Effects of Use of Agricultural Wastes on Nitrate or Chloride Transport in Porous Media

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Abstract: This paper investigated the possible use of agricultural wastes including rice husk, rice straw and rice bran for attenuation nitrate- or chloride-induced problems such as nitrate pollution or soil salinization in porous media. Column experiments with 30 cm in length were carried out under saturated flow conditions using two different solutions of KNO₃ and NaCl. Each agricultural waste was mixed with silica sand and filled into the column homogeneously. Mixture percentages of the weight of each material to silica sand were varied in order to examine the change of the degree of solute dispersion, mobility and mass attenuation, which were identified using temporal moment analysis based on experimental breakthrough curves of the effluent. The results showed that use of agricultural wastes provides the slight increase of the dispersivity relative to the case without agricultural wastes except for the case with rice bran in chloride ion transport. Each anion showed its own degree of solute mobility associated with mixed agricultural wastes, due to the hydrophobic property of the surface of wastes. The results also revealed that the use of rice husk and rice bran leads to the degradation of total mass from the effluent, although the rice straw has an extremely low property attenuating the mass of nitrate and chloride. Furthermore, a new quantity index to synthetically evaluate the potential of agricultural wastes was proposed. The results indicated that rice straw has the highest potential in terms of the attenuation of nitrate- or chloride-induced adverse effects in porous media.

Keywords: Nitrate transport; Chloride transport; Agricultural wastes; Attenuation; Column experiment; Porous media

1 Introduction

Decreasing environmental impacts, safeguarding consumer health, and developing recycling and reuse streams have been increasing interest in current agricultural and industrial activities. Rice is one of the crucial crops all over the world from the perspectives of production volume, value, cultivated land coverage and employment generation (Mussoline et al., 2013; Sharif et al., 2014). As part of the harvesting of rice and field preparation, farmers burn a great deal of rice residue. Rice husk, rice straw and rice bran are a large quantity of production and the main agro-industrial wastes from the rice milling industry. According to the Food and Agriculture Organization of the United Nations (FAO), residue burning can adversely affect both the health of the population and the climate (FAO, 2002). It may offer a useful solution for the management of these by-products produced by agro-food industries.

On the other hand, the primal agricultural non-point source pollutants are nutrients including nitrogen and phosphorus, animal wastes, pesticides, and salts. Reduction of nitrate leaching from cropland and livestock and operations has been conducted through changes in farm management such as proper use of manures and fertilizers and improvements in crop nitrogen use efficiency, which is recovered by the crop and is therefore not lost to the atmosphere or to surface and groundwater (Eagle et al., 2000). Although nitrate itself is relatively non-toxic, it can be microbially reduced to nitrite, which poses several health threats to humans including methemoglobinemia, liver damage and cancers (Grosse et al., 2006). To most effectively reduce the impact of nitrate on groundwater, a suite of improved practices is generally required, which must be chosen according to the unique field situation. However, there is no one set of management practices that will be the most effective in protecting the prompt rise of nitrate concentration in subsurface.

Additionally, salinization is the accumulation of soluble salts of sodium, magnesium and calcium in soil to the extent that soil fertility is severely reduced and is the process that leads to an excessive increase of water-soluble salts in the soil. The accumulation of salts, particularly sodium chloride and sodium sulphate, is one the main physiological threats to ecosystems (Wallender and Tanji, 2011). Salt prevents, limits or disturbs the normal metabolism, water quality and nutrient uptake of plants and soil biota. Although a combination of efficient drainage and flushing of the soil by water is often used, the leaching of salts from the profile is rarely effective. Adequate soil and water conservation practices based on a comprehensive soil or land degradation assessment may provide possibilities for efficient salinity or alkalinity control, the prevention of these environmental stresses and their undesirable ecological, economical and social consequences (Siyal et al., 2013).

