Spatial Distribution of Maximum Denitrification Rate in Grassland Soil

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1. Introduction

It is important to estimate the potential for denitrification rate of grassland soil from the viewpoint of environmental problems. Much fertilizer and droppings are spread on the grassland soil and finally these are changed to N_2 gas through the process of nitrification and denitrification. For the denitrification, there are still many unsolved processes including the production rate of N_2O gas.[1)-5)]

In this study, we try to estimate the maximum potential for denitrification rate of grassland soil. The maximum rate is measured from the change of the concentration of NO_3-N in suspensions by adding sufficient quantities of NO_3-N under the anoxic conditions. At the same time, we measure some properties of the soil, such as Ignition Loss and available Nitrogen, and try to estimate the spatial distribution of these soil properties including denitrification rate.

The final aim of this study is to determine the most suitable sampling distance on estimation of the denitrification rate of the grassland soil when taking the spatial distribution of these properties into accounts.

2. Methods

2-1 Sampling of Soil

The sampling was made based on the nested or hierarchical method as follows. We placed nine points on a square grid at intervals of 27 m. From each node of the grid, where we took a sample of soil, we chose a point one third of 27 m = 9 m away on a random direction, where we also sampled. From each of the two points, we chose another point 3 m away on a random direction and sampled the soil there too. We then repeated the procedure at distances of 1 m and 0.3 m, respectively. Fig.-1 shows the sampling plan for one node of the grid. The determination of the direction on each point is made by using random numbers produced by computer.

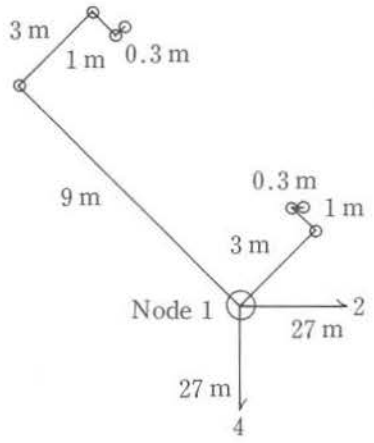

Fig. 1 Sampling Points around Node 1

The soil was sampled from the grassland of experimental farm of Wageningen Agricultural University in Drovendaal, the Netherlands, as shown in Fig. 2.

Fig. 2 Experimental Farm and Soil Sampling

2-2 Computation of Variogram

Experimental Variograms are computed by using the usual formula to estimate semivariances as follows.

$$\gamma(h) = \frac{1}{2m(h)} \sum_{i=1}^{m(h)} \{z(x_i) - z(x_i+h)\}^2 \quad (1)$$

where $m(h)$: the number of pairs

$z(x_i)$: the concentration or the rate at point x_i

$z(x_i+h)$: the concentration or the rate at h m away point from x_i

$\gamma(h)$: the semivariance of the concentration or the rate for distance h

The concept of semivariance is based on the variance of some properties between two sampling points and is similar to auto-correlaton functions.

2-3 Measurement of Denitrification Rate

A sufficient quantity of Nitrate solution is added to a bottle containing the soil sample. Under continuous shaking, the changes in the suspensions' Nitrate concentration are monitired.

We chose the soil to water ratio, the concentration of added Nitrate, temperature and the duration of experiment to be 50 g soil per 200 ml solution, 50 mg/l, 20°C and two weeks, respectively.

In order to maintain anoxious condition in a bottle, after introducing the soil into the bottle, we flushed with N_2 gas for 30 min. Thereafter Nitrate solution was added, then parged air further for 10 min. and closed the septum of the bottle. Then we started the sampling by using a needle. After 30 min. centrifuging, then we filtered with a milipore filter and were able to get at least 10 ml solution for analysis. And NH_4-N and NO_3-N concentrations were measured for the sample, respectively, by using auto-analyzer. These measurements were made for 19 soil samples selected randomly.

2-4 Measurement of soil properties

For all 72 samples, Water Content (WA), Ignition Loss (IL) and Available Nitrogen were measured respectively. Available Nitrogen is composed of two properties, NH_4-N and NO_3-N, and is measured by adding 50 ml 1 M KCl solution on 20 g soil and shaking vigorously for 2 hours, by using auto-analyzer.

3. Results and Considerations

3-1 Denitrification Rate

The examples of denitrification for 5 samples at some node are shown in Fig. 3. In this Fig., the x axis and the y axis show the time and the concentration of Nitrate respectively. The maximum rate can be caliculated from the maximum difference between the two points. Both the data of the overall maximum and the overall minimum is shown on this Fig.. In this case, the maximum rate takes place after 4 days from starting time. But for the second largest rate, we can see it is taking place at stating time. We can not explain this difference of mechanism yet. Generaly speaking, the maximum rate can be seen directly from the starting time or 2 days after starting time in many cases.

