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Soil solution chemical attributes, rice response and water use efficiency under different flood irrigation management methods

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ABSTRACT

The water availability is the main limiting factor of global rice production under flood irrigation. In this context, water suppression during the rice growing cycle (intermittent irrigation) arises as an alternative to traditional continuous irrigation. However, the intermittent irrigation may affect the dynamics of soil solution chemical attributes, the water use and the rice yield. Thus, our study aims to evaluate the electrochemical characteristics and nutrient availability in soil solution during the growing cycle, the plant response and the water use efficiency of irrigated rice under different flood irrigation management methods. For this, a field experiment was conducted in Southern Brazil, with three treatments: 1) continuous irrigation; 2) one water suppression (between V6–V8); and 3) two water suppressions (between V6–V8 and V8–V10). Regarding soil solution electrochemistry, the pH and redox potential (E_H) were affected by the water suppression, increasing and decreasing due to soil reoxidation, respectively. The electrical conductivity (EC) decreased during the rice growing cycle, accompanying the plant development. The nutrients (except the potassium) were affected by water suppression, diminishing their availability. However, when the water layer was reestablished, there were no differences on soil solution electrochemistry among the irrigation methods. Regarding rice response, no differences were observed and the amounts produced were, in average, 9.9 and 13.4 Mg ha^{-1} of grains and shoot dry matter, respectively. The same occurred for the water amount utilized and water use efficiency (WUE) and the values observed were, in average, 9094 m^3 ha^{-1} and 1.1 kg m^{-3}, respectively. More studies regarding different flood irrigation management methods are necessary to encourage the adoption of intermittent irrigation by rice farmers of Southern Brazil and increase the sustainability of rice production.

1. Introduction

The production area of irrigated rice is determined in many regions of the world by the water amount available. This same scenario occurs in Southern Brazil, where the largest producer state is Rio Grande do Sul, being responsible for 67.5% of Brazilian rice production (CONAB, 2013). Approximately 20% of its total area is characterized as lowlands (paddy environment), where rice cropping is performed. However, only 1/3 of this area is effectively cropped with irrigated rice, mainly due to limiting water availability (Pinto et al., 2004). The irrigation system traditionally used is the flood irrigation, maintaining a continuous water layer above the soil during 80–100 days. The water amount utilized in this system ranges between 8000 and 10000 m^3 ha^{-1} and, in extreme conditions, the water requirement can surpass 15000 m^3 ha^{-1} (SOSBAI, 2014). Thus, due to rainfall distribution and the water sources management, wide areas are affected by water shortage during the rice growing cycle, which normally occurred in the reproductive stage (the most sensitive to water deficit) (Yoshida, 1981). The intermittent irrigation is being used as an alternative in drought years, as those affected by *La Niña* phenomenon. This method consists in alternate cycles of irrigation and water suppression, diminishing the irrigation frequency and the

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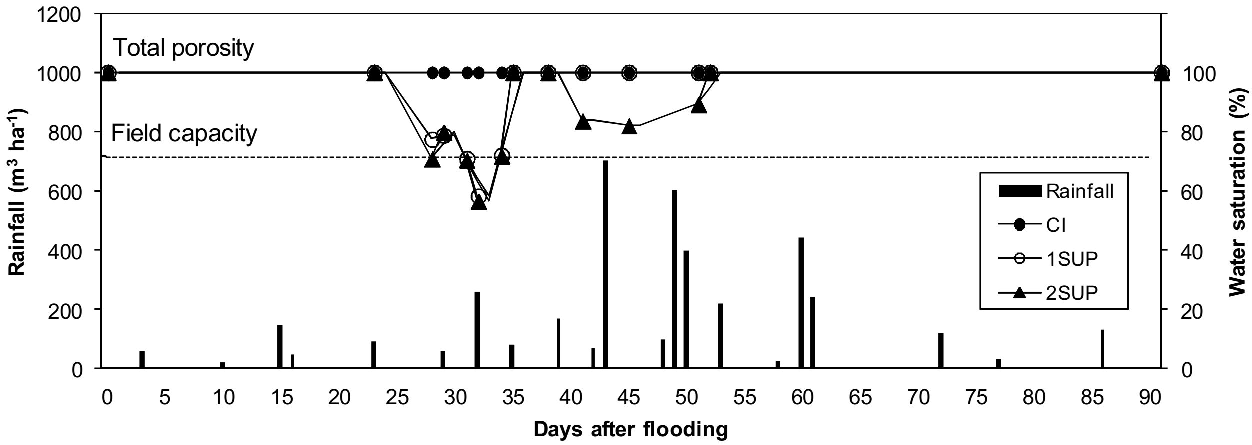

Fig. 1. Volumetric soil moisture during the irrigated rice cycle under different flood irrigation management methods (CI = continuous irrigation; 1SUP = water suppression between V6–V8; 2SUP = water suppression between V6–V8 and V8–V10) in Southern Brazil. The vertical bars indicate rainfall occurred in the period.

total amount of water utilized between 28 and 42%, preserving the water sources and labor force (Patel et al., 2010; Ye et al., 2013).

