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Influence of wet-dry cycles on the temporal infiltration dynamic in temperate rice paddies

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ABSTRACT

Rice paddy water infiltration is key for evaluating agrochemical groundwater migration. To this end, we designed and conducted an experiment with two aims: (1) to describe the water infiltration dynamic that occurs throughout the growing season and wet-dry cycling in rice paddies, and (2) to quantify the infiltration that takes place under two different water managements (continuous flooding (CF) and delayed submersion (DS)). The two-year field-scale study took place in Vercelli (Italy) during which the water balance in six rice paddies was monitored hourly and the infiltration rate dynamic was calculated for each wet-dry cycle.

The average daily infiltration rate decreased between the first and second cycles, increased after the third cycle, and reached its maximum value at the growing season end. Water infiltrated during the first 40 hours of each wet-dry cycle and particularly at the first and fourth wetting induced the highest groundwater pollution risk, with a larger potential in DS. Also, DS did not save water, as the total water used in the two treatments was identical.

KEYWORDS: infiltration rate; rice paddy; wet-dry cycle

1. Introduction

Rice paddies not only typify the landscape of Northwest Italy, but also utilize significant amounts of applied irrigation water (Bouman, et al., 2007). Rice field water flows result in great surface runoff and deep percolation that may be a vector of nutrients and chemical pollutants that can cause serious environmental problems. Preferential flow paths found often in rice paddy soils (Garg et al., 2009; Patil and Das, 2013; Sander and Gerke, 2007; Sander and Gerke, 2009; Zhang et al., 2014) can increase chemical contaminant leaching from surface water to groundwater (Boivin, et al., 2002), which makes it important to develop and maintain an efficient monitoring network to evaluate regional agrochemical migration and transformation (Vu, et al., 2005).

Rice paddy surface water flow is simple for a farmer to manage, as water outlet fluxes can usually be regulated—even suspended if necessary—to prevent nutrients and pesticides from exiting the field. However, water infiltration is the factor that most affects surface and groundwater quality. Its rate in rice paddies can be significantly influenced by soil texture and structure (Boivin, et al., 2001), flooded water depth (Liu, et al., 2003), hard pan hydraulic conductivity and puddling intensity (Aggarwal, et al., 1995), depth to groundwater table (Chen and Liu, 2002), cultivation history (Janssen and Lennartz, 2007), topography (Tsubo, et al., 2007), and different water managements (Sacco et al., 2012).

The two most common water managements in North Italy are continuous flooding and dry seeding with delay flooding. Dry seeding techniques are chosen by farmers as an alternative to more traditional continuous submersion as a means by which to reduce the labor required as more agricultural practices are performed in dry soil, to more efficiently develop rooting systems, and to reduce the risk of environmental impact from the absence of water at first fertilisation and herbicide application. In 2012 this techniques was applied on 66,099 ha out of 235,052 ha, representing about 28% of the paddy area (Ente Nazionale Risi, 2014).

Numerous experiments have demonstrated that cracks and/or macropores are fundamental to preferential flow creation and increased water infiltration (Janssen and Lennartz, 2009). They are usually created during the growing period (Kramers, et al., 2005; Sacco, et al., 2012; Tournebize, et al., 2006) and affected by different tillage practices (Cameira, et al., 2003), earthworm burrows (Sander and Gerke, 2007), water submersion, and alternated dry and wet flooding (Tournebize, et al., 2006). Typically, they are affected by great spatial and temporal variability in the macropore system.

Paddy soils present temporal changes in soil bulk density, soil shrinkage, and cracks with wet-dry cycles. The crack area density also depends on the clay and soil organic matter content (Zhang et al., 2013). In fine-textured soil, drying causes crack formation and disintegration of large clods into smaller aggregates (Alaoui et al., 2011). Further study of Zhang (2014) shows that cracks are generated during the wet-dry cycle, but not under continuous flooding conditions.

Another reason for creation of preferential flow is from the teeth on the iron tractor wheels that facilitate traction in the muddy soils during the submersion period. As made evident by soil profile analysis, the wheels lean on the ploughing pan as the teeth penetrate the layer, creating preferential pathways for water infiltration.

Until now, several models have been developed to simulate water infiltration in rice paddies. ARCSWAT 2005 has been used to compare agricultural water intervention with no-intervention in a basin-scale simulation (Garg, et al., 2012). RZWQM (Cameira, et al., 2005) is a one-dimensional dual porosity model that has been employed at the field scale to assess particular Mediterranean conditions that allow macropore in-flows, while the one-dimensional SAWAH model focuses on water management and percolation losses (Wopereis, et al., 1994). However, each of these models has applicability limitations (Kohne, et al., 2009), as most describe specific water systems and require detailed pedological and hydrological information.

