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# Water and matter dynamic balance in the rice field and its overflow estimate model

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**Abstract**— The rice field is the main land use type in the watershed of Chaohu Lake. Because of the water-dryness alternative farming applied there, the paddy soil has a unique quality regarding soil profile as well as special water and nutrient dynamics. Through the analysis of water and matter dynamics in rice fields, the field water level (H) and the concentrations of total nitrogen (TN) and total phosphorus (TP) in flood water layers of the fields were chosen to estimate the nonpoint pollution from rice fields. A simple model was built and used to calculate the quantity of N and P pollutants from rice field overflow. It shows the potential effects of rice fields on Chaohu Lake eutrophication.

**Keywords**: rice field; water dynamics; matter dynamics; nonpoint pollution; overflow estimate model.

## INTRODUCTION

The watershed of Chaohu Lake is a traditional agricultural region. The rice field is the main land use type. With the growing population and increasing demands of food, increasingly more fertilizers are applied in order to obtain higher yield of rice grain. But at the same time the over-application and improper use of fertilizers have caused two serious problems. One is the low fertilizer utilization ratio with only 25—52% N-fertilizer and 10—15% P-fertilizer being assimilated by the crop. The other is nonpoint source pollution with large quantity of nitrogen and phosphorus transported to Chaohu Lake to cause eutrophication.

Because of these problems, the subproject of "The Ecological Effects on Chaohu Lake Pollution" has been carried out both in the lake and its catchment area since 1987. In the catchment area research aspect. emphases have been put on the rice field for water and nutrient dynamic changes and their influences on nitrogen (N), phosphorus (P) nonpoint pollution during the rice growth period.

## AGROECOSYSTEM OF RICE FIELDS

Rice, water and paddy soil constitute a wetland agroecosystem. The profile of rice field is

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shown in Fig. 1.

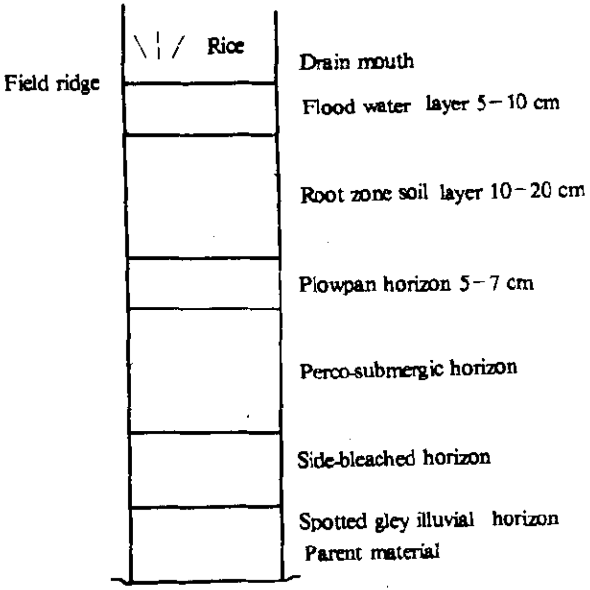

Fig. 1 Profile of rice field

In the Liuchahe subwatershed we chose for the case study, there are five types of rice fields. They are different in their origin, topography and parent materials or they are in different evolution stages of cultivation or irrigated with different water types. The types of rice fields, their characteristics of paddy soil, water conditions and their locations are shown in Table 1.

1. The water dynamic balance and the field water level in rice field is effeted by meteorological factors, crop physiology and anthropogenic activities.

Fig. 2 illustrates that the field water level rises with water input by irrigation and rainfall, and decreases with water output by evaportranspiration, discharge and percolation. The ground water table is lower than the flood layer surface of rice field, which is the usual situation.

When there is no flood layer in the field and the water content in the soil is less than the maximum capillary capacity, groundwater supply by capillary partially compensates the upper soil layer for water shortage until the next irrigation or rainfall.

If the rice field is situated at the bottom of a valley or at the lowland of a plain, the groundwater table may be equal to or higher than the surface of the rice field, and for these cases there is no percolation and the seasonal changes of the groundwater table influence the field water level of the rice field.

