Impacts of rice plant roots on the variation in electro-physico-chemical properties of soil waters

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IMPACTS OF RICE PLANT ROOTS ON THE VARIATION IN ELECTRO-PHYSICO-CHEMICAL PROPERTIES OF SOIL WATERS

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Abstract

Lowland rice crop is cultivated under continuous flooding and anaerobic conditions but rhizospheric region of the rice plants can have different physico-chemical conditions than in the absence of roots. However, it is very difficult to measure all physico-chemical parameters instantaneously in the rhizosphere because this region, being highly dynamic, altering rapidly those parameters of surrounding soil waters. Present study has compared the evolution of electro-physico-chemical properties (pH, redox potentials (pe), Electrical Conductivity (EC) and temperature) of soil waters during a complete day at two different phenological stages in the presence of rice roots (rhizosphere) and in the absence of roots to analyse the effect of rhizosphere on soil waters. In the rhizosphere, pH of soil waters was found comparatively low (<7) as compared to absence of roots (>7). Similarly, small EC values were observed in the rhizosphere. Great fluctuations (diurnal patterns) were observed during the complete days which were directly associated to atmospheric conditions (temperature and light) and rhizospheric activity, and these fluctuations were more during vegetative phase as compared to maturation stage of rice. It was also observed that incorporation of crop residues resulted in the more reductive conditions in the rice culture.

Introduction

Rice is the staple food of more than half the people in the world and generally cultivated in submerged conditions or lowlands. In the low land paddy fields, just after the flooding, anaerobic conditions are established as dissolved oxygen in the flood water is rapidly consumed by soil microbes and there is no quick diffusion of substituting oxygen from the atmosphere (Gao *et al*., 2004). Nowadays, for the betterment of the environment, incorporation of crop residues is carried out rather burning the residues (Gadde *et al*., 2009). No doubt, this type of post harvest management practice increases the fertility of soil (Sarwar *et al*., 2008) but it can result in comparatively more anaerobic conditions in paddy fields (Sudhalakhsmi *et al*., 2007).

The anaerobic conditions in soil waters are characterised by low redox potentials and reduced forms of some elements (Fe^{2+} and Mn^{2+}). If reducing conditions are severe, the reducing substances (Fe^{2+} and HS^-) can reach to phytotoxic concentrations in the rhizosphere (Gao *et al*., 2002). However, rice plant roots are capable of diffusing the atmospheric oxygen in rhizosphere through intercellular air spaces within leaves, stems and roots and lowering the concentrations of these toxic reduced substances (Couchat *et al*., 1993). But, the oxidizing capability of rice roots in the rhizospheric area is highly dependant on the variety of rice plants (root volume and root density) (Chutipaijit *et al.*, 2012) and largely affected by phenological stage of plant and age of the plant roots (Doran *et al*., 2006).

Rice plants pass through different phases during their growth cycles from germination to harvesting. The uptake of nutrients during these stages of rice plant is different and most of the nutrients uptake is carried out before flowering (Ramanathan & Krishnamoorthy, 1973). It is evident that absorption by roots is strongly affected by drought conditions (Abd-Allah *et al.*, 2010; Yang *et al*., 2012) and physico-chemical properties of soil waters (Murtaza *et al.*, 2005). Similarly, absorption of nutrients is more during day time (during photosynthesis) as compared to night (during respiration) and these absorptions of nutrients can influence the electrical conductivity and pH (Corwin & Lesch, 2003). Due to different plant behaviour during day and night, the existence of diurnal patterns has been noticed in the rhizosphere of rice plants in redox potentials, microbial activity and nitrogen contents attributed to the association of stomatal and photosynthetic activities of plants with daily solar cycles (Nikolausz *et al*., 2008). These variations in photosynthetic activities, respiration rates and absorption of nutrients in rhizosphere during night and day times can totally change the physico-chemical properties of soil solutions in rhizosphere.

So, rice plant rhizosphere can have completely different physico-chemical conditions as compared to only submerged soils without rice plant roots. Determination of chemical and physical parameters of soil solution in rice culture instantaneously is very difficult task but *In situ* recording of the electro-physico-chemical parameters (pH, temperature, redox potential, and electrical conductivity) during a complete day in the rhizospheric area and comparing it to an area without roots can allow us to observe all the ongoing changes in the physico-chemical parameters at field conditions. Furthermore, it can help us to establish a link between the electro-physico-chemical parameters and ongoing interactions in the soil (physico-chemical, physiological and biological). Objectives of this study were to determine the extent, nature and variation of electro-physico-chemical properties of soil solutions in the rhizosphere in rice culture under different residues management practices. Furthermore, the research work was carried out to observe the effect of rhizosphere on the dynamics of the electro-physico-chemical properties of soil waters during a complete day at two different phenological stages of rice plants.