Control and attenuation of non-point pollution remain relatively difficult tasks as compared to those of point sources of...
pollution (Ongley, 1996). Use of agricultural wastes as attenuation materials to obtain benefits in terms of the health and the prevention of nitrate pollution or salinization is a challenging research. To the best of our knowledge, there have been no attempts of the use of agricultural wastes for the purpose of nitrate or salinization attenuation in porous media. This paper explored the possible application of agricultural wastes including rice husk, rice straw and rice bran in the attenuation not only of nitrate pollution in groundwater but of salinization in porous media. From a practical point of view regarding salt transfer in a cropland, chloride ion was also employed in column experiments. Some quantity factors such as the dispersivity, the retardation factor, the mass recovery fraction and the degradation rate constant were identified using temporal moment approaches based on a time series of leachate concentration of nitrate or chloride ions. Additionally, a new quantity index for synthetically assessing the potential of agricultural wastes was proposed.

2 Materials and methods

2.1 Agricultural wastes and silica sand

Use of agricultural wastes for affecting transport characteristics of nitrate or chloride ions is expected to be a promising method with such advantages as (1) low cost, (2) easy operation and (3) little detrimental effects on a surrounding environment. In this study, three types of agricultural wastes including rice husk, rice straw and rice bran were collected from a field in Tokushima prefecture in Japan approximately one week after the field was harvested and were utilized to compare the characteristics of nitrate or chloride transport in porous media. In Figure 1, images of three agricultural wastes are shown. As shown in Figure 1, the length of artificially chopped rice straw was adjusted in approximately 1 cm length. All agricultural wastes were dried at 110 ºC before column experiments.

In column experiments, silica sand with a low uniformity coefficient of 1.25 was mainly repacked to reflect a relatively high hydraulic conductivity in porous formations such as tea garden, sugar cane field and maize field. Silica sand of interest had 0.050 cm, 2.68 g/cm³ and 0.11 cm/s of physical properties such as the mean particle size, the particle density and the hydraulic conductivity, respectively.

2.2 Miscible displacement experiments

Miscible displacement experiments under the saturated condition were carried out at room temperature (18 ± 2 ºC) under an air atmosphere. The soil columns were constructed of acrylic cylinders having 5 cm of inner diameter and 30 cm length and also had filter meshes attached to the top and bottom to which constant head reservoirs to control the water pressure were connected. The effluent solutions were collected at fixed effluent volumes using a fraction collector from the bottom of the column via the constant head reservoir. A schematic drawing of experimental setup is shown in Figure 2.

Silica sand and one of the agricultural wastes were completely saturated with deionized water before packing to avoid the entrance of air. An agricultural waste of interest mixed with silica sand was homogeneously packed with deionized water in 2.5 cm increments from the bottom of the column. Each layer was compacted with a rammer to adjust the porosity prior to packing the next layer. In order to examine the effect of the amount of agricultural wastes on the characteristics of nitrate or chloride transfer in each porous formation, the weight percentages of agricultural wastes to the total weight of silica sand were varied. The weight of silica sand equivalent to the column height of 1.5 cm, 2.1 cm and 3.4 cm was replaced with the agricultural waste of concern. In Table 1, physical properties of agricultural wastes mixed with silica sand are listed. The porosity was estimated in each experiment indirectly from the measurements of the total weight of the agricultural waste and silica sand filled in the column. The hydraulic conductivity was measured using the discharge rate of water from the column under a prescribed hydraulic gradient and the sectional area of the column.

After packing, deionized water was applied to the column up to a certain level controlled by constant head reservoirs at the top and bottom of the saturated media, while maintaining the saturated condition of porous media. Steady saturated flow field was established in the column when fluctuations in the observed drainage rate from the bottom reservoir became negligible. A needle was pierced through the stopper to intro-
duce a specific solution into the system. A volume of 40 cm³ of KNO₃ solution or NaCl solution was applied to produce a pulse input with an initial concentration of 1.5 × 10⁻⁴ g/cm³ of NO₃-N or NaCl. Despite of the condition of the weight percentage of agricultural wastes, pore water velocities were set to approximately 0.012 cm/s under the control of the hydraulic gradient. Pore water samples at the end of the column were taken at specific intervals using the fraction collector to measure experimental breakthrough curves (BTCs). Nitrate ion in the pore water samples was analyzed by capillary electrophoresis (G1600A, Agilent technologies, USA). The basic anion buffer and a fused silica capillary with 104 cm in length and 5 cm internal diameter were obtained from Agilent technologies. The temperature-controlled cartridge for fused silica was set at 15 °C. On the other hand, electrical sensors were used to measure the voltage of NaCl solution. Concentrations of chloride ion in pore water samples were from voltage readings of electrical sensors using a calibrated relationship between the specific concentration of NaCl solution and the corresponding voltage.