Water balance is the primary water movement-based method for effective quantification of water infiltration, and consequently of the potential for environmental pollution. It relies on large amounts of monitoring data and an efficient monitoring and measuring system. The water balance equation has several variables: input water quantities (irrigation, precipitation), output water quantities (evapotranspiration, outlet, lateral seepage, deep percolation), and changes in soil water storage per time period. Most current rice paddy water balance studies use daily (Garg, et al., 2009; Liu, et al., 2001; Xie and Cui, 2011) or weekly data (Yang, et al., 2012). Short-term dynamic calculations—-needed for the crack filling process—demand hourly data (Liu, et al., 2003; Mitchell and Van Genuchten, 1993).

A previous study by Sacco et al. (2012), describing the seasonal variation of soil physical properties under different water managements in the same experimental field, determined the two goals of this study: 1) to describe the infiltration dynamic over the growing season and during the different wet-dry cycles; 2) to quantify the amount of water infiltration in rice paddies under two different water managements. Infiltration rate was calculated based on direct measurements of field water balance.

2. Materials and methods

2.1. Site and climate

The experiment was carried out on the Vercelli plain (Northern Italy) at a study area located at 45°17' (lat.) and 8°25' (long.) in the western Po River basin (132 m a.s.l.). The area is characterized by a temperate, sub-continental climate that included rainy periods in spring (April and May) and autumn (September-November). The annual data during the last five years averaged a precipitation of 851 mm and a mean temperature of 13.2 ℃. The average monthly minimum relative humidity was the lowest (41%) during April and highest (75%) during January. The average monthly incoming solar radiation was highest (about 760 MJ/m^2/month) during July, and ranged from 624 to 650 MJ/m^2 during the months of May, June, and August. Groundwater levels ranged from 0.5 m to 2 m in different seasons.

Figure 1 reports the specific experimental period weather conditions (daily temperature and precipitation amounts) during 2009 and 2012. More stable temperatures and intense precipitation characterized June 2009, while 2012 was mainly characterized by low temperatures and rainfall amounts at sowing time that delayed rice growing season.

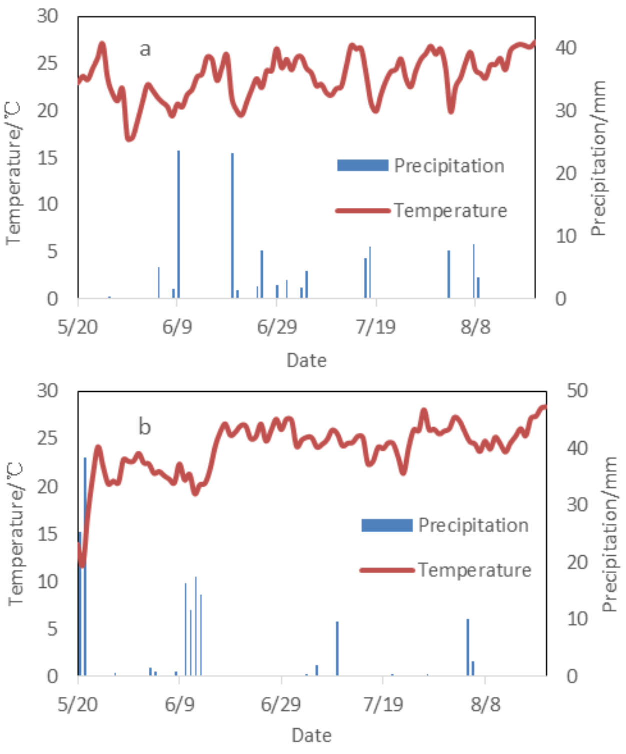

Figure 1. Daily temperatures and precipitation amounts in 2009 and 2012.

2.2. Soil characteristics

The soil was classified as Typic Endoaquept, coarse-silty, mixed, non-acidic, mesic (USDA, 1999). The soil profile, described at the beginning of the experiment, was based on a digging on one side of the field. The upper part of the soil profile revealed a ploughed first Ap horizon of 20 cm, a second Ap2 horizon of 10 cm, and a third Bwg horizon of 40 cm (IPLA, 2004). Soil texture of the second horizon was very similar to that of the first horizon, but bulk densities measured before ploughing revealed an abrupt transition in the first and second horizon increasing from 1.49 to 1.64 Mg m^{-3}. Additionally, the colour changed from 2,5Y 4/2 to GLEY 1 4/1. Based on these measurements, we concluded that the second horizon represented the plough pan.

