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Seasonal variation of soil physical properties under different water managements in irrigated rice

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ABSTRACT

While soil porosity and soil hydrological properties are key characteristics that define different soil types, they are influenced by many factors: land use, tillage management, and agricultural practices such as irrigation. As expected, water management impacts the physical properties of soil in irrigated rice significantly; however, the importance of seasonal variation on those soil properties requires further consideration, especially given the period of continuous submersion. In this paper, the different soil physical properties have been studied with two goals in mind: (1) to compare the bulk densities, cumulative pore size distribution curves, and near-saturated hydraulic conductivity values associated with seasonal variation induced by submerging water or rainfall on irrigated rice cultivated under two different water managements and in one rain-fed crop, and (2) to describe and parameterize the relationship that links near-saturated hydraulic conductivity to soil porosity in a generic semi-empirical model independent of treatment differences and seasonal variability.

The experiment was conducted in the Piedmont Region (NW Italy) in sandy loam soil on three contiguous fields cultivated as follows: (i) continuous rice in submersion, (ii) continuous rice seeded in dry soil submerged one month after the first field, and (iii) maize in rotation with rice (rain-fed treatment). The physical properties of the soil were measured five times over the year at depths of 0–12 cm and 12–25 cm.

Results showed a progressive compaction of the soil and a consequent reduction of the near-saturated hydraulic conductivity due to submersion. Macro- and meso-porosity decreased while micro-porosity increased. At the end of submersion, new large porosity was created and the situation reverted to that noted at the start of the year. The non-submerged field showed a different behaviour; in the absence of submersion, bulk density reduced as a result of rainfall but the effect on the different classes of pores was reversed.

Finally, a new semi-empirical model is presented that describes near-saturated hydraulic conductivity as a function of soil porosity.

1. Introduction

The relationship between soil physical properties and soil structure and porosity has been widely explained by Kutilek (2004). The author classified soil pores according to their hydrological functionality: (i) submicroscopic pores are considered non-active; (ii) micro-pores (capillary pores) are those where the unsaturated flow of water occurs; (iii) macro-pores (non-capillary pores) are those where capillary menisci are not formed across the pore and water flow is driven by gravity alone. Other authors have introduced the concept of meso-porosity (Luxmoore, 1981) as pores having an intermediate functionality between macro- and micro-porosity.

Other than hydrology, soil porosity influences biogeochemical processes and soil fertility. For example, pore size distribution, together with pore shape and connectivity, influences the transport of dissolved and non-dissolved chemicals and gases. It also acts upon plant rooting and on the conditions for the life of all soil biota (Kutilek et al., 2006). Furthermore, it helps explain the dynamics of soil C and N cycles (Juma, 1993) and is positively correlated with root growth and soil enzyme activity (Pagliai and De Nobili, 1993). Clearly its description is of primary import in agricultural systems.

Soil porosity can be described using direct methods based on microscopic techniques and image analyses (Pagliai and Vignozzi, 2002) or it can be described functionally using indirect methods

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based on the measurement of soil physical properties. A functional description of porosity requires the estimation of total soil porosity by pairing bulk densities with particle densities, the distribution of pore size in the soil by utilizing the water retention curve, and the identification of those soil pores that are highly active in water and solute transmission by measuring the near-saturated hydraulic conductivity (Ankeny et al., 1991).

Soil porosity and soil hydrological properties characterize the different types of soils, but are also largely influenced by land use (Bormann and Klaassen, 2008), tillage management (Moret and Arrùe, 2007a), and other agricultural practices. Moreover, they change over time due to anthropic soil perturbation and environmental forces. For example, as reported by Cameira et al. (2003) in a maize cultivation experiment, irrigation affected the macro-porosity and meso-porosity of the ploughed layer as evidenced by a decrease of 65% and 50%, respectively. This was attributed to the breakdown of fragile pores created by tillage. Furthermore, in the same experiment, seven irrigation events were found to effect a continuous reduction in macro-porosity until harvest when it increased, probably due to root development.

Many have described the effect of wet–dry cycles on soil porosity and consequently, on soil physical properties (Petersen et al., 2004; Schwartz et al., 2003). Additionally, many have focused on describing the soil physical property dynamics of irrigated rice under different puddling intensities and depths compared to unpuddled fields (Kukal and Aggarwal, 2002; Mohanty et al., 2004). They have demonstrated that the continuous presence of submerging water destroys porosity and reduces water percolation in treatments where puddling is not applied. However, description of the effect of submerging water on different soil physical properties as opposed to rainfall on rain-fed crops remains unexplored.