2.3 Parameter estimation

Solute transport through saturated, homogeneous porous media in a one-dimensional uniform flow field can be expressed in terms of advection, dispersion, linear equilibrium sorption and first-order degradation (Bear, 1972; Fetter, 1998):

\[
R \frac{\partial c}{\partial t} = \alpha v \frac{\partial^2 c}{\partial x^2} - \frac{\partial c}{\partial x} - \lambda c
\]

(1)

where \( c \) is the concentration of solute, \( x \) is the coordinate, \( t \) is the time, \( R \) is the retardation factor, \( v \) is the average pore water velocity, \( \alpha \) is the dispersivity and \( \lambda \) is the degradation rate constant.

Temporal moment analysis is a useful approach to characterize experimental BTCs without solving solute transport model (Valocchi, 1985; Inoue et al., 2013). The normalized temporal moment at a location \( x \) is defined as:

\[
\mu_n = \frac{M_n}{M_0} = \frac{\int_0^\infty t^n c(x,t)dt}{\int_0^\infty c(x,t)dt}
\]

(2)

where \( \mu_n \) is the \( n \)-th normalized temporal moment and \( M_n \) is the \( n \)-th order absolute temporal moment. In this study, the dispersivity, the retardation factor, the degradation rate constant and the mass recovery fraction were identified using temporal moment approaches based on the experimental BTCs of nitrate or chloride ions as quantity factors reflecting the effect of agricultural wastes.

The dispersivity from temporal moments was calculated as (Valocchi, 1985):

\[
\alpha = \frac{\zeta}{2} \left( \frac{\mu_2}{M_2^2} - 1 \right)
\]

(3)

where \( \zeta \) is the distance between the source and the observation location. The retardation factor can be expressed as (Pang et al., 2003):

\[
R = \frac{(\mu_1 - 0.5t_0)\sqrt{\nu^2 + 4\alpha v\lambda}}{x}
\]

(4)

where \( t_0 \) is the pulse duration. In all experiments, \( t_0 \) was set to 30 seconds to reflect the injection situation of solute.

The mass fraction of solute was used to estimate the mass recovery fraction (Das and Kluitenberg, 1996):

\[
MRF = \frac{\int_0^\infty Q(H,t)c(H,t)dt}{\int_0^\infty Q(0,t)c(0,t)dt}
\]

(5)

where \( MRF \) is the mass recovery fraction, \( Q \) is the volumetric flow rate and \( H \) is the length of the soil column. The degradation rate constant is also calculated by (Das and Kluitenberg, 1996):

\[
\lambda = \frac{1}{\mu_1} \ln \frac{1}{MRF}
\]

(6)

Prescribed solute source condition in column experiments was designed to clarify the transient concentrations of nitrate and chloride ions and to effectively provide the parameter identification relevant to solute transport using temporal moment approaches. In column experiments, a result obtained from a single experimental pattern in each weight percentage of agricultural wastes using KNO₃ or NaCl was adopted as the corresponding result whereas repeated experiments were conducted in some experimental patterns.

3 Results and discussion

3.1 Representative breakthrough curves

Representative BTCs as functions of the elapsed time for nitrate and chloride ions are shown in Figures 3 and 4, respectively, under different weight percentages of mixed rice straw to the total weight of silica sand without the mixture of rice straw. As shown in these two figures, the BTCs do not exhibit Gaussian-like symmetric distributions and a slight tailing of the BTCs, which shows an asymmetric shape and extends longer with time, appears. A slight difference of the

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Table 1: Physical properties of agricultural wastes mixed with silica sand.

