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SUITABLE BUFFER STRIP WIDTH ALONG RIVERS FOR NITRATE N REMOVAL FROM PADDY FIELD DRAINAGE

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ABSTRACT The buffer strip play an important role in removal non-point source pollution and improvement of the water quality of the river. Nitrate N in paddy field drainage can lead to the soil and underwater pollution caused the eutrophication of rivers too. Based on discussing of the function of buffer strips and the removal mechanism of nitrate nitrogen, the mathematical model for simulation of solute transport and the suitable width in buffer strips was established, the model accuracy was validated by the field experiment data. The distribution of nitrate nitrogen concentration in buffer alfalfa strips under different paddy field drainage conditions was calculated, and the buffer strips width was confirmed. The results showed that when the nitrate nitrogen concentration of paddy drainage is 10mg/l, the suitable minimum width of buffer alfalfa strips is 7.3m, for 20mg/l is 15.0m for the removal rate of nitrate nitrogen in buffer strips reached 90%.

Keywords: alfalfa buffer strip; paddy field drainage; nitrate nitrogen; removal effect; suitable width

INTRODUCTION As one of the major food crops, paddy field has large acreage and needs much nitrogen fertilizer. Unreasonable irrigation and drainage, the paddy production chain will bring a considerable amount of nitrogen pollution, which may pollute the river water through the surface runoff and groundwater pollution. The riparian buffer strip is a complex and unique ecological zone, which coordinates with the surrounding environment and maintains the biological system homeostasis. It's responsible for preventing runoff directly into rivers and reduces non-point source pollution. Research has shown that buffer strip plays an extremely important role in the agricultural non-point source pollution prevention and control [1], the soil and water conservation [2], ecological and environmental protection and improvement[3]. Yadav's research showed that there were 15% of nitrogen in fertilizer, 68% of the residual nitrate in the soil non-root layer and 20% of the residual nitrate in the root layer which could be leaching into the groundwater [4].Established a rational grass or woodland filter belt between farmland and water could greatly reduce the water of the N, P contents [5]. Peterjohn found that the 50m width vegetation buffer strip between farmland and water bodies could reduce the access to surface water 89% of nitrogen and 80% of phosphorus [6].The Grand Canal is a major water source in northern Jiangsu of China. It's vulnerable to be polluted by agricultural non-point source pollution. The on-site water quality monitoring results of 2007 shows that the average concentration of nitrate-N in paddy field drainage is 3.452-119.239mg / l along the Canal, the groundwater near the Canal is 13.385mg / l, the Canal water is 2.994 mg / l. Long-term or a mass of fertilizer will lead to the accumulation of soil nitrogen, which will not only cause the soil pollution and waste of nitrogen, but also provide a source of groundwater pollution [7-12]. In this study, a laboratory experiment and a numerical simulation test were carried out to monitor the water and nitrate-N dynamics in the riparian buffer strip, with the aims to study the suitable width of alfalfa buffer strip. The results will provide a theoretical basis for the construction of buffer strip.

MATERIALS AND METHODS

Laboratory experiment

Figure 1 shows the main part of the test device-riparian buffer strip physical model (the scale of model is 1:20). We can observe the root growth of plants and wetting front infiltrating process.

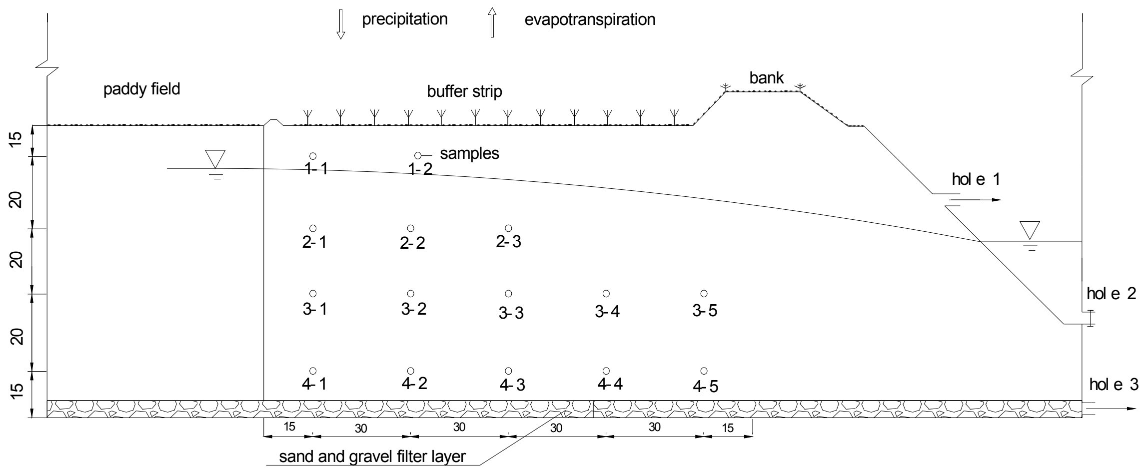

Figure 1. Riparian buffer strip physical model (unit: cm).

