was constructed where a continuous flow of shallow groundwater was expected, and the slurry which had a very low viscosity would easily percolate into soils. These conditions allowed us to clearly demonstrate the areal expansion, temporal changes and running path of groundwater contamination.

Through an aquifer, an immediate leakage of slurry was observed. On the other

hand, decrease of contamination was also observed at the early stage, suggesting that self-sealing effect of the lagoon had occurred. However, this fact may not rule out the risk of continued leakage of slurry because the contamination of groundwater was still detectable at 85 days after the first loading. Moreover, although we constructed a lagoon as large as possible, it was even smaller than those used in actual dairy farms. With 50 cows, our model lagoon might be filled up in approximately 40 days, only half of the period during which the influence of slurry on the contamination of groundwater was still observed. Persisting contamination was also detect-

ed in a swine farm in Japan<sup>6)</sup>, where a lagoon kept polluting the groundwater at a distance of 50 m even after 20 years of use which should have been long enough for self-sealing to occur.

Special attention must be paid to the presence of macropores. They largely contribute to the groundwater flow, but precise evaluation of their contribution is difficult. We detected a contamination at a distance of 50 m on the next day of slurry loading, which suggests that contaminated water moved down through some paths with a  $10^{-6}$  cm/s order hydraulic conductivity. Average hydraulic conductivity was  $10^{-3}$  cm/s order in permeable layers,

Table 1. Temporal changes in total nitrogen concentration of groundwater

Distance from lagoon	Total nitrogen concentration (mgN/L)									
	Days after slurry loading									
	-6 d	1 d	2 d	4 d	7 d	9 d	15 d	22 d	43 d	85 d
5 m	0.6	142.6	180.7	217.1	208.7	184.8	210.9	87.6	113.7	17.2
10 m	0.7	82.8	127.9	143.0	112.2	96.0	69.4	46.3	41.5	10.6
15 m	0.6	50.5	19.4	91.3	80.4	64.5	38.1	28.9	26.9	3.5
20 m	0.5	33.3	10.5	30.9	43.4	44.2	29.6	19.8	7.5	1.9
25 m	0.5	3.5	11.5	17.5	19.2	21.1	20.4	3.3	2.5	1.5
50 m	0.5	2.0	3.0	11.1	11.8	7.9	1.8	3.8	2.2	1.1
75 m	0.1	0.3	0.6	2.6	3.9	4.1	4.2	2.9	1.4	0.7
100 m			0.2	0.3	0.0	0.5	0.5	0.3	0.3	0.6

Samples were collected from wells on survey line A (Fig. 1). Values over 2 mgN/L are shadowed.

