PHILIPP AGRIC SCIENTIST
Vol. 97 No. 3, 243–251
September 2014

ISSN 0031-7454

Modeling Solute Transport in Soil under Conventional Plow-Based and Conservation Agriculture Production Systems in Claveria, Misamis Oriental, Philippines

Paul Michael O. Tarnate[1,*], Victor B. Ella[2] and Manuel R. Reyes[3]

[1]Department of Engineering Science; [2]Land and Water Resources Division, Institute of Agricultural Engineering; College of Engineering and Agro-industrial Technology, University of the Philippines Los Baños, College, Laguna 4031, Philippines
[3]Department of Natural Resources and Environmental Design, North Carolina Agricultural & Technical State University, USA
[*]Author for correspondence; e-mail: potarnate@up.edu.ph

This study aimed to model and to compare the solute-transport behavior of soil under conservation agriculture (CA) and plow-based (PB) production systems in the Philippines. Undisturbed soil core samples were taken from both production systems from experimental sites in Claveria, Misamis Oriental, Philippines. A stochastic method, following continuous-input soil column tests, determined the dispersivity of the soil samples while a laboratory flow-through method, using pulse-input soil column tests, calculated the retardation factor. Both the soil dispersivity and the retardation factor were optimized using the CXTFIT model to fit the observed values to the Convection-Dispersion Equation (CDE). Upper-layer PB soil, with a combined lowest retardation factor of 1.26 and dispersivity of 17.5 cm, had the highest peak concentration of 0.67 C_0 and the shortest time-to-peak of 44 s. Soils under conservation agriculture production systems (CAPS), having a high retardation factor of 6.54 inspite of the highest value of dispersivity of 27.3, exhibited the lowest peak concentration of 0.44 C_0 after nearly 7 min of peaking time. These results may be indicative of higher soil organic carbon content in soils under CA. Model efficiencies ranging from 77% to 98% signify that the CDE is able to adequately predict solute transport in these soils. Simulations of solute transport in response to changing soil organic carbon content for a 10-yr period were performed. Increasing the organic carbon by 30% in soils under CAPS reflects a 9.6% decrease in peak concentration and a 3.1% increase in time-to-peak. On the other hand, there are minimal changes in terms of both peak concentration and time-to-peak in soils under PB systems, assuming a 3% decrease in organic carbon.

Key Words: breakthrough curve, conservation agriculture, conservation agriculture production system, contaminant transport, dispersivity, modelling, retardation factor

Abbreviations: CA – conservation agriculture, CAPS – conservation agriculture production system, CDE – Convection-Dispersion Equation, EC – electrical conductivity, PB – plow-based, SANREM – Sustainable Agriculture and Natural Resource Management

INTRODUCTION

Conservation agriculture production systems (CAPS) involve a combination of three major aspects: minimal soil disturbance, continuous mulch or soil cover and diversified crop rotation (Reyes and GETS Team 2010). In general, soil properties improve with reduced tillage; hence, CAPS provide more benefits to the crops. No-till technology ensures water retention and increases soil carbon content (Brown 2006).

Roger-Estrade et al. (2010) pointed out that tillage should not be the sole consideration in soil management; soil ecology is an important factor as well. Recent studies have focused on the influence of tillage on the biological aspect of the soil (Melero et al. 2009; Šimun et al. 2009; Vakali et al. 2011). Mishra et al. (2010) found that no-till agriculture slows down organic carbon decomposition and enhances carbon sequestration in soil in the United States. Larsbo et al. (2009) determined that the higher organic carbon content accumulated on the top layer of reduced-tillage soils have the potential to reduce pesticide leaching. No-tillage practices have also been proven to improve soil quality and fertility in areas of the Spanish Mediterranean (Madejón et al. 2009).

Tillage affects carbon content in the soil in many ways. Among these are changing soil climate and the incorporation of external carbon inputs that cause highly variable fluctuations depending on the location and environmental factors. Also, organic carbon is exposed due to the recurrent disturbance of soil structure. This disruption causes carbon-protecting aggregates to disperse, a process further accelerated by cycles of wetting and drying and by exposure to precipitation (Balesdent et al. 2000).

Conservation practices have shown inconsistent effects on soil hydraulic properties through varying locations, soil types and experimental designs (Strudley et al. 2008), hence, the need to conduct studies in different locales. In the Philippines, CA is the subject of intensive research under the auspices of the Sustainable Agriculture and Natural Resource Management Collaborative Research Support Program (SANREM-CRSP) (CRSP 2014).

Solute transport studies and modelling have previously been done in selected soils in the Philippines (e.g., Ella 2004; Alibuyog and Ella 2008). In these studies, the solute transport behaviors of selected soils were characterized through miscible displacement experiments using laboratory soil columns and modeled using the Convection-Dispersion Equation (CDE). The results proved the adequacy of the solute transport models in predicting solute transport and in generating solute transport properties of the soils dealt with. However, no local studies have yet been done on solute transport characterization under CA production systems and conventional PB systems in the Philippines. Determination of solute transport properties of soils under CA production systems and PB systems could add value to the assessment of the effect of CA and soil disturbances on soil quality and the potential leaching of agro-chemicals in the soil which have far-reaching implications on the overall economics of these agricultural production systems. At the same time, knowledge of solute transport properties under the aforementioned crop production systems could serve as basis for assessing potential groundwater contamination due to leaching of harmful agrochemicals and, hence, could prove useful for addressing environmental protection concerns.