The tested soil samples were from the farmland near the Grand Canal, collected the samples according to naturally occurring levels. Its basic property is in Table 1. Using the physical model to simulated the nitrate-N of paddy field drainage migration process in buffer strip. The nitrate concentration in paddy drains is 10.00mg / l.

Table 1. Basic property of the soil profiles.

Soil depth (cm)	PH	Bulk volume (g/cm³)	porosity (%)	O.M. (g/kg)	$NH_4^+ - N$ (mg/kg)	$NO_3^- - N$ (mg/kg)	TN (g/kg)
0-30	7.85	1.33	43.32	25.7	34.64	49.67	2.11
30-50	7.49	1.35	32.18	14.9	27.63	20.95	1.43
50-70	7.49	1.35	32.18	14.9	27.63	20.95	1.43
70-95	7.93	1.15	22.55	17.2	19.68	7.92	1.15

Buffer strip planted alfalfa in treatment 1, and the seeding amount is 30g/m^2. Treatment 2(control treatment) is nude but other conditions are same as the treatment 1. After a month from alfalfa totally cover the surface , cut the first crop and collected the soil solution and soil samples through samplers and holes, analyzed the water and nitrate-N contentment.

Numerical simulation

The HYDRUS-2D model was applied to simulate water flow and nitrate-N in the soil of buffer strip. Two-dimensional unsaturated soil water movement was described by a modified form of the Richards' equation. It requires knowledge of the initial distribution of the pressure head within the flow domain. As a third type of boundary, the simulations of the upper boundary are on the ground, which are specified gradient boundary conditions. The soil water movement problem of buffer strip could be described by mathematical model as follows:

$$\begin{cases} \frac{\partial \theta}{\partial t} = \frac{\partial}{\partial x_i}[K(K_{ij}\frac{\partial h}{\partial x_j} + K_{ij})] - S_w \end{cases} \quad (1)$$

Where θ is the volumetric water content. t is time. $x_i\,(i=1,2)$ is the spatial coordinate , x_1 is transverse coordinate, x_2 is vertical coordinate (positive upward). K is the unsaturated hydraulic conductivity function. K_{ij} is the components of dimensionless anisotropy tensor K. h is the water pressure head. S_w is the sink or source term for water, which encompasses water uptake by plant roots. The potential root water uptake was distributed linearly throughout the whole soil profile with a maximum at the soil surface and zero uptake at the bottom of the root zone [13]. The total water uptake was assumed to be 0.9 cm/d, which together with the irrigation intensity of 1 cm/d resulted in a leaching fraction of 0.1cm/d.

The nitrate-N transfer in the soil of buffer strip was described by the two-dimensional convection - dispersion equation.

$$\frac{\partial(\theta c + \rho s)}{\partial t} = \frac{\partial}{\partial x_i}(\theta D_{ij}\frac{\partial c}{\partial x_j}) - \frac{\partial q_i c}{\partial x_i} - S_r \quad (2)$$

Where ρ is soil bulk density, c is nitrate concentration of the soil solution, D_{ij} is saturated - unsaturated hydrodynamic dispersion coefficient, q_i is the volumetric flux density given by Darcy's law and S_r is the sink or source term of nitrate-N in soil solution.

The governing flow and nitrate-N equations were solved numerically using standard Galerkin-type linear finite element schemes. The parameters were tested and modified in the experiment. The model input of numerical simulation such as simulation region, boundary conditions and initial conditions were determined by the data of laboratory experiment. The simulation time was from 2008 May 20 to September 30, which included the entire period of paddy growth and harvest as well as the whole corn planting period, which four observation nodes were arranged at 15, 35, 55 and 75cm of the soil columns. The soil hydraulic parameters were derived from the retention curve, which could obtain by the neural network prediction of Hydrus-2D.