Both of the maximum denitrification rate and the average rate are summarized in Table-1 with soil properties, Water Content, Ignition Loss and available Nitrogen, for 19 soil samples. The

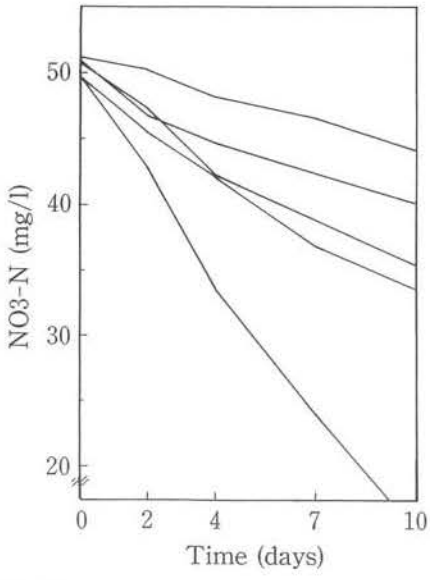

Fig. 3 An Example of Dinitrification

maximum rate and the average rate are calculated from the difference of NO_3-N concentration during 3～4 days and 2 weeks, respectively.

3-2 Frequency Distribution

We showed frequency distribution of denitrification rate and soil properities on Fig. 4 respectively. Of the 19 samples, we get two very high denitrification rates. From the frequency distribution of soil properities, we have tried to consider whether or not these observations should be included.

The frequency distribution of the 4 properities of soil are seen on Fig. 4. It can be seen that the extreme high values are found for all properities except water content due to easy diffusion. Especially for NH_4-N, the maximum value is about 10 times higher than the ordinary level. It can be seen that these high concentrations may effect the process of denitrification indirectly. Based on the behaviour of these soil properities,

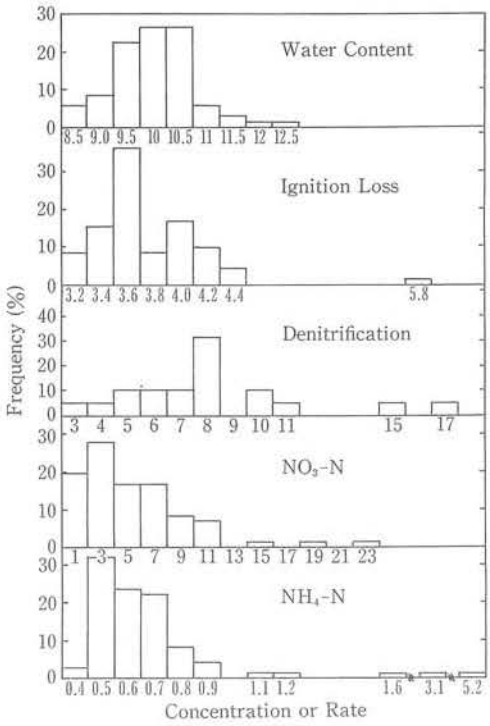

Fig. 4 Frequency Distribution

Table 1 Denitrification Rate and Soil Properties

Sampling Points	Denitrification Rate Mean (mgN/g soil/day)	Maximum	Water Content (%)	Organic Matter Content (%)	Available Nitrogen NH4-N	NO3-N (mg/l)	T-IN
1-27	4.87	8.08	8.66	3.34	0.855	9.04	9.90
2-27	3.21	4.15	9.97	3.68	0.472	3.53	4.00
2-9	4.24	5.97	10.8	3.76	0.539	6.71	7.25
4-27	5.62	10.6	10.1	3.68	0.700	22.8	23.5
5-27	5.34	7.89	10.7	3.58	5.21	3.88	9.09
5-9	4.55	6.98	11.9	4.00	0.612	3.08	3.69
5-3a	3.58	7.64	10.5	3.94	0.734	3.61	4.34
5-1a	5.52	8.80	9.84	3.93	0.628	8.93	9.56
5-03a	4.83	10.1	10.5	3.85	0.581	2.71	3.29
5-3b	11.8	17.1	10.8	3.55	0.551	2.36	2.91
5-1b	4.32	8.17	10.8	3.52	0.746	0.706	1.45
5-03b	2.21	3.68	10.7	3.50	0.578	6.60	7.18
6-27	4.82	8.36	10.2	3.50	0.616	2.36	2.98
8-27	5.55	11.8	10.6	4.22	0.714	5.99	6.70
8-9	3.75	5.45	10.5	4.22	0.705	2.47	3.18
8-3a	11.4	15.7	10.3	3.99	0.929	5.89	6.82
8-1a	5.02	8.13	10.3	4.25	0.759	10.8	11.6
8-03a	5.21	8.03	11.3	4.49	0.903	15.8	16.7
9-27	5.01	6.16	11.7	4.24	0.788	7.29	8.08

we concluded that the two extreme values for denitrification should not be excluded.