This study aimed to model the solute-transport behavior of soil under conventional PB and CA production systems in Claveria, Misamis Oriental, Philippines. Specifically, the study aimed to model and to compare breakthrough curves, soil dispersivity and retardation factor of the soil on the basis of production system (conventional PB and CA) and of two soil depth ranges; and to simulate the effect of changes in organic carbon content on the solute transport in soil under each production system.

MATERIALS AND METHODS

Soil Sample Preparation

The soil samples were collected from the experimental site of the SANREM project on conservation agriculture. There were six 9 m x 3 m experimental plots at about 8% –10% slope. Three plots underwent conventional PB agriculture; the other three were subjected to CAPS. Undisturbed soil samples were taken at depth ranges of 0–15 cm and 15–30 cm. Each specimen was carefully trimmed to fit 5.08-cm-diameter galvanized iron pipes that served as core samplers. Each sample was then transferred to a 5.08-cm-nominal-diameter polyvinyl chloride (PVC) pipe. Paraffin wax sealed the interface between the soil and the pipe.

Constant-Head Tanks

PVC cleanouts with a copper tube that served as an inlet/outlet were fabricated. All gaps were caulked using elastomeric sealants. The cleanouts were lined with cheesecloth before being attached to the bottom of the PVC pipe containing the soil samples. Silicone created a watertight connection between the pipe and the cleanout.

A constant-head tank was fabricated out of a plastic bottle with a copper tube that served as the tap placed near the base. Separately, a glass tube was punched through the bottle cap. Elastomeric sealants were used to ensure water-tight conditions. Once the sealants have fully set, the tank was filled with distilled water. The exposed end of the glass tube was temporarily closed as the tube was being inserted into the water-filled bottle. The protruding end of the glass was then exposed to the atmosphere, allowing atmospheric pressure to act on the submerged end of the glass tube.

A smaller version of this tank, to contain the tracer solution, was also fabricated. Potassium chloride (KCl) solution was prepared by dissolving 0.18 g KCl in 1 L of distilled water and diluting the solution to a final volume of 6 L in the smaller constant-head tank. Figure 1 shows the schematic of the setup.

Miscible Displacement: Constant Input

Miscible displacement experiments were done on the soil samples with constant 3.81-cm head above the soil column. Distilled water was introduced from the bottom of the sample through the copper tube to saturate the sample. Water was then directed to the top of the column to flush out ions using three to four pore volumes.

Once the surface water level on the soil sample has nearly completely entered the soil, a continuous input of the tracer was supplied to the top of the sample. Ten-

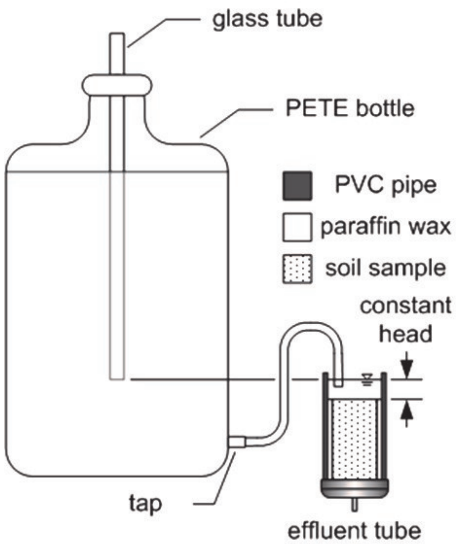

Fig. 1. The schematic of the miscible-displacement experiment setup.

milliliter effluents were thereafter collected in test tubes. Also, the average time required to collect a 10-mL effluent was noted. The electrical conductivity of the effluents, distilled water and KCl tracer were measured using an Oakton pH/CON 300 meter.

Determination of dispersivity utilizes Eq. 1 to 5 from Pickens and Grisak (1981a, b). Using the data from the miscible-displacement experiments, the average pore water velocity V_x was computed as follows:

$$V_x = \frac{V\!\!\!/}{nAt} \quad (1)$$

where $V\!\!\!/$ is the volume of the effluent, n is the porosity, A is the cross-sectional area, and t is the time interval. For every effluent reading, the pore volume U was calculated as follows:

$$U = \frac{V_x t}{L} \quad (2)$$

where t is the total time elapsed after the continuous-input tracer was introduced and L is the vertical length of the soil column.

The ratio of EC/EC_0 (the electrical conductivity at any instant relative to the initial electrical conductivity) was plotted against γ, which is defined as

$$\gamma = \frac{U-1}{U^{\frac{1}{2}}} \quad (3)$$

on a linear-probability scale.

The values of $\gamma_{0.16}$ and $\gamma_{0.84}$ were noted and were used in the following equation to determine the longitudinal hydrodynamic dispersion coefficient D_L :

$$D_L = \frac{V_x L}{8}(\gamma_{0.84} - \gamma_{0.16})^2 \quad (4)$$

In this context, $\gamma_{0.16}$ and $\gamma_{0.84}$ are the corresponding γ-values at relative electrical conductivities of 0.16 and 0.84, respectively.

