Available online at www.sciencedirect.com
ScienceDirect
Journal of Hydrodynamics
2008,20(3):382-390
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science/journal/10016058

ANALYSIS OF SOLUBLE CHEMICAL TRANSFER BY RUNOFF WATER IN FIELD*

TONG Ju-xiu, YANG Jin-zhong
State Key Laboratory of Water Resources and Hydropower Engineering Science, Wuhan University, Wuhan 430072, China, E-mail: tongjx111@163.com

(Received November 21, 2007, Revised January 4, 2008)

Abstract: In order to determine the main factors influencing soluble chemical transfer and corresponding techniques for reducing fertilizer loss caused by runoff in irrigated fields, a physically based two-layer model was developed with incomplete mixing theory. Different forms of incomplete mixing parameters were introduced in the model, which was successfully verified with previous published experimental data. According to comparison, the chemicals loss of fertilizer is very sensitive to the runoff-related parameter while it is not sensitive to the infiltration-related parameter. The calculated results show that the chemicals in infiltration water play an important role in the early time of rainfall even with saturated soil, and it is mainly in the runoff flow in the late rainfall. Therefore, prevention of shallow subsurface drainage in the early rainfall is an effective way to reduce fertilizer loss, and the coverage on soil surface is another effective way.

key words: soluble chemical transfer, runoff, incomplete mixing, sensitive, infiltration

1. Introduction

Fertilizers applied in fields are frequently transported into surface water body by rainfall or irrigation induced overland flow, consequently resulting in a significant impact on the water quality, which is also an economic loss and have become a matter of considerable concern [1-17]. Determining the accurate amount of soil chemicals of fertilizers transfer into runoff and reducing fertilizer loss are essential for the agricultural management of non-point source pollution.

The conventional mixing zone theory assumes that there exists a region below the soil surface in which surface water, soil solution, and infiltrating water mix completely and instantaneously and that there is no chemical transfer into that region from the soil below (see Fig.1).

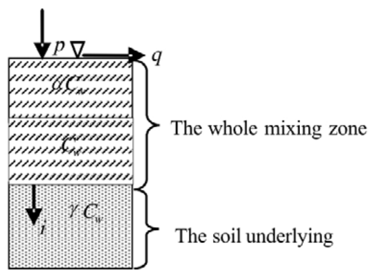

Fig.1 Sketch of simple two-layer model

In early efforts of past 30 years, it was generally assumed that, at any moment in time, a certain thin zone of surface soil (hereafter called the mixing layer) and soil water mix completely and instantaneously with rainwater[10,18], and the mixing layer depth is constant. Ahuja et al.[2] showed that the degree of interaction between rain water and soil water decreases exponentially with the depth, so they presented the concept of Effective Depth of

* Project supported by the National Nature Science Foundation of China (Grant No. 50639040), the National High Technology Research and Development Program of China (863 Program, Grant Nos. 2006AA100205, 2006AA100207)
Biography: TONG Ju-xiu (1981-), Female, Ph. D. Student

Interaction (EDI), within which the degree of mixing is uniform and equals that of the soil surface. Ahuja and Lehman[4] and Zhang et al.[16] showed that the observed mixing-layer depth is much shallower than the depth required to fit mixing-layer models to experimental data. Snyder and Woolhiser[19] also concluded that the complete mixing model might only be appropriate as the infiltration rate is high. Therefore, some scholars[4,13] modeled the chemical transport from soil to runoff with incomplete or non-uniform mixing theory. Based on the conservation law for the EDI, Wang et al.[20,21] established a soil chemical-runoff interaction model and further developed a new incomplete nonuniform mixing theory.

Much attention has been paid to the theory and modeling of fertilizer contaminant transport in saturated soil, and most studies were started from the initiation of ponding-runoff [4, 11-15]. In fact, a certain ponding water is needed to produce runoff [17,18, 22]. In addition, the majority of the current models often took the incomplete mixing parameters as constants rather than variable ones throughout a rainfall event, which could not give suggestions for reducing chemicals loss of fertilizer in detail.

In this article, a simple two-layer model for soluble chemical transfer of fertilizer in runoff water is presented with incomplete mixing theory in unsaturated soil. The ponding mixing layer of pre-runoff process is also considered with simulated rainfall. The model is verified with previously published experimental data. In order to investigate the values of the incomplete mixing parameters and find ways to reduce chemical loss of fertilizer, different forms of incomplete mixing parameters are introduced. The differences between experimental data previously published and calculated data are analyzed and compared to determine the best fitted parameters, and they could provide reference for the control of soluble chemical loss of fertilizer in fields under the condition of irrigation and drainage.

2. Model and solution

2.1 *Governing equations*

Chemicals in the soil mixing layer are the source of chemical constituents in infiltration and runoff water. The chemicals are only considered to transfer vertically [18]. For simplicity, at the bottom of soil mixing layer, the infiltration and diffusion processes are considered as vectors and downward positive. Infiltration and diffusion processes are simplified in the infiltration process with an incomplete mixing parameter γ (see Fig.1), which means that infiltration water interacts with water of the soil mixing layer incompletely and the diffusion process is neglected.

At the interface between the ponding-runoff and the soil mixing layers, the ejection of soil water by rainfall impact should also be considered[11, 12, 16, 23]. An incomplete mixing parameter α is adopted to consider those processes, which indicates ponding-runoff water mixes with solution of the soil mixing layer incompletely by ignoring other factors.

In the whole mixing layer, there exists the following relationship:

$$M_w = C_w\left[\alpha\left(h_w - h_{mix}\bullet\theta_s\right) + h_{mix}\bullet\theta_s\right] \tag{1}$$

where M_w is the soluble chemical quantity per unit area in water phase, h_w the volume of water per unit area stored in the whole mixing layer, h_{mix} the depth of soil mixing layer, θ_s the volumetric moisture content at saturation, and C_w the chemical concentration in water of the soil mixing layer.

The conservation law for chemicals in the whole mixing layer during rainfall containing no chemical may be written as

$$\frac{\mathrm{d}\left[M_w(t)\right]}{\mathrm{d}t} = -\gamma\bullet i\bullet C_w(t) - \alpha\bullet q\bullet C_w(t) \tag{2}$$

where i is the infiltration rate at the bottom of soil mixing layer, q the rate of overland flow, and $C_w(t)$ the chemical concentration in water of the soil mixing layer at time *t*,

Theoretically, chemical of fertilizer infiltrates into soil below the soil mixing layer, in which fertilizer decreases gradually with ongoing rainfall. Chemical concentration below the soil mixing layer is much higher than that in soil mixing layer, which results in a strong diffusion. The incomplete mixing parameter γ should decrease with time according to the definition of γ. The chemical concentration in runoff and soil mixing layer will decrease with time, and rainfall impact becomes weak with increasing depth of ponding water. Therefore, α will decrease with time in theory. As γ is set to be constant and α decreases with time, or both of them change with time, or α is set to be constant and γ decreases with time, the processes of finding solution for model are the same. For simplicity, the last one was taken an example to describe the processes of finding solution, in which we have

$$\gamma = 1 - e\bullet t \tag{3}$$

where e is the change rate of γ with time.