Table 2. Soil moisture characteristics

Soil depth cm	θ	θ	α (/cm)	n	l	K (cm/d)
0-30	0.078	0.43	0.036	1.56	0.5	24.96
30-50	0.034	0.46	0.016	1.37	0.5	6
50-70	0.034	0.46	0.016	1.37	0.5	6
70-95	0.068	0.38	0.008	1.09	4.8	0.5

RESULTS AND DISCUSSION

Experiment results

As the control treatment, in the period 1 (20-May to 20-June), the value of average daily change amount of nitrate-N in 0-30cm soil layer reduced 5.04μg/kg, period 2 (20-June to 31-July) the value reduced 5.26μg/kg, period 3 (31-July to 30-September) the value reduced 0.76μg/kg. The nitrate content is gradual increasing with the migration time extension, but the value of increased is gradually decreased in the period 1. The results showed that nitrate-N accumulation took place in the period 2, and loss in the period 3.

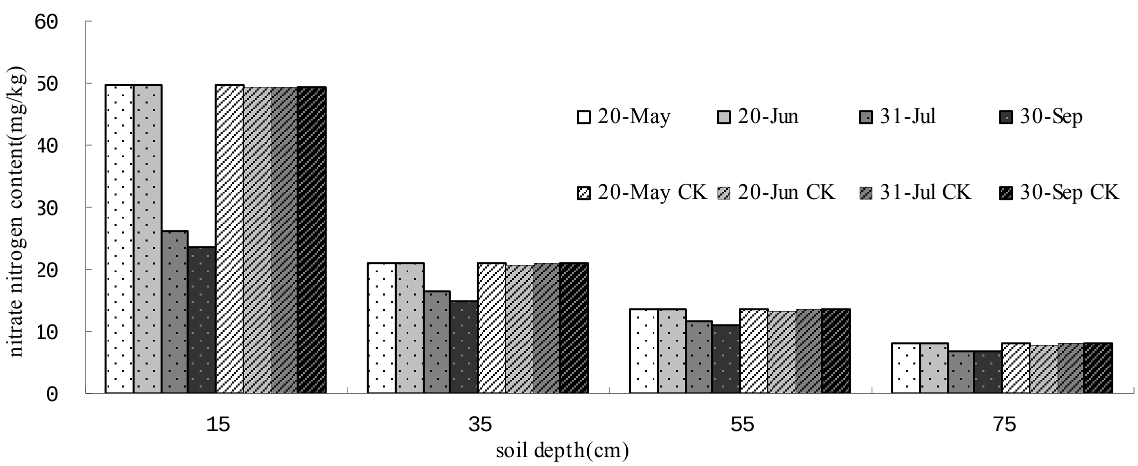

Figure 2. Nitrate-N content comparison in alfalfa buffer strip treatment.

Figure 2 shows the nitrate-N content comparison in alfalfa buffer strip treatment. As can be seen from the Figure 2, the concentration of nitrate-N decreased gradually with the increased of the distance vertical migration. For depth of 30-50cm, 50-70cm and 70-95cm soil layers, the concentration of nitrate-N were respectively 42.0%, 27.6% and 15.5% of the surface soil value on 20-June; on 31-July, the ratio were respectively 63.0%, 44.1% and 25.8%; on 30-September, the ratio were respectively 63.6,47.4% and 28.5%. The nitrate-N cumulated gradually in subsoil with the migration time increasing. On 20-May, at the growth initial stage of alfalfa, more nitrogen were demanded, so nitrate-N content in the topsoil rapidly decreased. The purification rate of nitrate-N on a daily was 0.31 mg/kg. With the alfalfa growth and maturity, the purification rates of nitrate-N on a daily were respectively 0.34 mg / kg and 0.04 mg / kg. In 30-60cm soil layer, the root distribution of alfalfa was relatively less, so the removal rate of nitrate-N was lower; the change of nitrate concentration was little in soil.

The concentration of nitrate-N in the groundwater near the Canal is 13.385mg / l before treatment measures was taken, while the average value in hole 3 of alfalfa buffer strip was 0.991mg / l at the end of this experiment, therefore, for the paddy field drainage, the purification rate of nitrate-N by alfalfa buffer strip was 90.09% under the experimental conditions, for groundwater, the purification rate was 83.76%. The purification rates of Treatment 2(control treatment)were 23.52% and 56.98%, far less than the alfalfa buffer strip. So alfalfa buffer strip could effectively remove the nitrate-N in the paddy field drainage.

Numerical simulation results

The soil moisture simulation results were very comparable to the laboratory experiment results at different times (Figure 3). The average relative error between water content simulated and measured values is 6% -9%. The simulation results also showed that nitrate-N accumulation took place mainly in the plow layer rather than in the surface soil layer. These showed that the HYDRUS-2D Model was capable of describing graphically the water and nitrate-N transport process in a comprehensive way and convenient for consultation and calculation, so it is practicable to do numerical simulation of soil water and nitrate-N transport by this model.