|                     | Rice husk         | Rice straw       | Rice bran        |
|---------------------|-------------------|------------------|------------------|
| Weight percentage of agricultural waste (%) | 0.95 ~ 2.6        | 1.0 ~ 2.2        | 0.8 ~ 2.5        |
| Porosity (−)        | 0.44 ~ 0.47       | 0.45 ~ 0.46      | 0.43 ~ 0.44      |
| Hydraulic conductivity (cm/s) | 0.10 ~ 0.11       | 0.053 ~ 0.11     | 0.046 ~ 0.061    |

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peak concentration and the fluctuation of BTCs at late breakthrough times also occur. This may be caused by the local heterogeneity in porous network where agricultural wastes exist and the reactive transport (Sugita and Gillham, 1995; Inoue et al., 2010). Such a behavior implies that the mixture of agricultural wastes affects the change of pore structure at microscopic level even lower weight percentages of agricultural wastes.

In order to quantify the degree of the tailing in each BTC, the second central temporal moment, which describes a measure of the temporal spread of the BTCs, were computed as follows:

\[ T_2 = \frac{\int_0^\infty (t - \mu_1)^2 c(x,t)dt}{\int_0^\infty c(x,t)dt} \]  

where \( T_2 \) is the second central temporal moment. As for nitrate ion, values of \( T_2 \) in the weight percentages of 1.0, 1.35 and 2.2% are 29.8, 45.8 and 46.6 hr², respectively, indicating the increase of \( T_2 \) with the increase of the weight percentages. The unit of hour (hr) means 3600 seconds. In comparison, values of \( T_2 \) in the weight percentages of 1.0, 1.35 and 2.2% are 36.7, 17.9 and 54.4 hr², respectively, for chloride ion. These results demonstrate that the transfer characteristics in porous formations where agricultural wastes exist are different from ions, leading to the application of parameter identification relevant to solute transport.

### 3.2 Solute dispersivity

The dispersivity is a medium-dependent hydrodynamic parameter that characterizes solute dispersion in porous media (Fetter, 1998). The results of the dispersivities in rice husk, rice straw and rice bran for nitrate and chloride ions, which were identified based on Eq. (3), are shown in Figures 5 and 6, respectively, as a function of the weight percentages of each agricultural waste. In these figures, the experimental results without the mixture of any agricultural wastes are also plotted.

From the practical point of view, larger dispersion contributes to a significant mixing or dilution of solute in a field. Hence, the decline of a dispersion characteristic due to the mixture of agricultural wastes is of particular concern for enhancing the increase of peak concentration of ions and the decrease of solute dilution in porous media. As a whole, the estimates of the dispersivity for both ions are larger than the dispersivity corresponding to the case without agricul-
tural wastes except for the case in rice bran for chloride ion. The change of the dispersivity depends on the variation of the mean diameter and uniformity coefficient in columns (Xu and Eckstein, 1997; Hunt et al., 2011) due to the mixture of agricultural wastes. On average, the dispersivity in nitrate ion exhibits lower values than that in chloride ion, except for the case in rice bran. This feature reflects that each anion has its own degree of solute spread with respect to mixed agricultural wastes like the anion transport within charged or uncharged porous media (Belline et al., 1996; Scheiner et al., 2013). The difference of the dispersivity between nitrate and chloride ions may be attributed to the difference of the reaction between the anion and the surface of an agricultural waste and may appear in the outcome of the retardation factor.

3.3 Retardation of solutes

In order to quantify the degree of the variation of anion mobility, the retardation factor was estimated using Eq. (4). The relation between the weight percentage of agricultural wastes and the retardation factor in all agricultural wastes are shown in Figure 7 for nitrate ion. The unity in the vertical axis means the solute travel without sorption onto the soil particle and desorption from the soil particle. The retardation factor can be treated as the mobility of solute in porous media during a course of transport. As for nitrate ion, the retardation factor in rice husk remains constant value of about 1.0 despite of the weight percentage of rice husk. Whereas the retardation factor in rice straw becomes larger than the unity, it is interesting to note that the mobility increase of nitrate below the unity in rice bran appears as shown in Figure 7. This point may be attributed to the nature of rice bran having the surface hydrophobicity and the negative charge of surface (Ju et al., 2001; Navas and Carrasquero-Durán, 2003), providing the increase of the velocity of nitrate and resulting in the lower values of the retardation factor less than the unity. In a practical situation, the retardation of nitrate in a cropland is of significance as the travel time of nitrate from the ground surface to groundwater becomes longer, subsequently leading to the reduction of nitrate loading to groundwater due to denitrification by microorganisms or uptake by plants.