With a known molecular diffusion coefficient of the tracer solute (1.5 × 10^{-5} cm^2 s^{-1} for KCl) D^*, the dispersivity a was then computed as follows:

$$\alpha = \frac{D_L - D^*}{V_x} \quad (5)$$

The relative effluent electrical conductivity was plotted against the corresponding number of pore volumes to generate breakthrough curves for each sample. Dispersivity was also determined using the CXTFIT/Excel code developed by Tang et al. (2010) adapted from the original line user-interface version of CXTFIT (Toride et al. 1999). Using the breakthrough curve obtained from experimentation, inverse solutions were done to determine the soil dispersivity.

Miscible Displacement: Pulse Input

Distilled water flushed the ions from the same samples utilized for the continuous-input miscible displacement experiment. For each soil sample, 50 mL of 25 mg L^{-1} potassium nitrate (KNO_3) solution was prepared. The standing water in the samples was allowed to nearly drain from the top surface of the soil sample. The pulse tracer was poured and 10-mL effluents were again collected. The time it took for the pulse-input tracer to enter the soil surface was noted. A continuous supply of distilled water was then directed to the top of the column.

Effluent collection continued until electrical conductivity no longer decreased significantly. For each soil sample, the relative electrical conductivity and the number of pore volumes were plotted to form pulse-input breakthrough curves. Using the computed dispersivity in the continuous-input miscible displacement experiment, CXTFIT/Excel was used to optimize the value of the retardation factor in the CDE.

Laboratory Flow-through Method

Using the data from the pulse-input miscible displacement experiment, the retardation factor was computed as follows:

$$R = \frac{V_x}{V_c} \quad (6)$$

where V_c is the contaminant or tracer velocity (US EPA 1999).

The pore-water velocity V_x can be calculated as defined by Eq. 1; whereas, the tracer velocity can be computed as the length of the soil column divided by the tracer's mean residence time (US EPA 1999), expressed as

$$t_{pulse} = \frac{\oint_{t_{min}}^{t_{max}} tC_i dt}{\oint_{t_{min}}^{t_{max}} C_i dt} \quad (7)$$

where

t_{min} = beginning of the breakthrough curve (T)
t_{max} = end of the breakthrough curve (T)
t = time elapsed (T)
C_i = concentration of the effluent (ML^{-3})
dt = time interval when the effluent was collected (T)

Simulation of Changes in Organic Matter

The empirical approach that is widely accepted as a measure of this coefficient (US EPA 1999) was the one proposed by Karickhoff et al. (1979):

$$K_d = f_{oc} K_{oc} \tag{8}$$

where f_{oc} is the fraction of organic carbon in the soil and K_{oc} is the ratio of the contaminant concentration on the organic matter to the dissolved concentration in the surrounding fluid.

One major benefit of conservation agriculture is improved organic matter in the soils. Arshad et al. (1990) reported a 26% increase in carbon content of no-till soils compared with conventionally tilled soils after a 10-yr period. Mazzoncini et al. (2011) found that the soil organic carbon content in the top 30 cm of soil increased by 61 g m^{-2} per year from 1993 to 2008 under no-till conservation practices. Likewise, soil organic carbon decreased by 6 g m^{-2} per year for conventional tillage practices for the same period.

Using this information, organic matter content was changed hypothetically in the upper 15 cm of the soil samples to simulate the effect on the breakthrough curve. The upper 15 cm of both plow-based and conservation-agriculture soil samples were selected because this upper layer would most probably show notable changes in organic matter as a result of the corresponding agriculture practices. CXTFIT/Excel was used to plot several curves that represent various fractions of organic matter.

To determine the fit of the observed values to the mathematical model, the Nash-Sutcliffe model efficiency was used (Nash and Sutcliffe 1970). The Kolmogorov-Smirnov test was used to compare whether or not two sets of distribution differed significantly (Smirnov 1944).

RESULTS AND DISCUSSION

Data obtained were for soil samples from the upper (0–15 cm depth) and lower (15–30 cm depth) layers of plow-based (PB) and conservation agriculture (CA) production systems.

Dispersivity

Chloride being a conservative tracer, the retardation factor was assumed to be negligible. Thus, the stochastic values for dispersivity (Eq. 5) were determined from the normal-probability plots of EC/EC_0 against γ (Eq. 3). The values were then optimized using CXTFIT. The values of dispersivity are presented in Table 1. Figures 2 to 5 present the breakthrough curves using the stochastic and optimized dispersivity.

For the upper PB, the most obvious feature of the breakthrough curve is the steep initial portion. Extrapolation using very small pore volumes distinguishes the typical curved portion from the asymptotic end (inset in Fig. 2). This near-horizontal characteristic of the curve may be attributed to the macropores that are likely to be present in tilled soils. While they may constitute a small fraction in a soil's porosity, macropores transmit the largest fraction of water flow (Cameira et al. 2003).

