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# Measurement and modeling of soil water regime in a lowland paddy field showing preferential transport

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ABSTRACT

Paddy is commonly grown under flooded or submerged condition in which substantial amount of water is lost by different processes. Puddling is traditionally done to reduce water loss from lowland rice fields. Since the very step of puddling, rice root zone undergoes structural changes leading to the formation of a layered profile having a hydraulically less-conductive plow sole below the root zone. However, studies have shown that soil cracking and the presence of preferential flow paths in puddle fields defeat this purpose. Description of soil water regime in such a dynamic soil requires an *in situ* measurement method for soil hydraulic properties. A field experiment was conducted in twelve 30 $m^2$ plots during the rainy seasons (June to October) of 2004 and 2005 to evaluate a suitable method for estimating soil hydraulic properties of lowland paddy soil. Results showed that piezometric (pressure) heads installed in different soil layers responded to the drying and wetting cycles typically followed in transplanted rice and are observed as a part of monsoon climate in eastern India. The Marquardt–Levenberg algorithm built in the HYDRUS-1D simulation environment was used to inversely estimate soil hydraulic parameters. Estimated parameters revealed larger hydraulic conductivity for the compacted plow sole than those published in literature, which may have resulted from alternate wetting and drying typically observed under monsoon climate and earthworm burrows observed in our experimental field. Results from simulation studies suggest that both the single- and dual-porosity models could simulate water flow considerably well in lowland paddy field although the latter described pressure head time series data slightly better in about 50% of simulations. Similar performance of the single- vs. dual-porosity model may have resulted from estimating a seasonally mean soil hydraulic properties which include the effect of both preferential flow and matrix flow as the specific soil and boundary conditions prevailed. While water may have preferentially transported through the macropores during the wetting cycles in a near-saturated soil, it would have dominantly moved through soil matrix during the drying cycles. This study shows that simple piezometers may be combined with a simulation model to estimate hydraulic properties of different soil layers in a lowland paddy field.

## 1. Introduction

In India, paddy (*Oryza sativa*) is grown over an area of 43 million ha with an annual production of 124 million tons (IRRI, 2004) and average productivity is only 2–3.5 tons/ha (Ladha et al., 2000). Two major management constraints in lowland paddy production systems are poor use efficiencies for water and nitrogen (N). The water use efficiency (WUE) for transplanted rice is only 20–30% (Walker and Rushton, 1984; Tuong and Bhuiyan, 1999). Similarly, N use efficiency (NUE) is 20–40% (Vlek et al., 1980; De Datta, 1987; Raun and Johnson, 1999). Generally, a substantial amount of applied water is lost during land preparation of soil from bypass flow through cracks (Cabangon and Tuong, 2000), by deep percolation from root zone, seepage through bunds (Janssen and Lennartz, 2007, 2008), and evapotranspiration (Hardjoamidjojo, 1992; Sharma and De Datta, 1992; Humphreys et al., 1992). Wopereis et al. (1994) estimated cumulative seepage and percolation (SP) losses during a crop cycle for a well-puddled paddy field alone to be as high as 350 cm. With such large quantity of water loss, the leaching of nitrogenous fertilizers may be a major reason for poor NUE in lowland paddy. Therefore, efforts to develop efficient water management techniques may improve both WUE and NUE in lowland paddy.

Puddling is traditionally done to reduce percolation losses from lowland paddy fields. Typically, it promotes the formation of a layered profile consisting of a slurry-like puddled top soil layer, a

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hydraulically less-conductive middle layer (also, called plow sole), and a less compact subsoil layer below the plow sole (Tuong et al., 1994). Hydraulic properties of plow sole dominantly control the water regime of puddled paddy fields (Wopereis et al., 1994; Tuong et al., 1994; Chen and Liu, 2002) often forming an unsaturated zone below the plow sole (Takagi, 1960; Wopereis et al., 1992; Tournebize et al., 2006). In paddy fields of eastern India, alternate wetting (ponding) and drying (drainage) is a natural phenomenon because of the occurrence of frequent dryspells and intense rainfall as a part of monsoon climate during the Kharif (July to October) season (Panigrahi et al., 2001). Wetting and drying conditions result in unsaturated soil water regime in paddy soils. Moreover, typical water-saving schemes in paddy production systems involve alternate wetting and drying conditions in lowland paddy soils (Tabbal et al., 2002; Belder et al., 2007) leading to unsaturated soil water regimes. Recently, Yang et al. (2007) showed 7–11% increase in yield with up to 38% reduction in irrigation water by maintaining critical soil water potential (SWP) at −15 kPa. Understanding of soil water movement in lowland paddy soils is an important step to effectively maintain a critical SWP (unsaturated soil water regime) in paddy root zone.