Table 1 Types of rice field

| Types of rice field | Paddy soil structure and characteristics | Location |
|---|---|---|
| Permeable rice field | A-P-W-Bg-C<br>Homogenous in profile adequate percolation | Near villages and rivers in plain area |
| Side-bleach rice field | A-P-WL-SL-Bg-C<br>Downward elucidation or side seepage between original and piled soil horizon | Terraced field in the slope of hilly area |
| Stagnating rice field | A-P-WL-Bg-C<br>Water stagnated in illuvial horizon, groundwater Tab. 50 cm | In higher plain |
| Water logged rice field | A-P-W-G-Bg<br>High groundwater table piling up the soil by digging drainage ditches | In polder area of Chaohu Lake shore |
| Percolating rice field | A-P-W-L<br>Young in cultivation | On lake side |

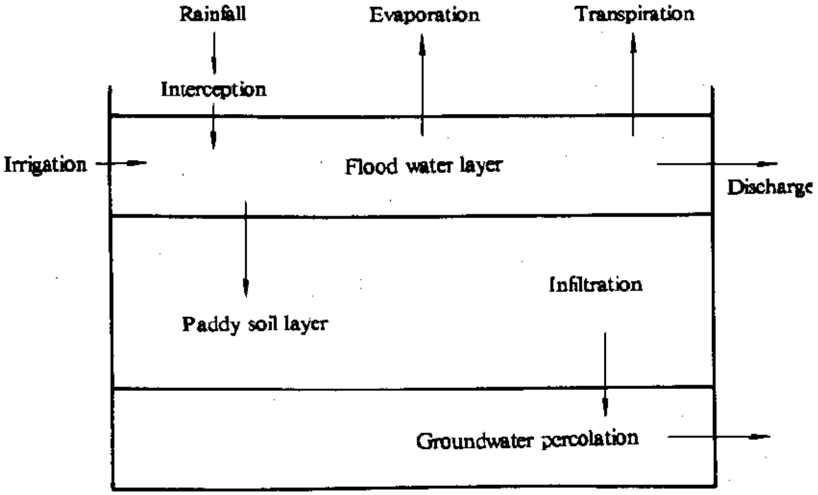

Fig. 2 Water dynamic balance in rice field

Fig. 3 illustrates the nutrient dynamics. The concentrations of TN and TP in the flood water layer of a rice field are influenced by the following factors:

(1) Paddy soil properties such as the pH and N, P capacities which relate to soil material composition and the mineralization characteristics.

(2) N, P assimilation by plants in different growth stages.

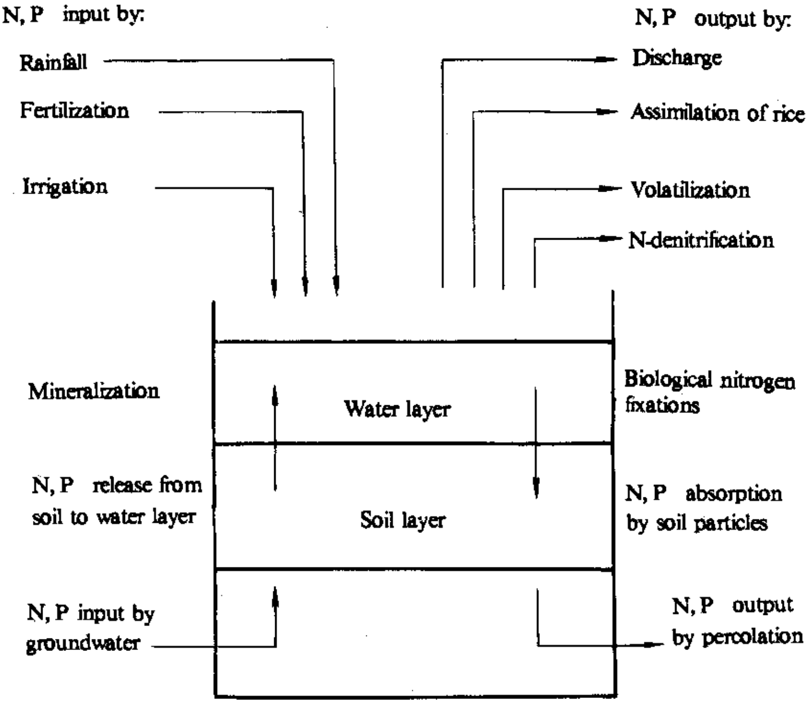

Fig. 3 Dynamics of N, P nutrients in rice field

(3) Fertilizer types, quantities, and application methods and time after application.