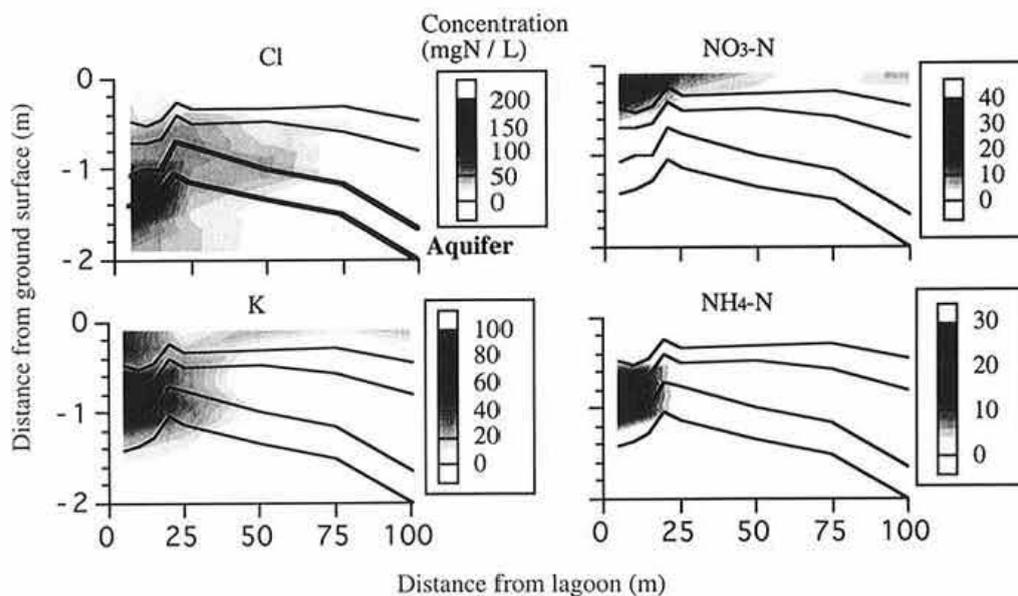


Fig. 5. Distribution of water-extractable ions in soils (along the slope)

and even the highest value of all the data obtained was  $10^{-2}$  cm/s order. Contribution of a considerable number of macropores was ruled out in the estimation of hydraulic conductivity despite repeated

tests. Therefore, it is unlikely that the velocity of the groundwater flow can be predicted based on the hydraulic conductivity.

Evaluation of the slurry loss is important to consider the risk of a lagoon. In this study, the depth of stored slurry was monitored (Fig. 7). It decreased rapidly at the earlier stages and gradually at the later stages. Increase after 54 days was due to heavy rainfall. Precise estimation of slurry loss was impossible because precise estimation of evaporation and dilution of slurry was uncertain. Therefore only a rough estimation was carried out by comparing the monitored slurry depth and the calculated one, assuming the absence of leakage, dilution and maximum evaporation (5 mm a day) from the lagoon. Calculated depth surpassed the monitored one, and the difference between the two increased throughout the period until 54 days after slurry application to the lagoon, when the monitored depth was only 77% of the calculated one. As the slurry had actually been diluted by rainfall during the experiment and the evaporation rate used for the estimation is maximum in this region, more than 23% of total nitrogen in the slurry initially stored in the lagoon was lost within 85 days.

This study demonstrated the risk of using an unlined lagoon for dairy waste storage although experimental conditions were drastic. Environmental problems around livestock farms are a major cause for concern in Japan as they may become more serious in the absence of proper measures. In particular, for the storage of animal excreta, further caution should be paid and risky constructions should be avoided.

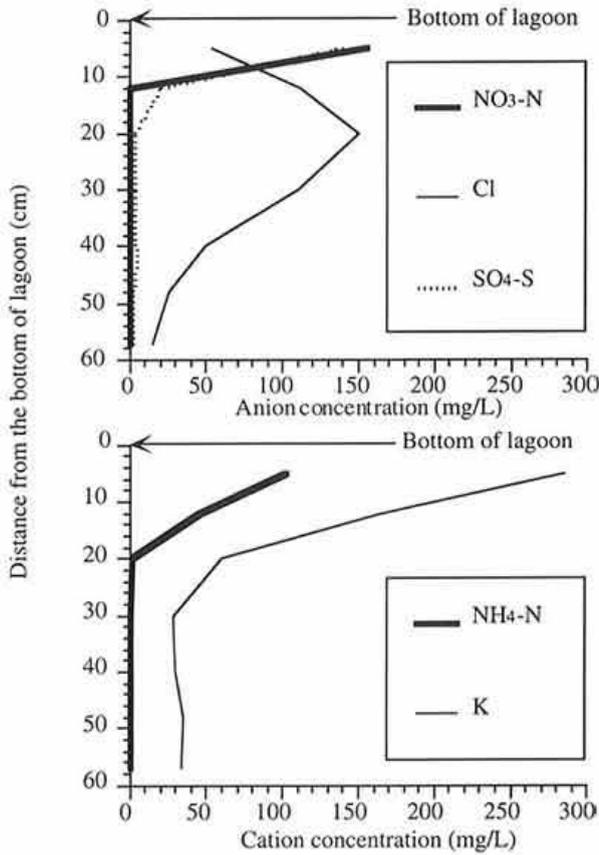


Fig. 6. Distribution of water-extractable ions in soils (beneath the bottom of the lagoon)