Further characterisations of the experimental field were carried out in the different plots without distinguishing the Ap and AP2 horizons due to the shallow second layer. Main characteristics are reported in Table 1. The horizon explored by roots (0–25 cm) was typed as sandy loam texture according to the USDA texture classification. The mean bulk density of the first horizon at sowing was about 1.18 Mg m^{-3}; it varied during the growing season (Sacco, et al., 2012). The average soil organic carbon content was 9.8 g kg^{-1} dry soil.

Table 1. Soil texture, pH, and organic carbon content in CF (average values ±95% confidence intervals) and DS treatments.

		CF		DS	
Depth	cm	0-25	25-50	0-25	25-50
Sand	%	40.3±7.5	36.4±17.2	34.83	21.30
Silt	%	48.5±6.94	48.82±13.47	54.70	59.67
Clay	%	11.2±1.79	14.81±4.21	10.47	19.03
pH		6.5±0.18	7.11±0.20	6.40	7.37
C. org.	%	0.93±0.16	0.34±0.10	1.08	0.30

Note: CF: continuous flooding, DS: dry seeding and delayed flooding technique. No variability is reported for DS as only one plot was analysed.

2.3. Experimental design

In this study, water balance was analysed in six contiguous fields, each with an area of about 1840 m^2, hydraulically separated by 80 cm-wide embankments and supplied with water from the same canal. The plots and treatments were established in 2003 and are still on going.

The original set-up was created to compare different crop residue managements. Due to this, five of the six plots underwent the traditional and most used rice management in the Piemonte Region, which is continuous rice (*Oryza sativa* L.) cultivated with burnt or buried straw in the autumn/spring, ploughed and laser levelled, and submerged from pre-seeding to as long as one month before harvest, interrupted by drainages for fertilisation and weeding. As the five plots differed only in crop residue management technique, they underwent the same water management and were considered replicates named CF-1, CF-2, CF-3, CF-4, and CF-5. In the sixth plot (DS), dry seeding and delayed flooding management (submersion begun about one month later) was applied. Table 2 reports the different agricultural practices over the two years.

Table 2. Growing period and water management applied during 2009 and 2012.

	2009		2012	
Practice	CF	DS	CF	DS
Beginning first submersion	22/05	-	20/05	-
Sowing	22/05	8/05	20/05	6/05
Beginning first drainage	25/05	-	24/05	-
Beginning second submersion	6/06	-	5/06	-
Beginning second drainage	16/06	-	15/06	-
Beginning third submersion	20/06	20/06	20/06	20/06
Beginning third drainage	14/07	14/07	8/07	8/07
Beginning fourth submersion	16/07	16/07	14/07	14/07
Beginning fourth drainage	25/08	25/08	23/08	23/08
Harvest	28/09	28/09	27/09	27/09

Note: CF: continuous flooding, DS: dry seeding and delayed flooding technique. Submersion and drainage refer to the start of water management practice and not to water flooding status.

In the six plots, water balance components were determined to calculate water infiltration as a difference between water inputs and the other water outputs.

From 2009 forward, the different plot inflows, outflows, water levels, and meteorological parameters were all measured. During 2010 and 2011, data were not recorded for the entire growing season period because of inoperable instruments resulting from lightning strikes; consequently, this work utilizes 2009 and 2012 data only.

Inflows from the canal and outflows from the field were measured by Endress+Hauser Promag 10W instruments placed at the inlet and outlet of each field. Water level was measured using an Endress+Hauser Liquicap T FMI21 instrument with sensors attached to a TER AC420 data logger and powered by a 12-v lead-acid battery. Inflow and outflow measurements were recorded automatically every 10 min and water levels were registered every 30 min, which were sufficient frequencies to describe fully the situation during agricultural practice. Data were stored in the data logger and downloaded weekly.

A weather station was established in the experimental field to collect weather data for calculating evapotranspiration. The station included a thermometer, anemometer, humidity sensor, net radiometer, tipping bucket rain gauge, and wind intensity sensor. The weather sensors were attached to a data logger and data were collected hourly. The wet-dry cycle is defined as the time interval between the start of each submersion period and when the field water level is zero. Infiltration rates have been calculated only during saturation periods, when fluxes are more important. Water infiltration was not calculated during the dry periods between two submersions.

During the growing season, four wet-dry cycles were identified and named C1, C2, C3, and C4, respectively. In DS, only C3 and C4 occurred. As water takes time to submerge or to leave soil, each wet-dry cycle actually differs more than that reported by the mere date difference in Table 2; Table 3 displays the dates when soil started/ended submersion and the actual length of each of these cycles during the two years.