The structural changes in rice root zone since the very first step of puddling yield a dynamic and transient rice rhizosphere. Moreover, rice soils are known to crack (Tournebize et al., 2006) under drying and wetting cycles leading to the formation of preferential flow paths (Janssen and Lennartz, 2007, 2008, 2009). In eastern Indian paddy soils, profuse earthworm casts are a common feature, which are known to entail preferential transport. In view of the poor water and nitrogen efficiency in rice production system, the dynamic nature of paddy rhizosphere have drawn renewed interest (Janssen and Lennartz, 2007, 2008, 2009). During the last decade, a few field-scale water flow studies have shown that the Richards equation may be applied to describe water flow in puddled paddy fields (Wopereis et al., 1992, 1994; Tuong et al., 1994; Liu et al., 2001; Chen et al., 2002; Tournebize et al., 2006). Solution to Richards equation requires soil hydraulic properties in addition to appropriate boundary and initial conditions. In general, soil hydraulic properties vary both in space and in time; the variation is large under field conditions. Such variations pose a challenge for devising a robust measurement method for soil hydraulic properties for the field-scale. Soil layering in lowland paddy soils poses added difficulty in obtaining these properties. Specifically, an *in situ* measurement method for hydraulic properties for different soil layers in a puddled paddy field has not been reported. Thus, the objective of this study was to estimate soil hydraulic properties and model water flow in the layered lowland paddy fields. The Marquardt–Levenberg algorithm built in the HYDRUS-1D simulation environment (Simunek et al., 1999) was used for modeling the experimental data.

## 2. Materials and methods

### *2.1. Field experiment*

The field experiment consisted of growing paddy (var. IR-36, duration 110 days) during the Kharif season of 2004 and 2005 in twelve 6 m × 5 m plots (Fig. 1) at the experimental farm of Agricultural and Food Engineering Department, Indian Institute of Technology, Kharagpur (22°19′N, 87°19′E), India. Mean annual rainfall at this site ranges from 1400 to 1600 mm with about 70% distributed over the months of July to October. Soils in this region are lateritic (Haplustalf) with the presence of a discontinuous clay pan below 80 cm depth. Table 1 shows different physical and chemical properties of soil layers for this site.

Twenty days old paddy seedlings were transplanted after the top soil (0–15 cm) was puddled. Three nitrogen treatments (T1: 80; T2: 160; and T3: 240 kg N/ha in the form of urea) with four replications were laid out in a completely randomized design. Data pertaining to the nitrogen transport in this field is reported elsewhere (Garg, 2007). Recommended dose of phosphate (30 kg/ha) and potash (40 kg/ha) was applied during puddling. About 3.3 cm of ponded water (equivalent to 1000 L of water per plot) was maintained during first 10 weeks after transplanting. Efforts were made to maintain a continuous ponded condition during 2005 by frequently irrigating the field as compared to the 2004 experiment. Soil water contents were measured in surface soils (0–5 cm depth) collected from a few plots when the plots were unsaturated following zero ponding conditions.

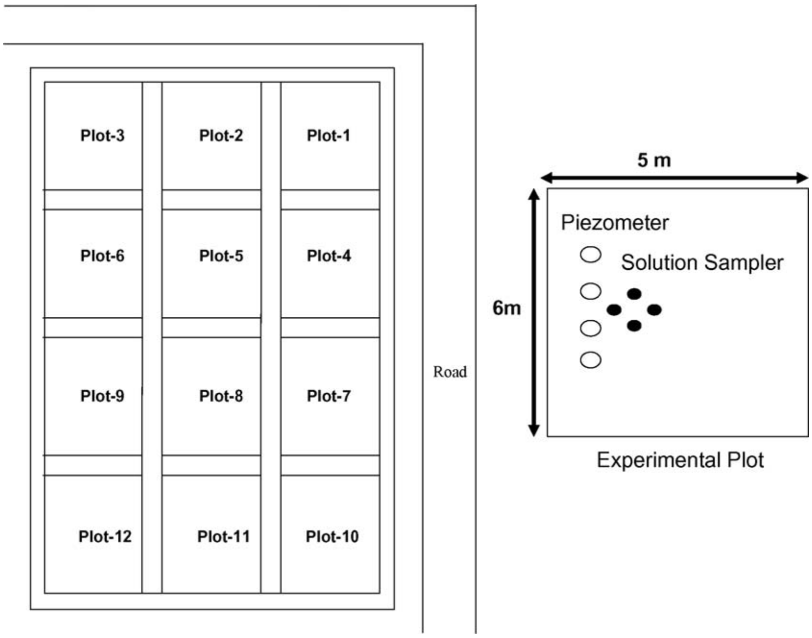

**Fig. 1.** Schematic of the field layout with sampler locations shown in the schematic for the experimental plot. Closed and open circles show the location of solution samplers and piezometers, respectively.