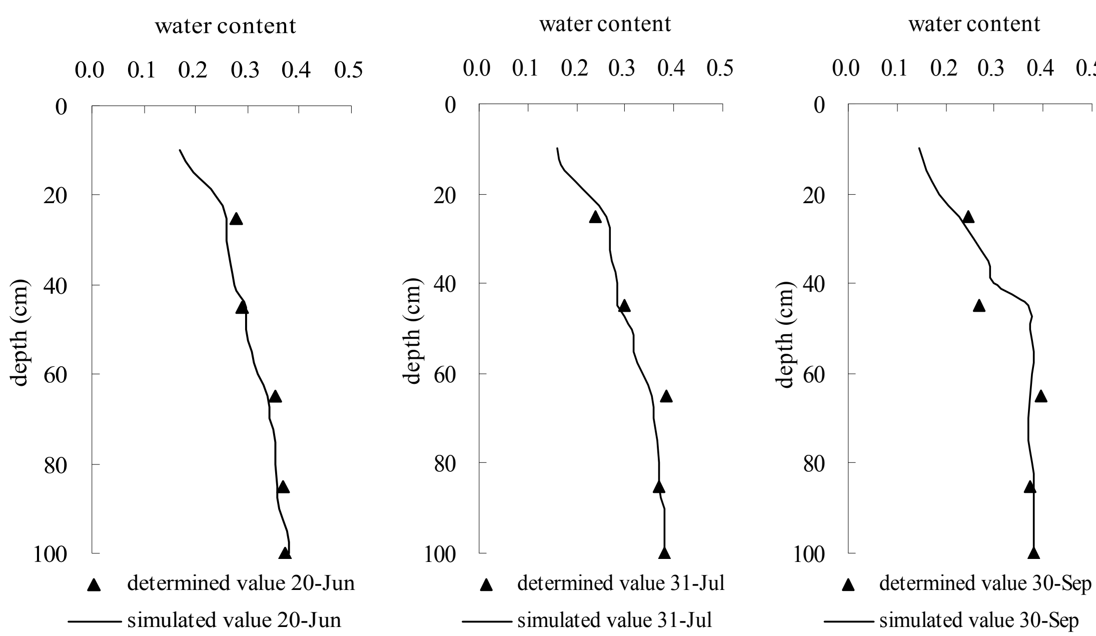

Figure 3. Water content comparison of measured and simulated.

The numerical simulation results that the HYDRUS-2D Model was capable of describing graphically the water and nitrate-N transport process in a comprehensive way and convenient for consultation and calculation, so it is practicable to do numerical simulation of soil water and nitrate-N transport by this model.

Discussion

Generally, nitrate-N in farmland drainage is the main pollution source of river or lakes. The riparian buffer strip could effectively retention and removal the nitrate-N by adsorption, sedimentation, plant uptake, microbial conversion and so on. This test proved that the reasonable alfalfa buffer strip could effectively remove the nitrate-N from paddy field drainage and improve water quality of groundwater and protection river environment.

(1)Purification mechanism

□There are a large number of organic, inorganic colloid, live micro-organisms and soil animals in the soil of riparian buffer strip, which is equivalent to a huge waste treatment plant, that can play filter, infiltration, absorption, retention roles for material and energy, reduction the pollutants of surface runoff, groundwater and riparian water. The soil and plants plays a role of adsorption, decomposition, transformation and migration through the soil physical, chemical and biological processes, so riparian buffer strip have purification capacity.

□The nitrate-N of buffer strip soil was absorbed by alfalfa and met the demands of its growth.

□Alfalfa transports oxygen into soil by its roots, it is favorable for the soil nitrification process and increase the absorption of plant and achieve the purpose of removal of soil nitrogen. When the alfalfa was vigorous growth, the purification rate was largest because its roots distributed thick, buried deep, fixed nitrogen ability strong.

(2) Removal effect

Table 3 shows the effect of nitrate-N distribution by alfalfa buffer strip. The following conclusions can be drawn.