(4) N loss by volatilization and denitrification; P absorption and fixation by soil particles and humus.

(5) N, P concentration and pH value in irrigation and rainfall water.

(6) The field water level of flood water layers.

## THE OVERFLOW ESTIMATE MODEL

The nonpoint pollution of nitrogen from a rice field includes three parts: gaseous loss, surface runoff and percolation. The surface runoff is emphasized in this paper and the special ploughpan horizon in the soil profile greatly reduces the percolation.

The nonpoint source pollution of a rice field can be measured by output of TN and TP through surface runoff. The quantities are calculated by a rainfall-runoff process.

This rainfall-runoff process can be divided into two stages by the threshold water level $H_o$ above which the flood of the rice field will start to flow out from the field discharge mouth automatically or by farmer's action (Fig. 4).

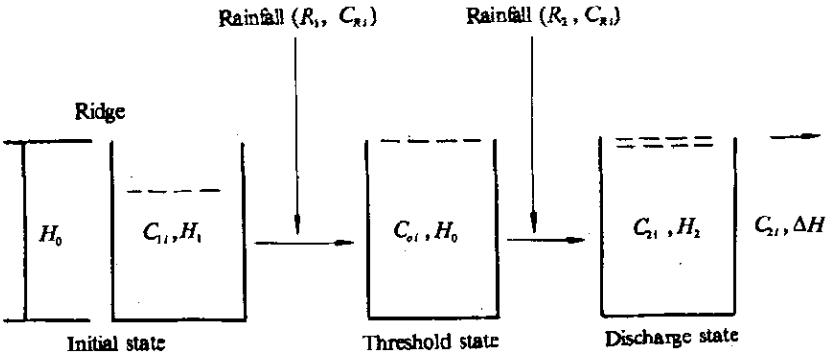

Fig. 4 Overflow process of rice field during rainfall

Where $H_o$ = threshold water level which is decided by the discharge mouth, in mm; $C_{1i}$ = concentration of $i$ pollutant in the flood water layer when rainfall begins, in mg/L; $H_1$ = flood water level when rainfall begins, in mm; $C_{Ri}$ = concentration of $i$ pollutant in rain water, in mg/L; $R_1$ = precipitation depth when the water level reaches $H_o$, in mm; $C_{oi}$ = concentration of $i$ pollutant when the water level reaches $H_0$, in mg/L; $R_2$ = precipitation depth after the water level reaches $H_0$, in mm; ΔH = after the water level reaches $H_0$, the instantaneous water level is produced by the instantaneous precipitation $R$; $C_{2i}$ = concentration of $i$ pollutant in discharge water; $H_2 = H_o + \Delta H$.

The first stage:

During this period, the field water level from the initial state $H_1$ increases to the threshold water level $H_o$. The rice field has no discharge. The concentration of $i$ pollutant is a mixed concentration of rainfall and rice field water before raining and it can be calculated as:

$$C_{oi} = \frac{C_{1i}H_1 + C_{Ri}R_1}{H_0} .$$

The second stage:

This stage is the coincidence of raining and discharging. To simplify the calculation, supposing there is additional instantaneous rainfall $R$, and the water level rises $\Delta H$. At that point the water level is $H_2 = H_o + \Delta H$. After rain water and rice field water are mixed, and the instantaneous concentration $C_{2i}$ of $i$ pollutant in the discharge is:

$$C_{2i} = \frac{C_{Ri}\Delta H + C_{0i}H_0}{H_o + \Delta H} .$$

The total $i$ pollutant freight discharged from the rice field $Q_i$ in the instantaneous discharge can by calculated as:

$$\Delta Q_i = A \cdot \ \Delta H \cdot \Delta C_{2i} = A \cdot \ \Delta H \ \frac{C_{Ri}\Delta H + C_{0i}H_0}{H_0 + \Delta H} .$$