Figure 8 also presents the results of the retardation factor in all agricultural wastes for chloride ion as a function of the weight percentage of agricultural wastes. Remarkably, the mobility of chloride ion is larger than the case without agricultural wastes. As well as rice bran, rice husk also has the surface hydrophobicity, which may affect the variation of the retardation factor in chloride ion. At a microscopic level, it is inferred that the degree of reaction between the anion and the surface of an agricultural waste is substantially different. Generally, adequate leaching and drainage are required especially in irrigated agriculture to prevent excessive salinization of soil (Ongley, 1996; Wallender and Tanji, 2011). Therefore, the increase of the solute mobility may contribute to avoid salt accumulation in rootzones and within pores since chloride ion becomes toxic to plants at high concentrations (Teakle and Tyerman, 2010).

As a whole, the degree of retardation in nitrate ion is larger than that in chloride ion, indicating that the mobility of chloride ion is higher than that in nitrate ion. Thus, the difference of the ion mobility in porous formations may lead to larger dispersivity of chloride ion relative to nitrate ion, as shown in Figures 5 and 6.

3.4 Mass recovery fraction and degradation of solutes

The change of mass balance is of interest and of significance during a course of transport associated with the mixture of agricultural wastes. As another quantity of anion transfer, Table 2 summarizes the results of not only the mass recovery fraction ($MRF$) but the degradation rate constant, which were computed from Eq. (5) and Eq. (6), respectively. Results in rice straw are not listed in this table, since $MRF$ and the degradation rate constant became 1 and 0, respectively, in all experimental cases.

In all experimental cases except in the chloride ion in rice bran, values of $MRF$ are less than the unity and corresponding degradation rate constants appear as non-zero values. Interestingly, up to 41% and 56% attenuation of the total mass can be seen in nitrate and chloride ions, respectively. This implies that part of nitrate or chloride ions may be strongly

![Figure 7: Relation between the weight percentage of agricultural wastes and the retardation factor for nitrate ion.](image)

![Figure 8: Relation between the weight percentage of agricultural wastes and the retardation factor for chloride ion.](image)
adsorbed onto the surface of rice husk or rice bran and/or may be trapped within pores. This is because rice husk and rice bran have a relatively high surface area (Kaupp, 1984).

From a practical point of view, as for nitrate ion, natural degradation of solute mass in a cropland is expected to attenuate the impact on water quality not only in soils but in groundwater. However, as for chloride ion, salt accumulation within pores or on the surface of an agricultural waste may lead to the rise of soil salinity. Hence, the use of rice husk in soils may provide a different outcome corresponding to anion of concern.

4 New quantity index

4.1 Concept of new quantity index

In order to synthetically assess the potential use of each agricultural waste under complex interactions during solute transport, a comprehensive judgment is required. In this study, a new quantity index is proposed as follows:

\[
I_{NO_3} = \frac{1}{N} \sum_{i=1}^{N} \frac{R_i + \frac{\alpha_i}{d_{50}}}{P_i + MRF_i} \quad (8)
\]

where \(I_{NO_3}\) is a dimensionless variable and is the proposed synthetic index of agricultural wastes for nitrate transport. Also, \(P\) denotes the weight ratio of the weight of each agricultural waste to the total weight of silica sand corresponding to the case without agricultural wastes and ranges from 0 to 1. \(N\) is the total number of experimental patterns in each agricultural waste, subscript \(i\) means the experimental pattern in each agricultural waste and \(d_{50}\) stands for the mean diameter of silica sand, which is introduced to convert the dispersivity to the dimensionless dispersivity and is set to 0.050 cm. As expressed in Eq. (8), four variables form the basis of the equation and incorporate the major factors which reflect and control the solute behavior including the retardation factor, the dispersivity, the mass recovery fraction and the mixture percentage of the waste. The degradation rate constant is not involved in the proposed synthetic index because the mass recovery fraction indirectly reflects the effect of the degradation rate constant.

