Estimation of Nitrate Leaching in Vegetable Fields in Relation to Precipitation

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There are a few simulation models presented recently for analysis of mechanism of nutrient movements in soils[6,11]. A large amount of fertilizers aiming at higher quality and greater production of vegetables are applied recently in fields where vegetables are grown consecutively all the year round in many vegetable producing areas of Japan. It will thus be very significant to clarify the nitrogen movement in soils under heavy application of nitrogen, as the basis for vegetable growth control, fertilizer economy, and environmental conservation of rivers, lakes and marshes. It may be seemingly difficult to predict the movement of soil nitrogen in relation to changeable climates, because of the difficulty of precise prediction of climate over a long period by statistical procedures.

The present paper deals with (i) estimation of nitrate-nitrogen leaching in soils by multiple regression procedures considering the influence of climatic factors on monthly amounts of the leaching of nitrate-nitrogen in continuously cropped cabbage fields of two different types of soil, and (ii) estimation of percolating water and leached nitrogen by using chloride-chlorine as a tracer of nitrate-nitrogen in soil.

Materials and methods

The lysimeters (2.4 m in length, 2 m in width and 1 m in depth) containing two types of soil, i.e., Andosol and Yellow soil, were used. Andosol was rich in humus and silty clay loam with 35 milli-equivalent CEC and Yellow soil was sandy loam, poor in humus with 10 milli-equivalent CEC.

In the first experiment, cabbage (*Brassica olelacia* L., var. *capitata* L.) variety "Kinkei No. 201" was grown by the three crops in 2 years cycle (summer cabbage cropping—no crop in autumn—spring cabbage—no crop in summer—autumn cabbage—no crop in spring) from May, 1982 to April, 1986. Fertilizers N–P_2O_5–K_2O–CaO–MgO (300–200–300–500–60 kg/ha) were applied in the form of urea, superphosphate, potassium sulfate and dolomitic lime. As the basal dressing, 100 kg/ha of nitrogen and potassium and the total amount of other fertilizers were applied. For the three times of topdressing, nitrogen and potassium were applied at the rate of 50, 100, 50 kg/ha. FTE of 40 kg/ha was applied as a source of micro-nutrients, in replacing organic matter application. Ammonium- and nitrate-nitrogen in leaching solution were analyzed by the Kjeldhal method and that with reducing catalyzer, respectively, but ammonium nitrogen was not detected[3]. Data obtained were analyzed by multiple regression procedures using variables selected by "prediction sum of squares" (pss) in Tsukuba Computing Center for Research in Agriculture, Forestry and Fisheries[4,5].

In the second experiment, chloride-chlorine movement in uncropped soil, which is relatively unchangeable biologically, was examined. As chloride, 300 kg/ha of potassium chloride was applied in comparison with the same amount of urea nitrogen application.

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Table 1. Precipitation, percolating water, crop yields and apparent nitrogen balance in cabbage fields where six crops were harvested during 4 years (the lysimeter experiment)

Soil	Precipitation (mm)	Percolating water (mm)	Yield of cabbage head (t/ha)	Nitrogen application (kg/ha)	Nitrogen absorbed by crops (kg/ha)	Leached nitrogen (kg/ha)	Apparent nitrogen balance* (kg/ha)
Andosol	7,012	4,566	306	1,800	1,280	810	−290
Yellow soil	7,012	4,984	299	1,800	1,250	370	180

* Apparent nitrogen balance = nitogen applied − nitrogen absorbed and leached.

Leaching solution was sampled in time course from the bottom of the lysimeter, and nitrogen and chlorine were analyzed by the above-stated method and the Mohr method, respectively[2,3]. The experiment was conducted, promoting the leaching with the irrigation of desalted water when little rain occurred during winter, from November, 1984 to May 1985. The formulation of chlorine leaching curve was obtained by the fitting of the orthogonal polynominals coded by A. Nishida in Tsukuba Computing Center[7].

Results and discussions

1) *Seasonal change of leaching of nitrate-nitrogen*

Table 1 shows the result of the measurement in the first experiment, in which six crops of cabbage were harvested in a period of 4 years. It shows cabbage yields, rainfall, leached nitrogen and nitrogen balance for 4 years in the lysimeter. Cabbage yields did not decrease in the continuous cropping for 4 years. For the estimation of the apparent nitrogen balance of applied nitrogen, it is necessary to postulate that (i) apparent denitrification and nitrogen fixation did not occur, (ii) minus balance of nitrogen came from mineralized nitrogen of soil organic matters which was absorbed by cabbage plants and leached into the subsurface in the same rate as applied nitrogen and (iii) plus balance of nitrogen was residual nitrogen in soil after the experiment. With such postulates, the fate of applied nitrogen was estimated as follows: in Andosol, 60% of applied nitrogen was absorbed by cabbage, and 40% was leached through the subsurface, and in Yellow soil, 70% was absorbed, 20% leached and 10% remained as residual nitrogen. The cabbage yields and nitrogen uptake shown in the present experiment indicated those of the ordinary vegetable cultivations[8-10].