The observed data points fell below the CXTFIT-optimized breakthrough curves at the latter portions (Fig. 3–5) and were most evident for the CA soils. This phenomenon may be ascribed to the heterogeneity of the soil column. Gao et al. (2009) have shown that the Convection-Dispersion Equation (CDE), including two other solute-transport models, exhibit anomalous tailing of the breakthrough curves when compared with the measured data for heterogeneous soil columns the lengths of which range from 200 to 1250 cm.

Notably, the retardation factor, once the variables were calibrated, is not equal to one. While the chloride ion may be conservative, the potassium ion may have been adsorbed in the soil. A study by Nuñez-Delgado et al. (1996) showed that chloride passed through soil faster than water but potassium exhibited a retardation factor in the range of 1.5 to 2.5.

To obtain a comparison between the stochastically obtained dispersivity and the CXTFIT-optimized dispersivity, the former was used in the CXTFIT as a constant and its corresponding retardation factor was optimized. The Nash-Sutcliffe model efficiency for each curve was computed. Higher model efficiency was naturally in favor of the CXTFIT dispersivity since two variables were used to optimize the CDE. A negative value for the upper PB indicates that the CDE was unable to predict the unusual behavior of this soil sample's breakthrough curve. The presence of macropores may have rendered the assumption of homogeneity moot.

Table 1. Dispersivity of soil samples for constant-input of KCl tracer.

Estimation Method	PB Soil		CA Soil	
	Upper	Lower	Upper	Lower
Stochastic	17.5	8.1	9.2	4.6
CXTFIT	17.5	21.1	27.3	5.5

PB – plow-based; CA – conservation agriculture

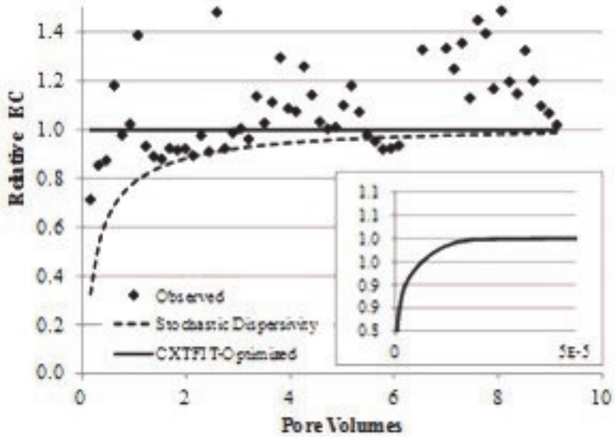

Fig. 2. Breakthrough curve for KCl tracer for the upper plow-based (PB) soil.

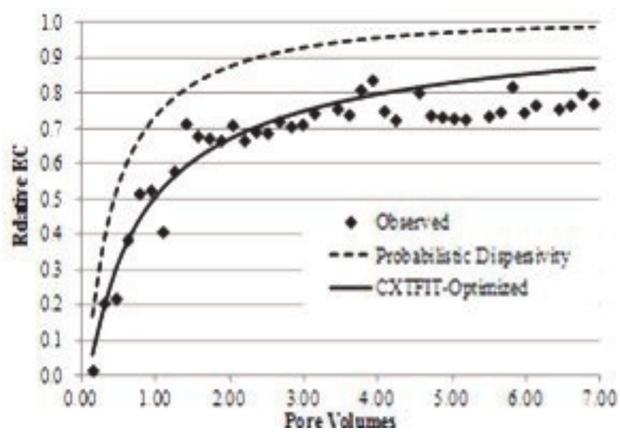

Fig. 3. Breakthrough curve for KCl tracer for the lower plow-based (PB) soil.

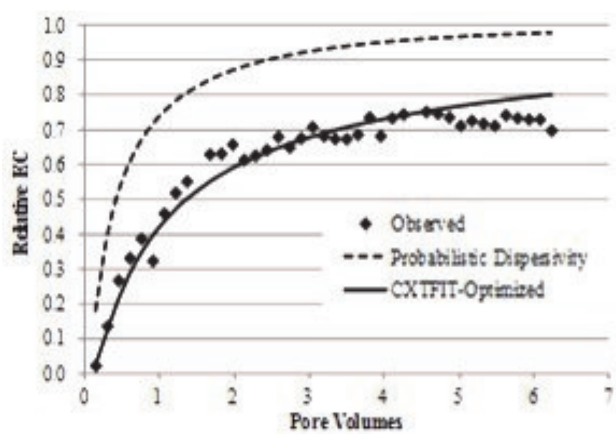

Fig. 4. Breakthrough curve for KCl tracer for the upper conservation-agriculture (CA) soil.

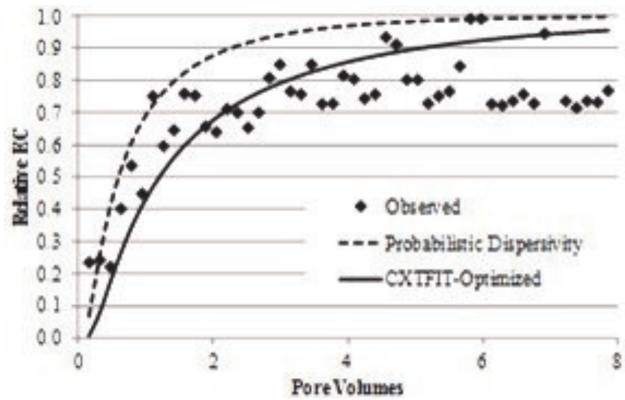

Fig. 5. Breakthrough curve for KCl tracer for the lower conservation-agriculture (CA) soil.