Table 3. Length of each wet-dry cycle.

	2009	2012
First cycle (C1)	10 days (22/05-31/05)	12 days (20/05-31/05)
Second cycle (C2)	10 days (06/06-15/06)	14 days (05/06-18/06)
Third cycle (C3)	25 days (20/06-14/07)	19 days (20/06-08/07)
Fourth cycle (C4)	47 days (16/07-31/08)	45 days (14/07-29/08)

2.4 Water balance model

Water balance in a flooded rice paddy can be described by a general mass conservation equation, in which the sum of inflow and rainfall equals the sum of outflow, evapotranspiration, change in in-field stored water, and infiltration during an interval of time. This allows infiltration—including deep percolation and lateral seepage from the rice paddy—to be estimated by the following water balance equation:

$$P + S = I + R - (Et_c + O + dW) \qquad \text{Eq. 1}$$

where P is deep percolation, S is lateral seepage, I is inflow from the irrigation network, R is rainfall, Et_c is crop evapotranspiration, O is outflow, and dW is water storage change during a certain period. Each variable is expressed in mm.

Lateral seepage was considered to be negligible as embankments were checked and properly maintained; fields were large enough for vertical flow to prevail.

Water balance was calculated both hourly and for the total period to correspond to the time from sowing to the end of the last wet-dry cycle (about one month before harvest). In the calculation of water balance over the total period, water storage differences were not considered, as water storage began the growing season and ended the last wet-dry cycle at zero. Soil water content variations were considered negligible when compared to total annual water infiltrated.

Crop reference evapotranspiration was estimated using the Penman–Monteith method (Allen, 1998). It was calculated by multiplying the reference crop evapotranspiration (ET_0) by a crop coefficient (K_c):

$$ET_c = K_c\, ET_0 \qquad \text{Eq. 2}$$

where, ET_c is crop evapotranspiration (mm/d); K_c is crop coefficient; ET_0 is reference crop evapotranspiration (mm/d)

Studies carried out by Smith et al. (1992) showed that the FAO Penman-Monteith method performs better and provides more consistent results than do other calculation methods. In this study, the FAO Penman-Monteith equation with average daily data was employed to calculate daily evapotranspiration. As infiltration rate changes during the crack filling process occur over a time scale smaller than day, hourly data were also calculated.

The crop coefficient (K_c) varies over the growing period with plant growth characteristics, cultivation, and local climatic conditions (Vu et al., 2005). In this study, standard condition K_c values were used as the rice fields were properly managed. In particular, as suggested by Allen et al. (1998), we considered three typical K_c values: initial stage crop coefficient ($\mathrm{K_{c-ini}}$), mid-season stage ($\mathrm{K_{c-mid}}$), and end-of-late season stage ($\mathrm{K_{c-end}}$). The values of K_c during crop development and the late-season stage were calculated by linear interpolation. According to recommendations in the FAO-56 method (FAO. 2002), under standard climatic condition, the study area can be defined as a sub-humid climate. As the average daytime minimum relative humidity ($\mathrm{RH_{min}}$) was 55% and having light to moderate wind speeds averaging 1.55 m/s, the adopted values of $\mathrm{K_{c-ini}}$, $\mathrm{K_{c-mid}}$, and $\mathrm{K_{c-end}}$ were 1.05, 1.2, and 0.9, respectively.

2.5 Data analysis

To investigate the effects that submerging water and wet-dry cycling have on the infiltration dynamic, two different analyses were performed.

A three-way analysis of variance (ANOVA) was applied to compare the average infiltration rate of each wet-dry cycle in each year. The analysis considered cycle effect, year effect, their interaction, and plot effect as block.

A repeated measure model was used to compare average infiltration rate during the first two days (time 1) with the rate during the second three days (time 2) for each cycle. The model included cycle, year, and plot as the main effects and time as a repeated measure.

Comparisons were made between the CF and DS water managements using confidence intervals; however, no ANOVA was performed in DS due to the lack of data during C1 and C2.

CF and DS water balance components were compared using confidence intervals once plot and year effect were extracted from the residual error used to calculate the confidence interval.

3. Results and discussion

3.1 Effects influencing the infiltration dynamic

3.1.1 Infiltration dynamic over the growing season

In this section, we describe the general dynamic of the average infiltration rate during the growing season, as calculated from daily measures of the different wet-dry cycles. Soil tillage and water management directly affect the hydraulic soil properties of rice paddies. In fact, the continuous presence of submerging water destroys porosity and reduces water percolation, even where puddling was not applied (Sander and Gerke, 2007). The results, shown in Table 4, indicate that the cycle and the year are the main factors that influence the average daily infiltration rate of each wet-dry cycle.