In addition to lower values of the weight ratio \(P\) and the mass recovery fraction \(MRF\), which mean smaller amount of agricultural wastes and larger mass degradation, larger values of the retardation factor \(R\) and the dispersivity \(\alpha\) are preferable because of the delay and dilution of nitrate. Hence, this synthetic index demonstrates that the larger synthetic index becomes, the higher the potential of agricultural waste of concern is. However, an immediate leaching and non-persistence of chloride is preferable in terms of the alleviation of salt accumulation. Therefore, as for chloride ion, the following equation is proposed.

\[
I_{Cl^-} = \frac{1}{N} \sum_{i=1}^{N} \frac{MRF_i + \frac{\alpha_i}{d_{50}}}{P_i + R_i} \quad (9)
\]

where \(I_{Cl^-}\) is a dimensionless variable and is the proposed synthetic index of agricultural wastes for chloride transport. Practically, in management of a field, the use of agricultural wastes and the solute of concern depend highly on an agricultural activity in a field. Under the assumption that no interaction may occur between nitrate and chloride ions total synthetic index with considering two relevant anions is also proposed as:

\[
I = w_1 I_{NO_3} + (1 - w_1) I_{Cl^-} \quad (10)
\]

where \(I\) is the total synthetic index. Also, \(w_1\) denotes the weight coefficient and determines the balance or importance between two anions in decision-making.

For all experimental cases, the results of the proposed synthetic index based on Eq. (8) through Eq. (10) are listed in the second to fourth columns in Table 3. In this table, the value of 0.5 of the weight coefficient \(w_1\) is employed as one example and yields the results of the total synthetic index listed in the fourth column. These results reveal that the use of rice bran and rice husk is the most effective in the attenuation of

| Weight ratio of waste (%) | Nitrate ion mass balance fraction (−) | Degradation rate constant (hr⁻¹) | Chloride ion mass balance fraction (−) | Degradation rate constant (hr⁻¹) |
|--------------------------|--------------------------------------|----------------------------------|----------------------------------------|----------------------------------|
| Rice husk                | 0.95                                 | 0.77                             | 0.43                                   | 0.44                             | 1.60                             |
|                          | 1.6                                  | 0.95                             | 0.072                                  | 0.71                             | 0.50                             |
|                          | 2.6                                  | 0.73                             | 0.50                                   | 0.44                             | 1.70                             |
| Rice bran                | 0.8                                  | 0.76                             | 0.40                                   | 1.0                              | 0.0                              |
|                          | 1.6                                  | 0.81                             | 0.33                                   | 1.0                              | 0.0                              |
|                          | 2.5                                  | 0.59                             | 0.84                                   | 1.0                              | 0.0                              |

* For both ions, results of rice straw exhibited 1 and 0 of the mass balance fraction and the degradation rate constant, respectively, in all cases.
adverse effects of nitrate or chloride ions in porous media, respectively. On the other hand, a noticeable disparity is exhibited between nitrate and chloride ions, especially for rice straw and rice bran. This attributes to the difference of the synthetic index depends strongly on the dimensionless dispersivity.

In Eq. (8) and Eq. (9), each variable relevant to solute transport has own range to be identified. For example, the weight ratio $P$ has the range of 0.01 to 0.026, whereas the identified dispersivity $\alpha$ ranges from 0.149 to 0.578 cm and is normalized to the dimensionless dispersivity $\alpha/d_{50}$ having the range of 2.98 to 11.56, indicating the different order and range. This implies that the proposed synthetic index may be influenced by a specific variable, particularly the dispersivity, although such equations become one candidate evaluation for adjusting the degree of sensitivity associated with each variable.

The second synthetic indexes indicate that the use of rice bran and rice straw is the most effective in the attenuation of potential problems derived from the transport of nitrate or chloride ions in porous media, respectively. On the contrary to the results of the first synthetic indexes, the use of the second synthetic index results not in rice bran but in rice straw as the highest potential waste among three agricultural wastes. Notice that both total synthetic indexes listed in Table 3 were computed under the value of 0.5 of the weight coefficient $w_1$.