Retardation Factor

Table 2 summarizes the data needed to compute the retardation factor for the soil samples. The retardation factors—and hence, the partition coefficient—are greater for conservation-agriculture soils and may indicate the slightly higher organic carbon content in no-till conservation agriculture soils relative to those of conventional plow-based soils.

The lowest retardation factor is that of the upper PB. It may primarily be due to the presence of macropores. The faster flow rate through these macropores reduces the likelihood of soil-resident solutes to diffuse into the mobile water as evidenced by a study by Matthews et al. (2000).

The retardation factors of the lower PB and upper CA were close, which may be due to the possible slight compaction of lower PB as the upper layer was being plowed. Also, since conservation agriculture on the experimental site was only applied for a few years, it may be possible that soil organic matter is not significantly different among the treatments.

Table 2. Pertinent data for the retardation factor via flow-through method.

Variable	PB Soil		CA Soil	
	Upper	Lower	Upper	Lower
Mean residence time (s)	54	744	901	610
Pore-water velocity (cm s^{-1})	0.13	0.011	0.01	0.02
Tracer velocity (cm s^{-1})	0.12	0.01	0.01	0.01
Retardation factor	1.12	1.26	1.25	1.54

PB – plow-based; CA – conservation agriculture

Pulse-input Breakthrough Curves

Dispersivity, being a function of the soil structure, was assumed to be constant regardless of the tracer used. Thus, the optimized values of dispersivity obtained from the continuous-input column tests were also used in the pulse-duration column tests. The retardation factors were then calibrated to fit the observed values. Table 3 presents the dispersivity and retardation factor optimized

Table 3. Optimized variables and model efficiencies for pulse-input breakthrough curves.

Variable	PB Soil		CA Soil	
	Upper	Lower	Upper	Lower
Dispersivity (cm)	17.5	21.1	27.3	5.6
Retardation factor	1.26	3.67	6.54	1.64
Model efficiency	0.96	0.98	0.91	0.77

PB – plow-based; CA – conservation agriculture

for the four breakthrough curves as well as the corresponding model efficiencies while Figures 6 to 9 show the pulse-input breakthrough curves. With model efficiencies ranging from 77% to 98%, it can be said that the CDE adequately predicts the solute transport in the soil.

For a constant retardation factor, increasing the dispersivity shortens the time-to-peak and increases the peak concentration value. On the other hand, with constant dispersivity, increasing the retardation factor prolongs the time-to-peak while reducing the peak concentration value.

The relatively low model efficiency of the lower CA soil may be attributed to the relatively higher observed data points interspersed among those coinciding with the breakthrough curve. When these points are connected with the other points, multiple peaks appear. This occurrence of multiple peaks, as well as having more skewed curves, may be explained by the randomness of porosity fields in the soil (Hu et al. 2009).

Effect of Production System

Soils taken from the PB plots had higher dispersivity compared with the CA plots. Conventional tillage mechanically disturbs the soil and macropores are likely to form. These macropores serve as preferential flow paths and thus lead to higher dispersivity.

On the other hand, the CA soils had mixed results. Upper CA had the highest dispersivity while the lower CA had the lowest among the treatments. Upper CA may have been riddled with earthworm-generated macropores. A 3-yr study by Peigné et al. (2009) found an increase in earthworm abundance and biomass in no-till and reduced -till soil. This increase in biomass may also explain the high retardation factor in lower CA despite its high dispersivity.

PB soil samples had lower retardation factors compared with CA soil. This observation suggests that there is loss in organic matter due to tillage.

PB soil, with a combined lowest retardation factor and a high dispersivity, had the highest peak concentration of 0.67 C_0 and the shortest time-to-peak after 44 s. CA soil, having a high retardation factor in spite of the highest value of dispersivity, exhibited the lowest peak concentration of 0.44 C_0 and one of the longest time-to-peak after nearly 7 min.

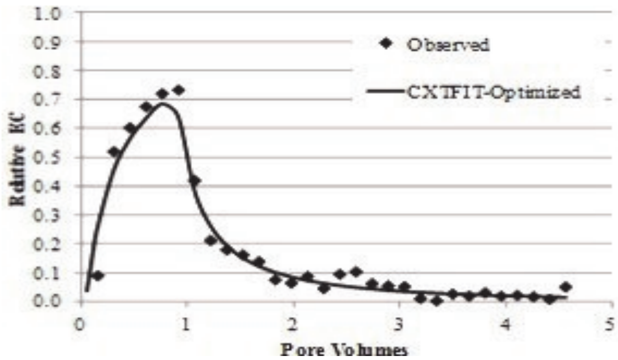

Fig. 6. Breakthrough curve for KNO_3 tracer of upper plow-based (PB) soil.