3-3 The Contour Map of the Concentration

Though roughly, we can draw the contour map of the concentration of soil properities from 72 or 19 samples. This is useful in understanding the structure of soil and spatial distribution of some properities.

From the contour maps shown in Fig. 5 and 6, we can say that there are some spots on the grassland which have very high concentrations compared to the surrounding ones. These are like hot spot. Some properities of these spots such as diameter, the number and maximum concentration are interesting issues. These spots of denitrification appear to relate to the spots of NH_4-N and NO_3-N, though not directly. But in our study, we could not find out the direct relationship between denitrification rate and some soil properities.

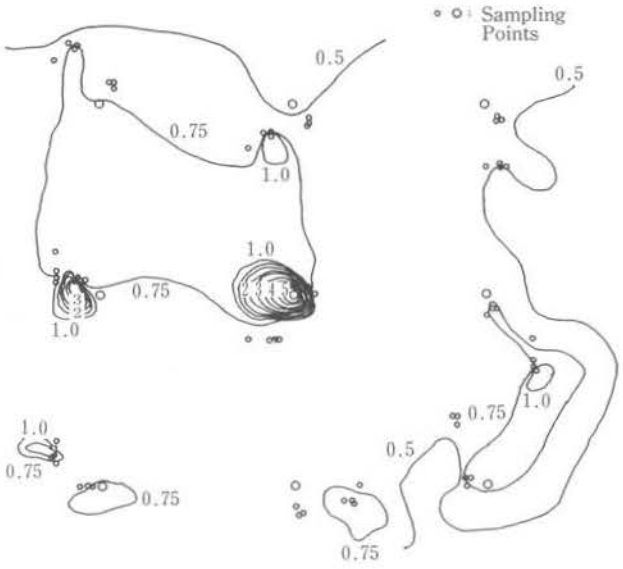

Fig. 5 The Contour Map of NH_4-N

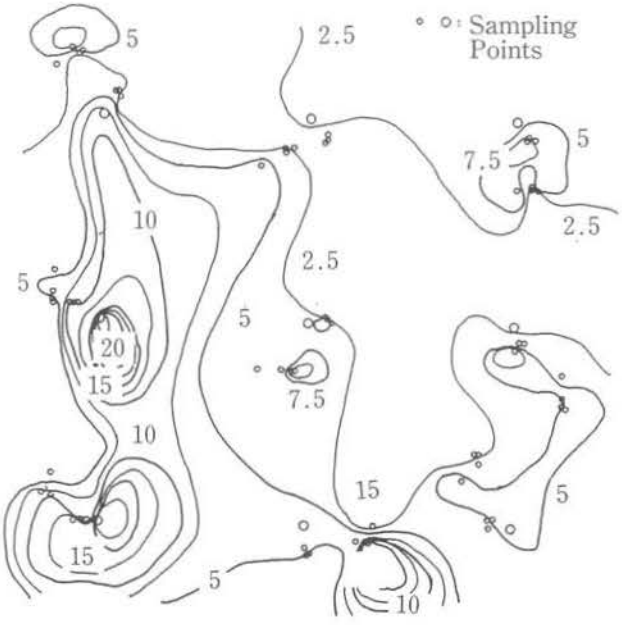

Fig. 6 The Contour Map of NO_3-N

3-4 Variogram

What extent of total variance does each distance component occupy?

We employed a 5 stage nested survey, and each distance is 27, 9, 3, 1 and 0.3 m respectively. In the variograms shown on the Fig. 7, there is not the usual or expected maximum. This may be a reflection of the small sampling distances