The intermittent irrigation was already adopted many years ago in several Asian countries, with a wide range of periods, duration and frequency of occurrence (Bouman and Tuong, 2001). This management presents many advantages, such as control of insects that spread diseases, reduction of Fe^{2+} contents in soil solution that cause toxicity to plants (Becker and Asch, 2005; Scivittaro and Gomes, 2007), increase of C sequestration by inhibiting residue decomposition (Yao et al., 2011), increase of plant root biomass (Buresh et al., 2008; Ye et al., 2013) and increase of water use efficiency with no impacts in grain yield (Bouman and Tuong, 2001; Belder et al., 2004; Cabangon et al., 2004; Ye et al., 2013; Shao et al., 2014). Furthermore, the intermittent irrigation decreases water losses due to surface runoff and, as a consequence, the movement of active ingredients of pesticides (Mezzomo, 2009; Ye et al., 2013), decreases the nutrient losses as phosphorus, nitrogen (potential environmental polluters) and potassium (Liang et al., 2013) and mitigates the greenhouse gases emission (Moterle et al., 2013).

In the irrigated rice cropping performed with continuous flood irrigation, the molecular oxygen is quickly exhausted after the soil submersion and the inorganic elements previously oxidized start to be preferred electron acceptors, being reduced (Camargo et al., 1999). Thus, the environment becomes hypoxic and the E_H decreases (Ponnamperuma, 1977), indicating a lower electrons activity involved in redox system (Sousa et al., 2009). In these reactions, there is protons consumption and the pH increases (Scivittaro and Machado, 2004), contributing to the increase of soil cation exchange capacity (CEC). This increase favors the rice cropping, since the ideal pH for rice is 6.6, where release reactions of N and P are favored; the Cu, Fe, Mn and Zn contents are adequate; and the potentially toxic elements present contents below the phytotoxicity limits (Sousa et al., 2010). Furthermore, in reduction reactions occur the ion solubilization and mobilization for the soil solution and consequent increase in EC values (De Datta, 1981), providing higher nutrient contents for plants, particularly those that are present as cations. Combined with the negative charges dissociation after the flooding, the anaerobic environment favors the NH_4^+ accumulation (Cantarella, 2007; Buresh et al., 2008). However, in these conditions, the proximity of the soil surface layer and the rhizosphere (both oxidized) with the anaerobic region facilitates the losses by the nitrification-denitrification process (Sousa et al., 2010; Liu et al., 2010), which represents 10% of total N losses even in continuous flood irrigation systems (Buresh et al., 2008).

By performing the water suppression (intermittent irrigation), the soil is reoxidized and electrochemical reactions occur on the contrary, compared to continuous flood irrigation (Thompson et al., 2006). Beyond the lower water amount for plants, the intermittent irrigation promotes the Fe precipitation and modifies the elements speciation and availability in soil solution due to pH decrease (Sparks, 2003). Thus, the P is adsorbed in soil solid phase, which may lead to higher P deficiency for plants, verified by a marked decrease in absorption (Kirk, 2004). The Ca and Mg contents in soil solution also decrease due to its resorption to soil exchange sites (Buss et al., 2011). The decrease at lower levels is not enough to depress the nutrients from soil solution because the soil phases are in equilibrium and the solid phase (whose ion contents are considerably higher as compared to liquid phase) replace the extracted ions from liquid phase (Sousa et al., 2009). In addition, the water suppression affects N dynamics, modifying the environment and increasing or decreasing the higher growth of microorganisms involved in N soil cycle (Reddy and Patrick Jr., 1974). Due to aerobic environment, the ways and proportion of N transformation and losses processes are modified, as compared to the anaerobic environment occurred in the continuous flood irrigation, and nitrification is favored. Although volatilization losses are reduced by N incorporation, applying urea in dry soil and immediately performing the flooding and maintenance of water layer (Buresh et al., 2008; Knoblauch et al., 2012), the N losses by denitrification are increased due to this management (Eriksen et al., 1985; Liu et al., 2010).

The nutrient availability and the rice crop response under continuous flood irrigation to achieve its productive potential are well defined. However, there is a lack of research regarding water suppression managements for the rice cropped in subtropical region. In this context, our hypothesis is that although the soil solution chemical attributes are affected by flood irrigation management method, the water suppression leads to lower water use without impacts in rice grain yield. To verify this, our study aims to evaluate the electrochemical characteristics and nutrient availability in soil solution during the growing cycle, the plant response and the water use efficiency of irrigated rice under different flood irrigation management methods in Southern Brazil.

2. Materials and methods

2.1. Characterization of the experimental area and trial's implementation

For the current study, a field experiment was conducted in the Rice Experimental Station of Rio-Grandense Rice Institute (IRGA), located at Cachoeirinha County (29°55′30″S, 50°58′21″W, 7 m asl), in the physiographic region of Depressão Central of Rio Grande do