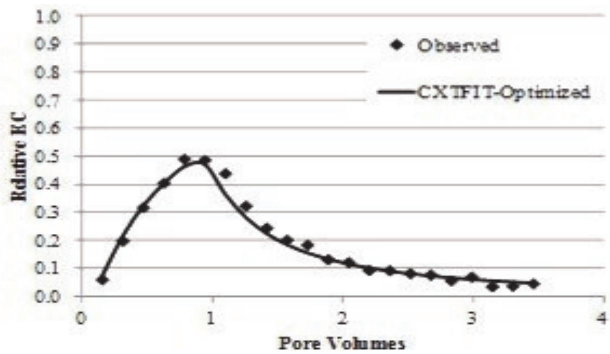

Fig. 7. Breakthrough curve for KNO_3 tracer of lower plow-based (PB) soil.

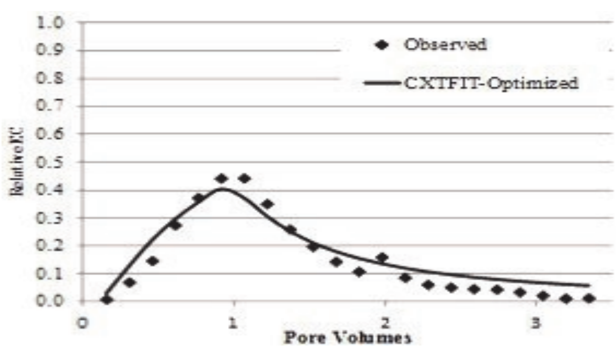

Fig. 8. Breakthrough curve for KNO_3 tracer of upper conservation-agriculture (CA) soil.

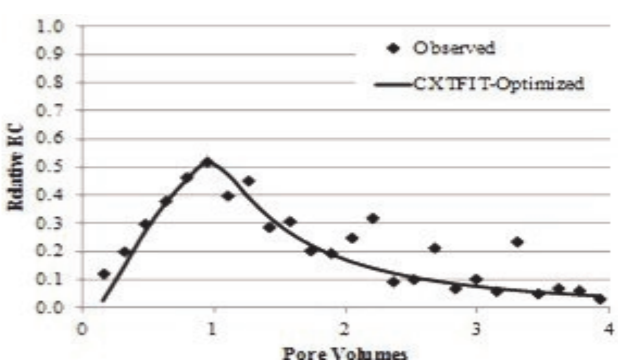

Fig. 9. Breakthrough curve for KNO_3 tracer of lower conservation-agriculture (CA) soil.

Effect of Depth

PB samples had close values of dispersivity. The retardation factor, however, was smaller in upper PB than in lower PB. Plowing disturbs the soil and the upper layers are often more exposed to the atmosphere. Therefore, the top layer of the soil may be more susceptible to carbon losses.

Upper CA had a greater dispersivity compared with lower CA. Again, this observation may be attributed to earthworm-induced macroporosity. Capoweiz et al. (2009) have shown that macropores, presumably due to earthworm burrowing, decrease in conservation-agriculture soils with increasing depth; the minimum number of macropores was found at 30-cm depth. The same suppositions can be made for the higher retardation factor in upper CA compared with lower CA. Also, carbon sequestration is most likely to occur faster near the soil surface rather than in the layers beneath.

Simulation of Solute Transport in Response to Changes in Soil Organic Carbon

Due to lack of local information, estimates of increase and decrease in organic carbon were made from the data from other studies. For no-till soils, there was a 26% increase in organic carbon after 10 yr (Arshad et al. 1990). Using proportional relationships for the rates of change determined by Mazzoncini et al. (2011), there would be an approximate 2.5% decrease in organic carbon for PB soil also after 10 yr.

For the hypothetical 10-yr-period simulation, the maximum increase in organic carbon for CA soils was set to 30%; decrease in organic carbon for PB soils, to 3%. Tables 4 and 5 summarize the effect of annual changes on the breakthrough curve.

From Table 4, there will be a decreasing trend in peak concentration amounting to 9.6% after 10 yr. For a specific peak concentration, increasing the organic carbon content will prolong the time-to-peak, a net increase of 3.1% after 10 yr. Results of the Kolmogorov-Smirnov tests indicated no significant differences among the curves.

From Table 5, peak concentration will increase from 0.81 C_0 to 0.82 C_0 after 10 yr. Again, for a specific peak concentration, decreasing the organic carbon content will shorten the time-to-peak. The time-to-peak after 10 yr seems virtually unchanged. Results of the Kolmogorov-Smirnov tests indicated no significant differences among the curves.

For contrast, the projected breakthrough curves for conventional PB and CA production systems after the hypothetical 10-yr period are shown in Figure 10.

Simulations have shown that increasing the organic carbon content may improve the soil retardation factor. This trend implies longer residence time of possibly both fertilizers and pesticides. The nutrients will be made available to crops for longer periods while crop-protection chemicals will have greater chances of performing their intended function. Farmers will get more value for their money: not only will they save on fertilizers and pesticides, they will also maximize yield. As the crops take in the nutrients more efficiently with high soil retardation factors, the amount of chemicals leaching into the groundwater may also be minimized.

In terms of dispersivity, the previously mentioned argument would still apply. Highly dispersive soils may

Table 4. Changes in the breakthrough curves with increasing organic carbon under conservation agriculture (CA) production system.