Table 4. Significance analysis of the average daily infiltration of the total wet-dry cycle

Source	Sig.
Cycle	0.000
Year	0.010
Year * Cycle	0.003
Plot	n.s.

However, even after acknowledging that a significant interaction exists between Year and Cycle, our study results showed that in CF, the average daily infiltration rate of each cycle decreased between C1 and C2 (Figure 2), remained constant between the C2 and C3, and then increased after

C3 to its maximum value attained the end of the growing season. Between-year differences are probably attributable to different meteorological occurrences and soil behaviour. Either way, both years demonstrate the general dynamic described above.

Data calculated in DS for C3 and C4 also confirm the same trend during the two years, although the magnitude of the trend is amplified in 2012 with respect to 2009.

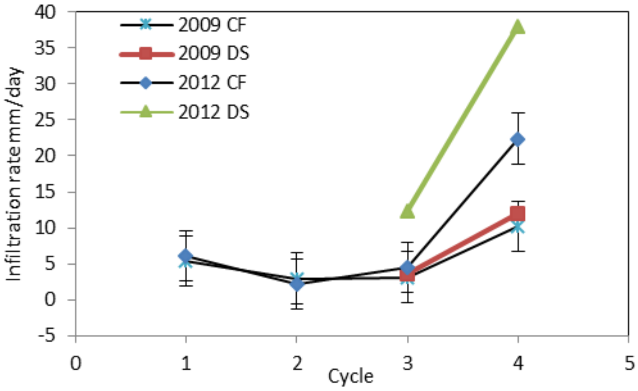

Figure 2. The trend of average daily infiltration rates for each wet-dry cycle in CF (with 95% confidence interval) and in DS. CF: continuous flooding, DS: dry seeding and delayed flooding technique.

The study of Sacco et al. (2012), conducted at this same experimental site, showed that macro porosity and near-saturated hydraulic conductivity decreased during the beginning of the growing season, and then increased later. The bulk density showed the opposite trend. As expected, soil properties influenced water infiltration to a great extent. The results reported here confirmed that the general infiltration rate dynamic trended like macro porosity and near-saturated hydraulic conductivity.

The daily infiltration rate increase observed in the last cycle may be caused by preferential flow, which occurs through the interconnected cracks, inter-aggregate pores, earthworm burrows, and crop root development canals (Cameira, et al., 2003; Lennartz, et al., 2009; Sidle, 1998; Zehe and Fluhler, 2001). Cracks are evident at the soil surface during the period between two successive floods, but during submersion water creates mud and it is not possible to verify the presence of cracks. Moreover, during submersion the hydraulic property of cracks may change as the surrounding soil matrix swells due to its clay content and mineral composition (Zhang, et al., 2013). Indeed, cracks may not fully disappear, even under wet conditions (Gerke, 2006). In the study area considered, the soil is not typically puddled. Indeed, studies have found repeated puddling increases sealing and decreases mechanical top soil-swelling (Lennartz, et al., 2009), and that macropore and crack network persistence can lead to preferential flow, even under flooding conditions (Sander and Gerke, 2007).

A similar phenomenon can occur in the crack networks below the ploughing pan in paddy rice fields, which may persist during ponding to form preferential flow paths. The ploughing pan is the most efficient layer to stop or reduce the rate of rice paddy infiltration by controlling vertical water loss to the subsoil (Zhang, et al., 2013). Experiments have demonstrated that the infiltration rate can increase by as much as 3.7 times if the ploughing pan is removed through digging (Chen and Liu, 2002). The ploughing pan is quite effective at reducing water infiltration after soil ploughing and laser levelling, but during the growing season it faces the effects of mineral shrinking and swelling, interconnected crack formation, earthworm burrowing, and crop root canaling that can all impact its hydraulic characteristics greatly.

3.1.2 Infiltration dynamic in each wet-dry cycle

The variation in the infiltration rate during the first five days of each cycle was studied by comparing the average daily infiltration rate during first two days (time 1) with the average daily infiltration rate of the second three days (time 2) of each wet-dry cycle in both years. Data were averaged over a two- or three-day period to remove short-term variability. The length of the two periods was chosen based on the infiltration rate variation that is greater during the first period and smaller during the second period.

Table 5 reports the results of ANOVA. In the between subject analysis, Cycle, Year, and their interaction (Cycle x Year) all resulted as significant. Moreover, in the within subject analysis, Time alone was significant in the interaction with all other sources, which included the three way interaction of Time*Cycle*Year.