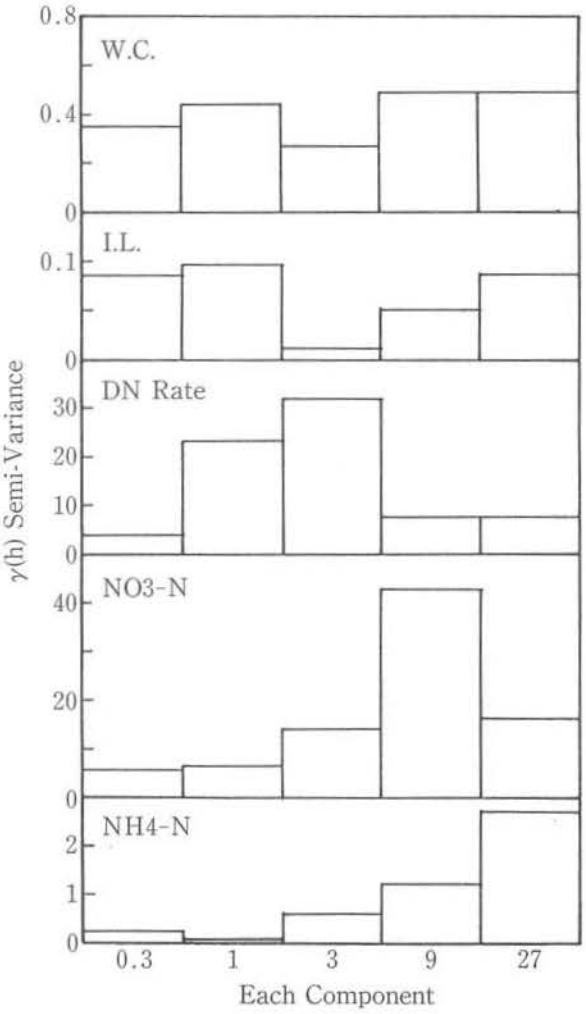

Fig. 7 Vaviogram of Each Component

(max. = 27 m) and the existence of hot spots.

For Water Content, approximately same ratio can be obtained. It is easy to understand because of water' rapid diffusion in soil. But we can get the peak component on the figures for the other 4 properities. This means that the effect of hot spots has appeared on the variogram and that we can consider the most effective sampling distance from this peak. The 0.3 and 1 m components occupy high ratios and also 27 m component does for Ignition Loss. For denitrification rate, the 1 and 3 m components are big and the 9 m component is the biggest for NO_3-N. On the other hand, the 27 m component is the largest for NH_4-N. These peak components show the extent of diffusion in soil of that substances. It is interesting that the diffusion rate depends on the substances.

3-5 Cumulative Variogram

The cumulative variograms of 5 properities is shown on Fig. 8. The ratio of cumulative semivariance of NH_4-N and NO_3-N is less at small distance when compared to Water Content and Ignition Loss. However at larger distances, only NH_4-N occupies low ratios than the other properities.

From this figure, it is possible to select the most effective sampling distance in order to obtain the desired variance. For example, it is necessary to take a sampling distance of at most 20 m for NH_4-N, in order to get 80% variance. On the other hand, it is estimated to be at most 12 m for Water Content and Ignition Loss and 9 m for NO_3-N. But it can be seen that a smaller distance of 3 m should be recomended for denitrification in order to obtain the same variance. As shown in the figure, it is characteristics for denitrification that large fluctuations of rate can be seen within small distances such as 3 m.

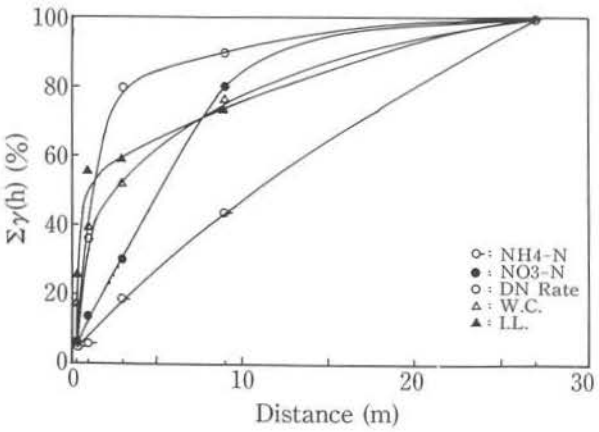

Fig. 8 Cumulative Vaviogram

4. Conclusions

1) There are some spots on grassland which have higher concentrations than the surrounding area and the number, concentration and diameter of these spots depends on the studied substances.
2) The existence of these spots may at times effect the rate of denitrification and produce extremely high values.
3) In the studied field, there are a few spots for NH_4-N which had very high concentrations and small diameter. For NO_3-N, there were more spots which had lower concentrations than NH_4-N and larger diameters, about $2 \times 9 = 18$ m. On the otherhand, there are no spots for Water Content. Results suggest that Ignition Loss hot spots with small diameter (less than 2 m) could be present, though with smaller extreme values than found in the cases of NH_4-N and NO_3-N. The variation pattern of denitrification rate was found to be between that of Ignition Loss and NO_3-N with hot spot diameters of less than 6 m.
4) The obtained average value of the maximum denitrification rate was 8.57 mg NO_3-N/Kg soil/day and the highest maximum denitrification rate was 2 times larger than this value.
5) When quantifying the denitrification rates of grassland, the sampling distance which must be taken in order to get 80% variance of total variance is estimated to be less than 3 m.

From the viewpoint of statistics, 19 data of denitrification is not enough. So, more detailed investigation is necessary to get more precise information on the denitrification potential of grassland.

Acknowledgement

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