Table 2. Correlation coefficients between monthly amounts of nitrogen leaching, and climatic factors and others (n=21)

Independent variables	Xn[1]	Andosol	Yellow soil
Precipitation(mm)	X_1	0.880**	0.795**
	X_2	0.504**	0.680**
Air temperature(°C)	X_3	0.765**	0.565**
	X_4	0.648**	0.486*
Solar radiation	X_5	0.325	0.169
(Cal/cm²/day)	X_6	0.606**	0.256
Absorbed nitrogen	X_7	0.201	0.139
(kg/ha)	X_8	0.424*	0.387*

1): Odd numbers of n express the correlation between the amount of N leached in each month and climatic factors of that month.
Even numbers of n indicate the correlation of the leached N to the climatic factors in the preceding month.
*, ** Significant at 5 and 1 % level respectively.

Statistical analysis with the results of the first half two years was performed. Table 2 shows single correlation coefficients between the amount of nitrogen leached and climatic factors. The correlations with absorbed nitrogen are also shown. The factor relating most closely to nitrogen leaching is the monthly amount of precipitation in both soils. A factor associating secondarily but significantly with the leaching is monthly air temperature in Andosol and the precipitation of the preceding month in Yellow soil. It may be considered that more mineralized nitrogen was

Table 3. Multiple regression equations of monthly nitrogen leaching as related to selected factors

Soil	Multiple regression equations[1)]	Determinant coefficient (R^2)
Andosol	$\hat{Y}= 0.290+0.0083X_1$	0.774**
	$\hat{Y}=-0.216+0.0062X_1+0.0544X_3$	0.841**
	$\hat{Y}=-0.262+0.0078X_1+0.0552X_3-0.101X_8$	0.884**
Yellow soil	$\hat{Y}= 0.022+0.0050X_1$	0.632**
	$\hat{Y}=-0.201+0.0039X_1+0.0025X_2$	0.762**
	$\hat{Y}=-0.016+0.0046X_1+0.0032X_2-0.0270X_3$	0.787**
	$\hat{Y}=-0.044+0.0056X_1+0.0033X_2-0.0274X_3-0.0650X_8$	0.814**

1): Independent variables Xn are the same ones as shown in Table 2.
** Significant at 1 % level.

Table 4. Nitrogen leaching in the cabbage field of Andosol in early spring and climatic factors at that time and in the preceding autumn

Year	Nitrogen leached in Mar. (kg/ha)	Mean air temp. in Mar. (°C)	Precipitation in Mar. (mm)	Precipitation of autumn (Sept.-Nov.) in the preceding year (mm)
1983	12.0	7.7	160	563
1985	45.5	8.2	149	218

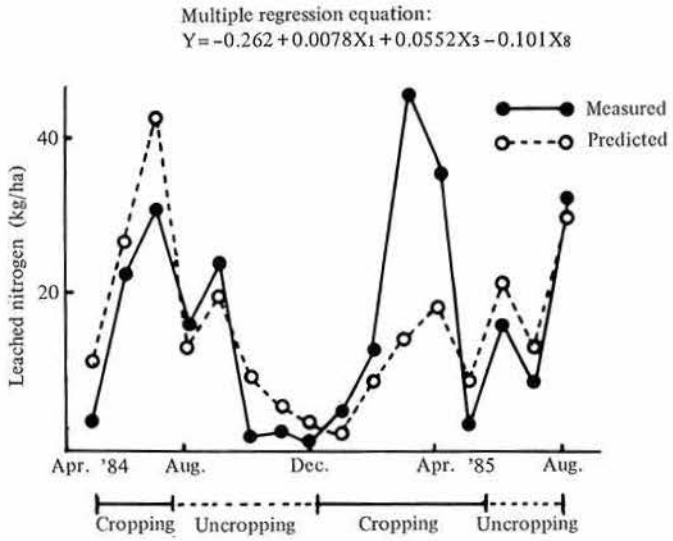

Fig. 1. Monthly amounts of nitrogen leaching actually measured and those estimated by using a multiple regression equation (obtained in the first half two years' experiment) in the Andosol field

released from easily decomposable organic matters at higher temperature in Andosol and the time delay of water percolation occurred due to poor water permeability in Yellow soil.

Table 3 shows the results of multiple regression analysis using precipitation, air temperature and absorbed nitrogen as independent variables selected significantly by the "predic-

tion sum of squares" procedure[4,5]. The determinant coefficient (R^2) of multiple regression equations increased gradually according to additional introduction of independent variables with higher correlation coefficient in order. The estimation of nitrogen leaching may thus be possible even with precipitation itself, although the determinant coefficient is not so high. Further studies on the estimation of nitrogen leaching at districts with different patterns of precipitation in Japan will be necessary.

Fig. 1 shows the estimated values of nitrogen leaching for the second half two years calculated by using the multiple regression equation (obtained in the first half two years' experiment), in comparison with the actual values measured. The estimated values accord fairly well with the observed ones. But the difference between both was large particularly in Andosol in spring of 1985. The difference may come possibly from the precipitation of autumn in the preceding year rather than that of the year as shown in Table 4. It may be deduced that mineralized nitrogen remained in the soil in autumn with less precipitation and it was leached concentratively in the next spring. The prediction of nitrogen leaching in spring will thus need to consider the precipitation of the preceding autumn.