Table 5. Significance analysis of the infiltration rate variation in each cycle.

Source	**Sig.**
Between subject analysis	
Cycle	0.00
Year	0.00
Cycle * Year	0.01
Plot	n.s.
Within subject analysis	
Time	0.00
Time * Cycle	0.00
Time * Year	0.00
Time * Cycle * Year	0.00

Although the significance of the three-way interaction denotes a different behaviour for Time effects in Cycle, in Year, and in their interaction, some information can be derived from the result. As reported in Figure 3, the average daily infiltration rate of the first two days decreased from the first cycle (C1) to the second cycle (C2), and then increased during the last cycle in both years. This trend is similar to the average daily infiltration rate trend for the total wet-dry cycle as discussed in sub-section 4.1.1. However, in C1, the average daily infiltration rate in time 2 decreased dramatically relative to time 1. During the three cycles that followed, the amplitude of this reduction fell to lower levels, or in some cases, to a constant average infiltration rate during times 1 and 2. In DS, C1 and C2 did not occur. In this water management, the soil was not submerged before C3, which allows comparison of C3 in DS with C1 in CF. Figure 3 reported data referring to DS water management confirm this expectation in both years. The general trend of the infiltration rate reduction between times 1 and 2 in CF between C1 and C2 was also noted in DS between C3 and C4.

In general, after a dry period, soil water content is less than saturated and some cracks and macropores are dry. As re-wetting begins, a lot of water goes to filling them. Tan et al. (2013) found that cumulative percolation during the first five days after submersion began in non-constant flooding is significantly greater than that in continuous flooding. In the first cycle of our study, the daily infiltration rate decreased dramatically after two days in both 2009 and 2012. Prior to C1 the soil was tilled, but never submerged, making it as mainly built of juxtaposed aggregates. Then, at the beginning of C1 when the soil was wetted, its structure was destroyed by the submerging water; consequently, the infiltration rate was reduced. It has been observed that in paddy soil macropores and fractures formed by tillage before the first submersion maintain a high infiltration rate only temporarily, which then decreases to even lower levels than that measured on non-cracked soil derived from swelling that closes the fractures (Liu, et al., 2003). The same process can be found in DS at C3 as this treatment was not previously submerged and then the soil was dried.

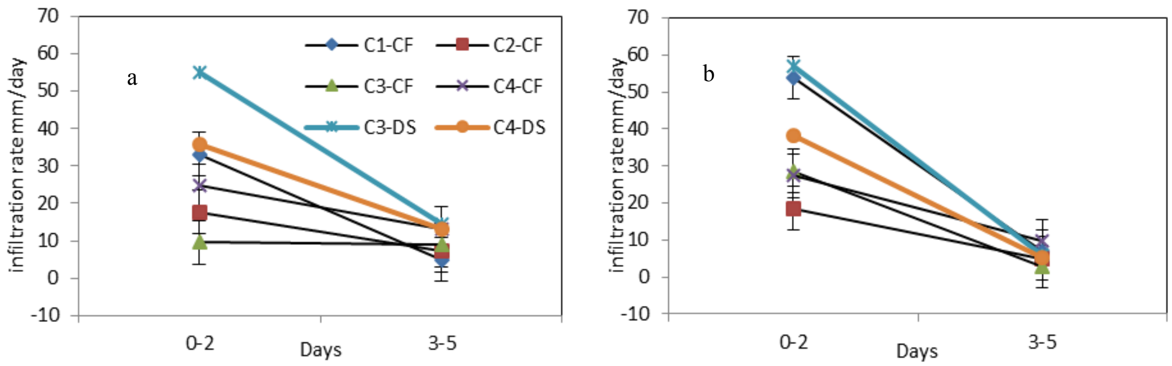

Figure 3. Dynamic of average daily infiltration rate in CF (with 95% confidence interval) and DS during days 0-2 and 3-5. CF: continuous flooding, DS: dry seeding and delayed flooding technique. C1, C2, C3, C4 are respectively Cycle 1, 2, 3, and 4. a) 2009; b) 2012.

To improve our understanding of the development of the infiltration rate at the start of re-wetting, the cumulative infiltration depth was calculated during the first 40 hours as shown in Figure 4. This data represents the cumulated infiltration quantity obtained by summing hourly water balance calculations. It is known from the literature that the initial soil intake of water in the first five hours is about two-thirds of the total intake (Mitchell and Van Genuchten, 1993).