Table 3. The removal effect of nitrate-N in alfalfa buffer strip (units:mg /kg).

time	site	ΔC					
		1	2	3	4	5	average
20-June	15cm	10.424	8.365				9.394
	35cm	7.675	4.092	0.126			3.965
	55cm	5.720	4.341	1.271	1.616	-1.478	2.294
	75cm	4.520	2.927	1.794	-0.333	-0.588	1.664
31-July	15cm	22.632	23.869				23.251
	35cm	10.162	3.503	-0.333			4.444
	55cm	7.116	3.261	1.222	0.743	-2.502	1.968
	75cm	4.500	2.391	1.428	-0.969	-1.216	1.227
30-September	15cm	25.286	26.442				25.864
	35cm	9.593	6.554	2.000			6.049
	55cm	7.322	4.756	1.292	0.986	-2.209	2.429
	75cm	4.805	2.652	1.273	-0.805	-1.130	1.359

(ΔC is the difference value of nitrate-N between Alfalfa buffer strip and CK)

□ 0-30cm: Alfalfa roots have thick distribution in the region, its roots squeeze the soil porosity in the soil so that the pores become discontinuous, the root distribution block the nitrogen migration rates. The other hand, alfalfa rhizobia have a good conversion and absorption of nitrogen role. Therefore, as compared with the control treatment, alfalfa buffer strip have the greatest impact on the nitrate content of surface of soil, and with the tests carried out, the alfalfa need much water and nitrogen. So the content of nitrate-N in the soil gradually decreased.

 30-50cm: Alfalfa roots is less than the 0-30cm soil layer, the reduction content of nitrate-N is less than the surface soil. In this region, the nitrate-N content present that in the first increased and then decreased, this is impacted by soil nitrogen accumulation and alfalfa growth together results.

 50-70cm: There is not approximately roots in this region, migration is the main effect factor. The soil nitrate content was increased first and then decreasing trend on the same site with the extension of time. The same depth, the soil nitrate content was decreased with the increase of levels distance.

 70-95cm: There is no root distribution in this region. The nitrate-N of soil accumulated loss through the drainage hole 4, such as the nitrate concentration was increased to a certain degree, then it reduced. Alfalfa buffer strip was more flat than control treatment, because alfalfa could effective hold nitrogen in a certain depth. Alfalfa could effectively reduce soil nitrogen to the soil or groundwater of the deep migration

(3)Appropriate width of buffer strip

The concentration distribution function of nitrate-N in buffer strip was described by the equation (1) and (2). Supposing the appropriate width of buffer strip is L, then the nitrate-N content of soil water should be less than the target water quality at any time or any depth. The appropriate width of contaminant attenuation zone is as follows:

$$\begin{cases} c_L \le c_Y \\ c_L = \max(c_L^0, c_L^1, c_L^2, \ldots, c_L^{z-1}, c_L^z) \\ L_Y \le L \end{cases} \quad (3)$$

Where c_L is the concentration of pollutants of near the river cross-section; z is the depth of contaminant attenuation zone, determined by the degree of pollution and the type of river cross-section; $c_L^{0,1,2,\ldots,z-1,Z}$ is the pollutant concentration at different depths near the river cross-section when the width is L; c_Y is that rivers water quality requirements; L is that contaminant attenuation zone with maximum allowable width, determined by the actual situation of buffer strip.

For example as the water quality objectives of The Grand Canal is the nitrate content less than 0.02mg / l, the appropriate width of buffer strip was determined by the above-mentioned models. According farmer's paddy fertilizer, the initial paddy water concentration of nitrate-N were 10mg / l and 20mg / l, the minimum width of alfalfa buffer strip which meet the water requirements were respectively 7.3m and 15.0m.

CONCLUSION This paper studied the nitrate-N removal effect from paddy field drainage by alfalfa buffer strip, and revealed the purifying mechanism of plant buffer strip. The main conclusions are as follow:
(1)Under the test conditions, the nitrate-N purification rate in control treatment is

23.52% for the soil interflow which will go to river; the value is 56.98% for the water which will go to groundwater. The nitrate-N purification rate in alfalfa buffer strip is respectively 90.09% and 83.76%. Therefore, alfalfa plays a very good absorption role to the nitrate-N, it could effectively remove the nitrate-N in the drainage of farmland.

(2)The nitrate-N contentment is inversely proportional to the migration distance. For soil layers of depth 30-50cm, 50-70cm and 70-95cm, the concentration of nitrate-N were respectively 56.2%, 39.7% and 22.3% of the surface soil value respectively. Because alfalfa need a lot of water and nitrogen, alfalfa buffer strip have more impact on the nitrate migration, the content of nitrate-N in the soil with the time is gradually decreased.

(3)To meet the river water quality requirements, the appropriate alfalfa buffer strip width is 7.3m while the nitrate concentration of paddy field drainage is 10mg / l; the appropriate width is 15.0m while concentration is 20mg / l.

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