Year	% Organic Carbon	Retardation Factor	Pore Volumes to Peak	Peak Concentration (C_0)
0	2.55	5.49	1.52	0.52
1	2.63	5.66	1.56	0.52
2	2.70	5.82	1.54	0.51
3	2.78	5.99	1.58	0.51
5	2.93	6.32	1.59	0.50
6	3.01	6.48	1.56	0.49
7	3.09	6.65	1.60	0.49
8	3.16	6.81	1.57	0.48
9	3.24	6.98	1.61	0.48
10	3.32	7.14	1.57	0.47

PB – plow-based; CA – conservation agriculture

Table 5. Changes in the breakthrough curves with decreasing organic carbon under conventional plow-based (PB) production system.

Year	% Organic Carbon	Retardation Factor	Pore Volumes to Peak	Peak Concentration (C_0)
0	2.55	1.29	1.47	0.81
1	2.47	1.28	1.46	0.81
2	2.40	1.27	1.45	0.81
3	2.32	1.26	1.44	0.81
4	2.24	1.25	1.43	0.81
5	2.17	1.25	1.42	0.81
6	2.09	1.24	1.51	0.82
7	2.01	1.23	1.50	0.82
8	1.94	1.22	1.49	0.82
9	1.86	1.21	1.48	0.82
10	1.79	1.20	1.47	0.82

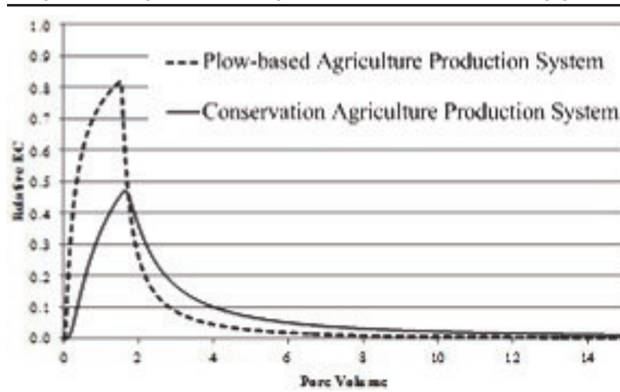

Fig. 10. Breakthrough curves representing the end of a 10-yr period under conventional plow-based (PB) and conservation agriculture (CA) production systems.

cause fast percolation rates of water, which may carry with it the fertilizers and/or pesticides. This would mean losses on the farmers' part and potential hazard to the environment. As CA production systems offer no tillage, the soil would be consolidated and less disaggregated. These favorable conditions would decrease soil dispersivity and thus provide the requisite gains.

This study has proved the applicability of the CXTFIT model for characterizing the solute transport behavior of soils under CA and conventional PB system in upland areas in the Philippines. From both production and environmental protection standpoints, increasing retardation factors and decreasing dispersivity—both of which may be attained through conservation agriculture production systems—may prove beneficial. Therefore, this production system may ensure good soil quality for generations.

ACKNOWLEDGMENT

The authors are grateful to the SANREM project "Conservation Agriculture for Food Security in Cambodia and the Philippines" funded by the United States Agency for International Development (USAID) for making the conduct of this research possible.

REFERENCES CITED

ALIBUYOG NR, ELLA VB. 2008. Predicting copper transport in an undisturbed soil column using the two-region transport model. Philipp J Agric Biosyst Eng 6: 25–35.

ARSHAD MA, SCHNITZER M, ANGERS DA, RIPMEESTER JA. 1990. Effects of till vs. no-till on the quality of soil organic matter. Soil Biol Biochem 22(5): 595–599.

BALESDENT J, CHENU C, BALABANE M. 2000. Relationship of soil and organic matter dynamics to physical protection and tillage. Soil Till Res 53: 215–230.

BROWN L. 2006. Introduction. In: Goddard T, Zoebisch M, Gan Y, Ellis W, Watson W, Sombatpanit S, editors. No-till Farming Systems. Special Publication No. 3. The World Association of Soil and Water Conservation. p. 3 – 6.

CAMEIRA MR, FERNANDO RM, PEREIRA LS. 2003. Soil macropore dynamics affected by tillage and irrigation for a silty loam alluvial soil in southern Portugal. Soil Till Res 70: 131–140.

CAPOWEIZ Y, CADOUX S, BOUCHANT P, RUY S, ROGER-ESTRADE J, RICHARD G, BOIZARD H. 2009. The effect of tillage type and cropping system on earthworm communities, macroporosity and water infiltration. Soil Till Res 105: 209–216.

[CRSP] Collaborative Research Support Program. 2014. Conservation agriculture for food security in Cambodia and the Philippines. Retrieved June 20, 2014 from the World Wide Web: http://crsps.net/resource/ltra-12-conservation-agriculture-for-food-security-in-cambodia-and-the-philippines/

ELLA VB. 2004. Modeling contaminant transport in selected soils in the Philippines. ASAE/CSAE Meeting Paper No. 04-2015. St. Joseph, Michigan. Paper presented at the 2004 Annual International ASAE/CSAE Meeting, Ottawa, Ontario, Canada. July 31–August 4, 2004.

