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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 h 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.

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, 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., 2002), 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

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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 et al., 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 °C. 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.

Fig. 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.

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 Mg m^{-3} 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.

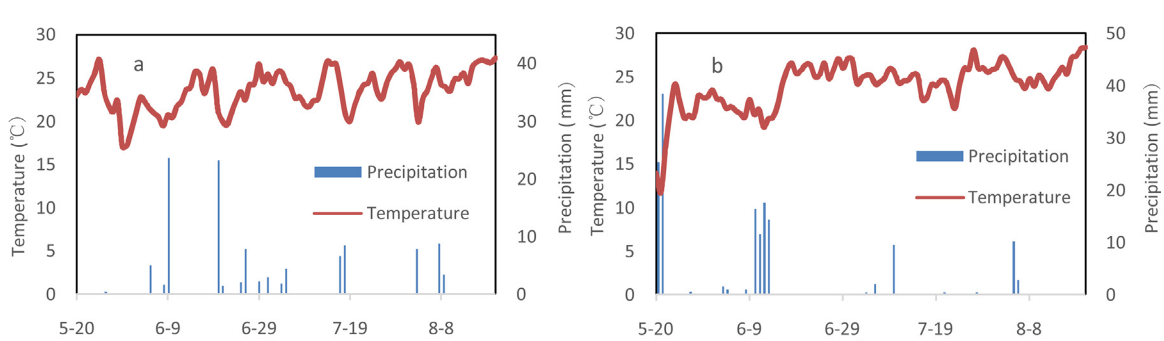

Fig. 1. Daily temperatures and precipitation amounts in 2009 and 2012.