Figure 4 highlights a general trend describing a logarithmic function reaching different cumulative depths, which are dependent on the infiltration rate. When year-specific differences are ignored, water infiltration in CF during the first 40 hours amounted to, on average, 79 mm, 35 mm, 42 mm, and 59 in C1, C2, C3, and C4, respectively. In DS the amount of water infiltrating during the first 40 hours averaged 112 mm and 74 mm for C3 and C4, respectively.

The higher infiltration depths seen in C1 (CF) and in C3 (DS) demonstrated the short but high infiltration rate previously described in Figure 3 resulting from the first submersion in these treatments.

During the last cycle in CF, the cumulated infiltration depth is relatively higher than in C2 for the same treatment. The comparison with C3 is year-specific as 2009 and 2012 showed different behaviours. This increase is mainly affected by soil structure change during the lengthy flooding time, alternated wetting and drying, and root growth. It also confirms that cracks formed during drying periods and root canals fail to disappear under flooding conditions. Cracks developed during the soil drying period did not completely close upon rewetting, resulting in high loss of water to percolation (Zhang et al. 2014; Cabangon and Tuong, 2000).

Crack filling usually occurs within the first 20 hours, during which the infiltration rate is extremely high and might allow large quantities of nutrients and pesticides to leach into the local groundwater.

Considering the amount of water that infiltrated during the first 40 hours of the different wet-dry cycles in CF and DS, the highest potential risk of groundwater pollution was during C1 and C4 (CF) and during C3 and C4 (DS). Also worthy of note is that the infiltration depth measured in C4 (DS) was greater than that measured from C2 to C4 (CF). As fertilisers and herbicides are typically distributed before C1 and C4, and fertiliser alone is distributed before C3, fertiliser and pesticide applications should be carefully timed, so that the soil is re-wetted prior to chemical spreading and maintain a closed outlet closed for some days.

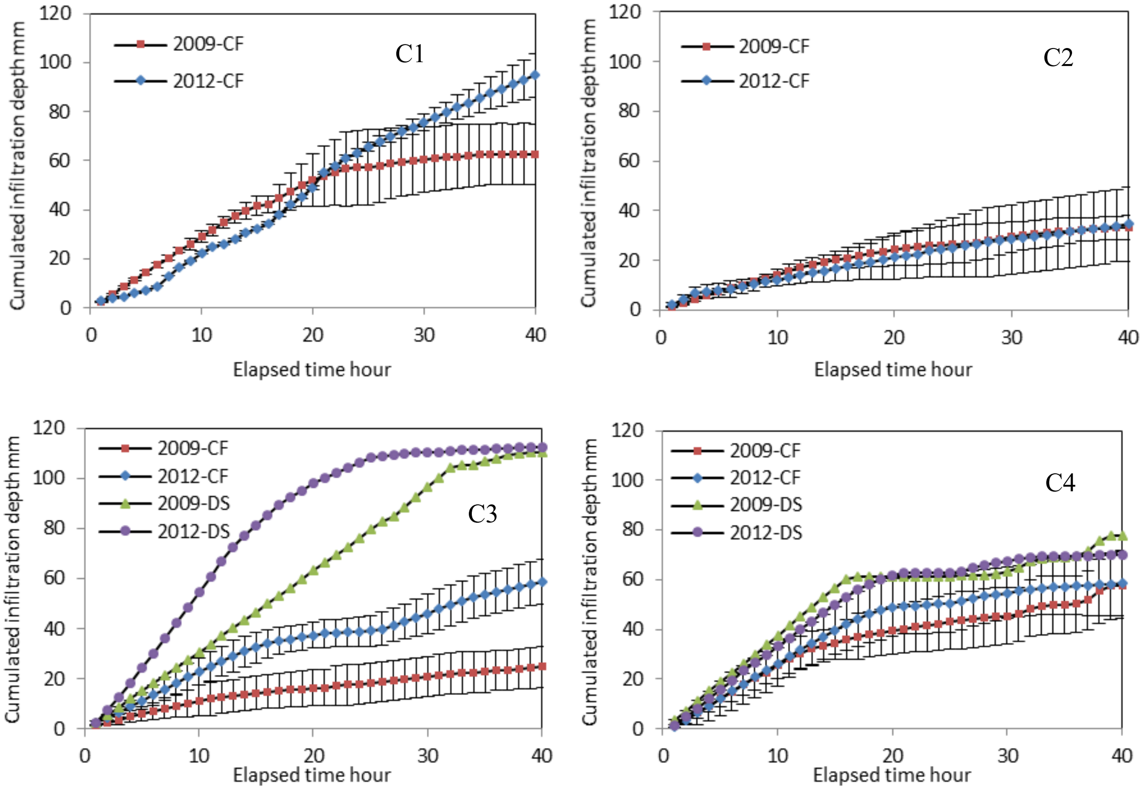

Figure 4. Infiltration rate trends in first 40 hours after irrigation in four wet-dry cycles

3.2 Water infiltration quantification

Table 6 reports the total water infiltrated in 2009 and 2012 from the six plots, five under CF and one under DS water management, as well as the components of balance (irrigation, rainfall, outlet, evapotranspiration, and infiltration difference). The CF plot water levels averaged 68±3.7 mm (95% confidence interval (CI)) with a 6% coefficient of variation (CV), which is a low value given that the variable is fully controllable.