GAO G, ZHAN H, FENG S, HUANG G, MAO X. 2009. Comparison of alternative models for simulating anomalous solute transport in a large heterogeneous soil column. J Hydrol 377(3–4): 391–404.

HU BX, MEERSCHAERT MM, BARRASH W, HYNDMAN DW, HE C, LI X, GUO L. 2009. Examining the influence of heterogeneous porosity fields on conservative solute transport. J Contam Hydrol 108: 77–88.

KARICKHOFF SW, BROWN DS, SCOTT TA. 1979. Sorption of hydrophobic pollutants on natural sediments. Water Res 13(3): 241–248.

LARSBO M, STRENSTRÖM J, ETANA A, BÖRJESSON E, JARVIS NJ. 2009. Herbicide sorption, degradation, and leaching in three Swedish soils under long-term conventional and reduced tillage. Soil Till Res 105: 200–208.

MADEJÓN E, MURILLO JM, MORENO F, LÓPEZ MV, ARRUE JL, ALVARO-FUENTES J, CANTERO C. 2009. Effect of long-term conservation tillage on soil biochemical properties in Mediterranean Spanish areas. Soil Till Res 105: 55–62.

MATTHEWS AM, ARMSTRONG AC, LEEDS-HARRISON PB, HARRIS GL, CATT JA. 2000. Development and testing of a model for predicting tillage effects on nitrate leaching from cracked clay soils. Soil Till Res 53: 245–254.

MAZZONCINI M, SAPKOTA TB, BÀRBERI P, ANTICHI D, RISALITI R. 2011. Long-term effect of tillage, nitrogen fertilization and cover crops on soil organic carbon and total nitrogen content. Soil Till Res 114(2): 165–174.

MELERO S, LOPÉZ-GARRIDO R, MURILLO JM, MORENO F. 2009. Conservation tillage: Short- and long-term effects on soil carbon fractions and enzymatic activities under Mediterranean conditions. Soil Till Res 104: 292 – 298.

MISHRA U, USSIRI DAN, LAL R. 2010. Tillage effects on soil organic carbon storage and dynamics in Corn Belt of Ohio USA. Soil Till Res 107: 88 – 96.

NASH JE, SUTCLIFFE JV. 1970. River flow forecasting through conceptual models part I – A discussion of principles. J Hydrol 10(3): 282–290.

NUÑEZ-DELGADO A, LOPEZ-PERIAGO E, DIAZ-FIERROS-VIQUEIRA F. 1996. Breakthrough of inorganic ions present in cattle slurry: Soil Column Trials. Water Res 31(11): 2892–2898.

PEIGNÉ J, CANNAVACUOLO M, GAUTRONNEAU T, AVELINE A, GITEAU JL, CLUZEAU D. 2009.

Earthworm populations under different tillage systems in organic farming. Soil Till Res 104: 201–214.

PICKENS JF, GRISAK GE. 1981a. Scale-dependent dispersion in a stratified granular aquifer. Water Resour Res 17(4): 1191–1211.

PICKENS JF, GRISAK GE. 1981b. Modeling of scale-dependent dispersion in hydrogeologic systems. Water Resour Res 17(6): 1701–1711.

REYES MR, GETS Team. 2010. Conservation agriculture for food security in Cambodia and the Philippines. Electronic Presentation. SANREM CRSP Knowledgebase. Retrieved September 19, 2011 from http://sanrem.cals.vt.edu/1327/Reyes-CA%20for%20Food%20Security.pdf.

ROGER-ESTRADE J, ANGER C, BERTRAND M, RICHARD G. 2010. Tillage and soil ecology: Partners for sustainable agriculture. Soil Till Res 111: 33–40.

ŠIMUN T, JAVŮREK M, MIKANOVÁ O, VACH M. 2009. The influence of tillage systems on soil organic matter and soil hydrophobicity. Soil Till Res 105: 44–48.

SMIRNOV NV. 1944. Approximate distribution laws for random variables, constructed from empirical data. Uspekhi Mat Nauk 10: 179 – 206.

STRUDLEY MW, GREEN TR, ASCOUGH JCII. 2008. Tillage effects on soil hydraulic properties in space and time: State of the science. Soil Till Res 99: 4–48.

TANG G, MAYES MA, PARKER JC, JARDINE PM. 2010. CXTFIT/Excel – A modular adaptable code for parameter estimation, sensitivity analysis and uncertainty analysis for laboratory or field tracer experiments. Comput Geosci 36: 1200–1209.

TORIDE N, LEIJ FJ, VAN GENUCHTEN MTH. 1999. The CXTFIT Code for Estimating Transport Parameters from Laboratory or Field Tracer Experiments. Version 2.1. Research Report No. 137. U.S. Salinity Laboratory. Agricultural Research Service. U.S. Department of Agriculture. 121 p.

[US EPA] United States Environmental Protection Agency. 1999. Understanding Variation in Partition Coefficient, Kd, Values. Volume I: The Kd Model, Methods of Measurement, and Application of Chemical. p. 3.9–3.11.

VAKALI C, ZALLER JG, KÖPKE U. 2011. Reduced tillage effects on soil properties and growth of cereals and associated weeds under organic farming. Soil Till Res 111: 133–141.