The description of the dynamics of the different soil hydrological properties can be simplified by the fact that some of them vary together. In particular, authors have related the near-saturated hydraulic conductivity to the amount of pores hydraulically active (Kozeny, 1927; Carman, 1937, 1956; Aimrun et al., 2004). Consequently, the near-saturated hydraulic conductivity dynamic – a time consuming measurement – can be described using other easier-to-measure variables, such as the dynamic of total soil porosity.

The different soil physical properties considered in this paper have been studied with two goals: (1) to compare the bulk densities, cumulative pore size distribution curves, and near-saturated hydraulic conductivity values associated with seasonal variation induced by submerging water or rainfall on irrigated rice cultivated under two different water regimens and in one rain-fed crop, and (2) to describe and parameterize the relationship that links near-saturated hydraulic conductivity to soil porosity in a generic semi-empirical model independent of treatment differences and seasonal variability.

2. Materials and methods

The experiment was carried out in 2005 in the Piedmont Region (NW Italy, lat. 45°17′, long. 8°25′) in the widest European paddy area on a Typic Endoaquept, coarse-silty, mixed, non-acidic, mesic soil (USDA, 1977). The explored horizon (0–25 cm) was classified as sandy loam according to USDA texture classification. The average soil organic carbon content was 9.8 g kg^{-1} dry soil.

We analysed the physical properties of the soil in three contiguous fields totalling about 1840 m^2, hydraulically separated by 80 cm large embankments, and supplied with water derived from the same channel.

The three fields differed in that each underwent a unique water management described in Fig. 1. The first management (M1) was based on continuous rice (*Oryza sativa* L.) submerged from before seeding up to one month before harvest with two drainages of about five days each; it represented the traditional management of the area. In the second (M2), rice was seeded in dry soil and irrigation was delayed for one month later than in the M1 field. The third (M3) field was cultivated with maize (*Zea mays* L.) after two years of continuous rice; it served as the experimental control as it never received irrigation during the studied year.

All three fields were ploughed in spring with a moldboard plough and laser levelled. The seedbeds were prepared using a rotovator. Additionally, the maize crop was weeded and ridged two months after sowing. Although puddling is a common practice in

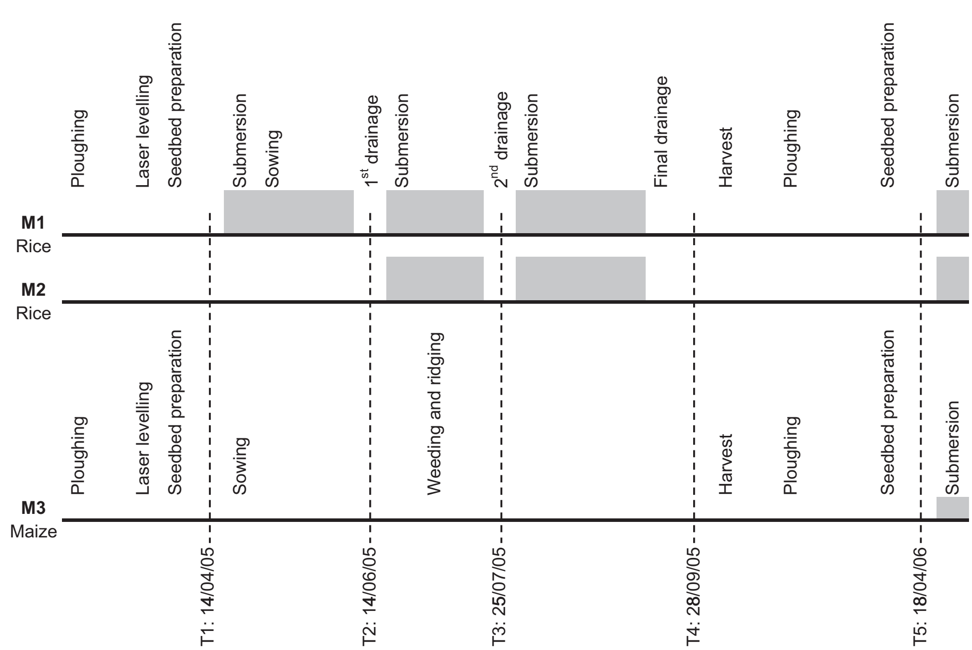

Fig. 1. Samplings and managements of the three fields in the experiment.