where $A$ is the rice field area. When the water level reaches the threshold level, the accumulative quantity of pollutant $i$ in the discharge which is produced by rainfall $R$ can be calculated using the following integral equation:

$$Q_i = \Sigma\Delta Q_i = A\int_0^{R_2} C_{2i} \cdot dH,$$

$$Q_i = A\,[C_{Ri}R_2 + [C_{1i}H_i + C_{Ri}R_1 - C_{Ri}H_0)(1 - e^{-\frac{R_2}{H_0}})] .$$

With this model system, the total quantity of $i$ pollutant can be calculated. It has been tested in Liuchahe subwatershed of Chaohu Lake from April to October, 1988. The following shows the calculation of N, P output in a plot of a 0.21 acre rice field under the rainfall event on June 28 – 29, 1988. With $A = 847.09\ m^2 = 0.21$ acre

$H_1 = 0.065$cm $C_{1N} = 0.48$ mg/L $C_{1P} = 0.0928$ mg/L
$C_{RN} = 0.34$mg/L $C_{RP} = 0.0120$ mg/L $H_0 = 0.0106$ m
$R = 0.052$ m $R_1 = 10.6 - 8.5 = 2.1$ cm $R_2 = 0.011$m

$$C_{ON} = \frac{C_{1N}H_1 + C_{RN}R_1}{H_0} = \frac{0.48 \times 0.065 + 0.34 \times 0.041}{10.6} = 0.426$$

$$C_{OP} = \frac{C_{1P}H_1 + C_{RP}R_1}{H_0} = \frac{0.093 \times 0.065 + 0.012 \times 0.041}{0.106} = 0.062$$

$$Q_N = 847.09[0.34 \times 0.011 + (0.48 \times 0.065 + 0.34 \times 0.041 - 0.34 \times 0.106)(1 - e^{-\frac{0.011}{0.106}})]$$
$$= 3.93\ (g)$$

$$Q_P = 847.09\,[0.012 \times 0.011 + (0.0928 \times 0.065 + 0.012 \times 0.041 - 0.012 \times 0.106)(1 - e^{-\frac{0.011}{0.106}})$$
$$= 0.55 \text{ g}$$

This calculation means that during this rainfall and under these certain conditions of field water level and N, P nutrient concentrations in the flood water layer, one square kilometer of rice field can produce 4.64 kg N and 0.65 kg P. If the heavy rainfalls happen during May or August, the N, P outputs are bigger than these figures because of the N, P concentrations in the flood water layer of a rice field are higher due to fertilization. Hence, the influences of rice fields on nonpoint pollution and Chaohu Lake eutrophication are quite important.

## CONCLUSION

The nonpoint pollution from rice field is mainly produced by the rainfall discharge process. During rainfall, the quantities of N, P output from overflow are closely related to the N, P concentrations in flood water layer of rice field, the threshold water level, precipitation and N, P concentrations of rainfall. A simple model can be used to estimate the nonpoint pollutants generated by this rainfall- overflow process. That is:

$$Q_i = A\,[C_{Ri}R_2 + (C_{Ii}H_i + C_{Ri}R_i - C_{Ri}H_0)(1 - e^{-\frac{R_2}{H_0}})]$$

## REFERENCES

Di Toro, D. M. and M. J. Small, J. Environ. Engineer. Div., ASCE, 1979, 105(EE1) : 43

Donigian, Jr. A. S. and Huber, W. C., Modeling of nonpoint source water quality in urban and non-urban areas, EPA/600/3-91/039, Washington: USEPA, 1991 : 72

Novotny, V. and G. Chesters, Handbook of nonpoint pollution: source and management, Van Nostrand Reinhold Company, 1981 : 555

Ryding, S.-O. and W. Rast, Man and the biosphere series, UNESCO, Paris and the Parthenon Publishing Group, 1989 : 314

Solbe, J. F. de L. G., Effects of land use on fresh waters: agriculture, forestry, mineral exploitation, urbanization, Chichester: Ellis Horwood Limited Publishers, 1986 : 568

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