### Table 3: Results of the synthetic indexes.

|                | Synthetic index Eq.(8)-Eq.(10) | Synthetic index Eq.(11)-Eq.(13) |
|----------------|--------------------------------|---------------------------------|
|                | $I_{NO_3}^*$ | $I_{Cl}^*$ | Total synthetic index $I_s^*$ | $I_{NO_3}^*$ | $I_{Cl}^*$ | Total synthetic index $I_s^*$ |
| Rice husk      | 5.35   | 4.08   | 4.71                       | 5.50   | 5.71   | 5.60                       |
| Rice straw     | 6.99   | 3.90   | 5.44                       | 5.75   | 6.12   | 5.94                       |
| Rice bran      | 11.87  | 2.64   | 7.25                       | 5.87   | 5.85   | 5.86                       |

* Calculation results under the value of 0.5 of the weight coefficient $w_1$.

4.2 Effect of the weight coefficient

As aforementioned above, the rank of agricultural wastes is evaluated using the two types of the total synthetic index expressed in Eq. (10) and Eq. (13). In these equations, the weight coefficient $w_1$ is a key factor to determine the values of the total synthetic index and may affect the subsequent rank of agricultural wastes. Based on the experimental results, the results of the first total synthetic index using Eq.(10) are shown in Figure 9 as a function of the weight coefficient. The value greater than 0.5 of the weight coefficient means that a nitrate-induced problem is the primal problem and the evaluation of a potential use of agricultural wastes will be prioritized in the comparison with a chloride-induced problem. As shown in Figure 9, rice bran is the highest potential waste followed by rice straw and rice husk under the condition of the weight coefficient larger than about 0.2. In
contrast, the weight coefficient of less than 0.1 leads to the opposite results.

Figure 10 illustrates the results of the second total synthetic index using Eq.(13) as a function of the weight coefficient. Like the results of the first total synthetic index as shown in Figure 9, the rank of three agricultural wastes is influence by the employed value of the weight coefficient. However, rice husk is exhibited as the lowest potential waste under any values of the weight coefficient. Contrary to the first synthetic indexes, each variable related to solute transport has the same range of 1 to 2 in the second synthetic indexes. Hence, the second synthetic indexes are a comprehensible manner to assess the potential use of agricultural wastes.

The synthetic indexes proposed herein provide only a relative evaluation based on experimental data associated with solute transport phenomena in porous media and is not designed to provide absolute answers. Nonetheless, such synthetic indexes will assist in helping to prioritize protection, monitoring or clean-up efforts relevant to nitrate or chloride-induced problems in subsurface and can be applied to the use evaluation of other wastes. These indexes may also assist planners, managers and researchers in the task of evaluating the relative feasibility of agricultural wastes and contribute to the efficient use of agricultural wastes in optimized management and application techniques.

5 Conclusions

In the present study, the possible use of agricultural wastes including rice husk, rice straw and rice bran toward attenuating the nitrate pollution or the salt accumulation was assessed through column experiments under saturated flow conditions. Temporal moments associated with observed breakthrough curves in the effluent of nitrate or chloride ions were utilized to quantify the dispersivity, the retardation factor, the mass recovery fraction and the degradation rate constant.

Results indicated that the mixture of agricultural wastes resulted in the slight increase of the dispersivity relative to the case without wastes except for the case with rice bran in chloride ion transport. Interestingly, each anion showed its own degree of solute mobility associated with mixed agricultural wastes. Particularly, a marked increase of the mobility for chloride ion appeared in all agricultural wastes. Rice husk and rice bran were found to have a property to decrease the mass balance up to about 41% and 56% in nitrate and chloride ions, respectively, although the use of rice husk may result in the enhance of salinity within pores.

Moreover, a new synthetic index for evaluating the attenuation potential of agricultural wastes was proposed and clarified a noticeable difference in terms of anions as well as agricultural wastes. As a result, among three agricultural wastes employed in this study, the use of rice straw in soils showed the highest potential to the attenuation not only nitrate ion but also chloride ion followed by the use of rice bran and rice husk.

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