2) *Leaching of chlorine as a nitrogen tracer*

The concentration of nitrate-nitrogen in percolating soil solution in the present lysimeter experiment was similar to that of chloride-chlorine. This result reconfirmed the fact that the use of chloride-chlorine is easy and effective as an alternative tracer of nitrate-nitrogen in soil[1]. Although the concentration of nitrate-nitrogen in percolating water was always slightly higher than that of chloride-chlorine in Andosol because of the increase of nitrate-nitrogen mineralized from soil organic matters, it was not so high as to make it difficult to use chlorine in the experiment. Fig. 2 shows that the chlorine leaching (in percentage of the chlorine applied) increased according to the increase of percolating water, showing smooth sigmoid curves in both soils. The chlorine leaching reached 92% for 1,200 mm of percolating water in Andosol and 91% for 1,000 mm in Yellow soil.

The formulation of the above curves was examined by the fitting of the logistic curve

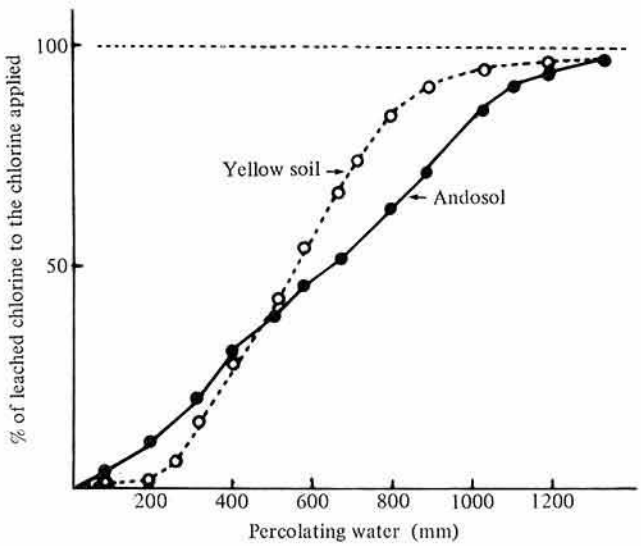

Fig. 2. Accumulated amounts of chloride-chlorine leaching in Andosol and Yellow soil

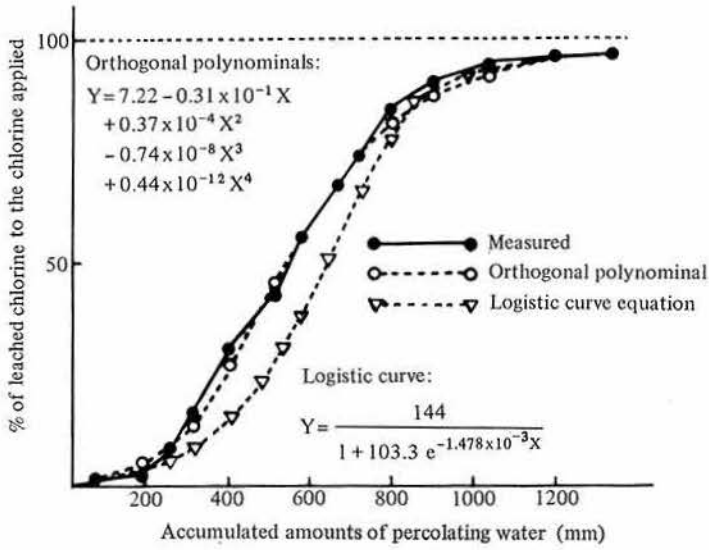

Fig. 3. Application of orthogonal polynominals and logistic equation of chlorine leaching in Yellow soil

and the orthogonal polynominal[5]. Fig. 3 shows that an orthogonal polynominal accords with the observed values much better than a logistic curve equation. It is inferred from the result of the present experiment that the relationship between the largest amount of nitrate-nitrogen leaching and percolating water is explicable in an experimental formula. Further studies will be needed to clarify the influence of the frequency of percolation as real rain on nitrate-nitrogen leaching, particularly in cumulatively observed data of several experiments based on different patterns of rain.

Summary

The relationship between nitrate-nitrogen leaching and climatic factors was examined with vegetable cultivation under heavy application of fertilizers in Andosol and Yellow soil. Multiple regression analysis was performed with influences of climatic factors on monthly amount of the nitrate-nitrogen leaching. The precipitation influenced most effectively the nitrate-nitrogen leaching in both soils, but air temperature also influenced the leaching in Andosol. The values estimated by using the multiple regression equation accorded fairly well with the measured ones. However, the result indicated that it is necessary to take into consideration the precipitation of the preceding autumn for the assay of the leaching in the spring season.

The use of chloride-chlorine is effective as an alternative tracer of nitrate-nitrogen. Smooth sigmoid curves between the leaching of chlorine and percolating water were obtained, in which the orthogonal polynominal was applied most effectively.

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(Received for publication, April 25, 1988)