Total cumulative inlet water (irrigation) ranged between 2197 mm and 2700 mm in 2009, and between 2481mm and 3130 mm in 2012; the overall total averaged 2596 mm. In DS, despite an irrigation start one month later than in CF plots, the irrigation water total was within the 95% CI of the CF water management total. The reason for this probably relates to the large amount of water needed to completely fill the paddy field from the water table to the soil surface that represents the main water consumption, while the following water use, applied to maintain an appropriate water level is much lower than this amount. The relatively low CV indicated that the irrigation supply was quite stable among the different plots, which is not surprising given it can be well controlled by the farmer. Rainfall during these two years contributed only 5% of the input water total.

After taking output into account, 47% of the water flowing into the field leaves via the outlet although this measure is less precise and less controllable than the inlet. Therefore, the CV of this measurement is higher (20%).

The hourly infiltration rate across all CF plots and irrigation periods averaged 0.36 ± 0.14 mm/h (95% CI) had the highest CV (37%), as it cumulated all the uncertainty of the other balance components. The average DS infiltration rate was within the 95% CI of CF measures.

Table 6. Water balance components.

Year	Treatment	Average water level(mm)	Inlet(mm)	Rainfall (mm)	Total input (mm)	Outlet(mm)	ET(mm)	Total output(mm)	Calculated infiltration (mm)	Calculated infiltration rate(mm/h)
2009	CF-1	67	2275	114	2389	1343	516	1859	529	0.21
	CF-2	74	2453	114	2567	1614	516	2130	437	0.17
	CF-3	71	2197	114	2311	1392	516	1908	389	0.15
	CF-4	60	2700	114	2815	904	516	1420	1395	0.56
	CF-5	75	2484	114	2598	1077	516	1593	971	0.39
2012	CF-1	61	3130	155	3285	1951	565	2516	680	0.29
	CF-2	79	2736	155	2892	737	565	1302	1456	0.63
	CF-3	68	2481	155	2636	1165	565	1730	802	0.34
	CF-4	56	2553	155	2709	1196	565	1761	948	0.41
	CF-5	63	2954	155	3109	1335	565	1901	1070	0.46
	Average	**68**	**2596**	**135**	**2731**	**1271**	**541**	**1812**	**868**	**0.36**
	LL	64	2371		2506	912		1452	537	0.23
	UL	71	2821		2956	1631		2172	1199	0.5
	CV	6%	9%		8%	28%		20%	38%	37%
2009	DS	55	2334	114	2448	1297	516	1813	618	0.25
2012	DS	24	2723	155	2878	556	565	1079	1728	0.74
	Average	**40**	**2528**		**2663**	**926**	**541**	**1446**	**1173**	**0.49**

Analysis of the CF and DS water managements suggests that it is inefficient to delay irrigation one month to reduce rice paddy irrigation. In this study, no water savings was realized by employing the dry seeding and delayed flooding (DS) water management technique. While this rice paddy management presents many agronomical advantages mainly related to soil trafficability, crop health and reduced risk of lodging during the first part of the growing cycle, it does not represent a potential solution for future water saving in rice paddy areas.

CONCLUSION

A field-scale study was carried out to study the infiltration rate dynamic throughout the growing season and during each wet-dry cycle in rice paddies and quantify the infiltration that takes place under different water managements (continuous flooding (CF) and delayed submersion (DS)).

The average daily infiltration rate decreased between the first and second cycles, increased after the third cycle, and reached its maximum value at the end of growing season. Water infiltrated dramatically during the first 40 hours of each wet-dry cycle and particularly at the first and fourth wetting in DS, which were the highest potential groundwater pollution risk periods. As fertilisers and herbicides are typically distributed before C1 and C4, and fertiliser alone is distributed before C3, fertiliser and pesticide applications should be carefully timed, so that reduce the chemical spreading.

Also, compared the total amount of irrigation in DS and in CF, no water savings was realized by DS water management technique, as the total water used in the two treatments was identical.

From the results we can see that in rice paddies, infiltration rate dynamic study is essential to water resource management and water quality management.

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