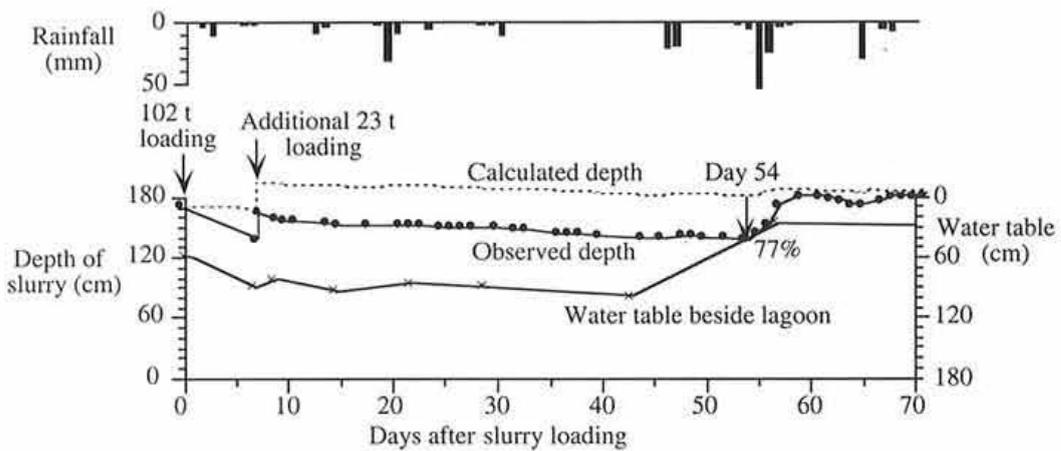


Fig. 7. Temporal changes in depth of slurry  
Dotted line shows calculated depth of slurry. Line with closed circles shows observed depth (refer to text). Average air temperature was 18.8°C during the experiment (June 14–September 7, 1995).

## References

- 1) Ciravolo, T. G. et al. (1979): Pollutant movement to shallow ground water tables from anaerobic swine waste lagoons. *J. Environ. Qual.*, **8**, 126–130.
- 2) Culley, J. L. B. & Phillips, P. A. (1989): Retention and loss of nitrogen and solids from unlined earthen manure storages. *Trans. Am. Soc. Agric. Eng.*, **32**, 677–683.
- 3) Culley, J. L. B. & Phillips, P. A. (1989): Groundwater quality beneath small-scale, unlined earthen manure storages. *Trans. Am. Soc. Agric. Eng.*, **32**, 1443–1448.
- 4) Japanese Association of Water Pollution Research (1982): Survey manuals for lake environment. Association of Environmental Pollution Control, 134–136 [In Japanese].
- 5) Miller, M. H., Robinson, J. B. & Gillham, R. W. (1985): Self-sealing of earthen liquid manure storage ponds; I. A case study. *J. Environ. Qual.*, **14**, 533–538.
- 6) Ozaki, Y. et al. (1991): Effects of nutrients leached from pig waste reservoir on shallow groundwater. *Div. Environ. Planning Res. Rep., Natl. Inst. Agro-Environ. Sci.*, **7**, 117–132 [In Japanese].
- 7) Rowsell, J. G., Miller, M. H. & Groenevelt, P. H. (1985): Self-sealing of earthen liquid manure storage ponds; II. Rate and mechanism of sealing. *J. Environ. Qual.*, **14**, 539–543.
- 8) Shimura, M. & Tabuchi, T. (1996): The relation between nitrogen concentration of stream waters and pig stocking density. Research on nitrogen outflow from high stocking density area (III). *Trans. JSIDRE (Jpn. Soc. Irrig. Drain. & Reclam. Eng.)*, **182**, 17–23 [In Japanese].
- 9) The National Institute of Agro-Environmental Sciences (1995): Classification of cultivated soils in Japan, third approximation. [In Japanese].

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