Materials and Methods

The study was conducted in the Camargue (France) under Mediterranean climate in two neighbour plots located at 31°62` E and 48° 29` N. Two adjacent rice plots were selected due to their different post harvest residues management practices: in plot R178 rice residues are burnt while in plot R179 the rice residues are incorporated in soil since 20 years. In general, soils on both plots were alluvial, clayey loamy (about 40% clay, 55-56% silt and 4% sand), naturally less or more saline, with hydromorphic conditions and were deposited in Holocene by Rhône River. The soils of the Camargue are generally referred as transformed soils because rice has been cultivated here for 50 years. Soil analysis revealed that at the depth of 5 to 10 cm, soils in plot R179 were more saline (higher EC and more Na^+) as compared to R178 which was attributed to small difference in altitude of both plots.

Measurements of electro-chemical parameters: pH, redox potentials (Eh or pe) and electrical conductivity (EC), and electro-physical parameter: temperature (t°C), were carried out by using modified lysimeters and multiparametric probes (manufactured by IDROMAR). Manual measurements using lysimeters and portable multimeter were carried out in the root zones while measurements with probes were away from root zone as shown (Fig. 1). These two different methods were selected as probes were not capable to carry out measurements directly in root zones due to their field precautions for installation.

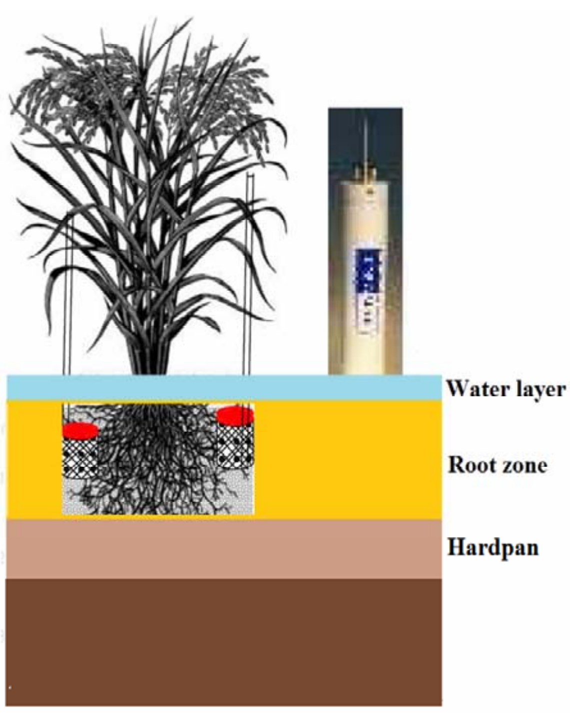

Fig. 1. A typical rice culture model showing the installation of lysimeters (porous plastic pots with red corks) in the root zone of rice plant and installation of probe away from root zone.

Two multiparametric probes, developed mainly for water quality monitoring both in marine coastal areas and inland waters: lagoons, lakes, rivers, reservoirs, were installed separately in each rice plot to carry out measurements after each hour under submerged conditions (with out roots) throughout the rice cultivation period. Each probe was equipped with one stirrer and 4 different sensors (electrodes) to measure 4 parameters: pH, Eh, EC and t°C. Ten measurements per parameter per hour were carried out but only average of these ten measurements was recorded in the internal memory. Measurement time between two parameters was of ten seconds and stirrer started working one minute before the measurement time. The oxido-reduction potentials (Eh values), measured with a platinum electrode against a standard Ag/AgCl electrode, were converted to the normal hydrogen scale (NHE) with temperature correction and were converted to pe values; higher values of pe represent more aerobic conditions and *vice versa* (Fiedler *et al*., 2007).

The lysimeters were decontaminated with HNO_3, perforated and covered with inert tissue to avoid entrance of soil particles before installation in the field. Each lysimeter was provided with a PVC tube to sample the soil solution with the help of a syringe (Fig. 1) without perturbing root zone. 15 polypropylene made lysimeters were installed in both plots some days before the sampling day (about one week) to allow chemical equilibrium in the rhizosphere and PVC tubes were sealed with the help of a clip to avoid the entrance of oxygen. Manual sampling was carried out during two different phenological stages of rice plant: vegetative growth stage and maturation stage. During sampling day, soil solution was sucked from one lysimeter after every one or one and half hour and all the above said measurements (pH, pe, EC and t) were carried out immediately with the help of calibrated electrodes and portable multimeter.

Results and Discussion

The evolutions of physical parameters during complete day at two different stages (vegetative growth and reproductive growth) have been presented in Figs. 2-4. Average values with standard deviations of measured electrophysico-chemical parameters in the presence or absence of roots in two plots are presented in Table 1. During the interventions at two stages, in the absence of roots, the pe values during complete day were more reductive and comparatively stable (Fig. 2a): in R179_probe (from -3.87 to -4.16) and in R178_probe (from -3.10 to -3.50), as compared to pe values in the presence of roots: R179_roots (from 0.4 to 2.2) and R178_roots (from 1.4 to 3.6). It was also observed that incorporation of crop residues (in R179) resulted in more reducing conditions at both stages as compared to the burning of the crop residues (in R178) either in the presence or in the absence of roots. During the vegetative phase, higher values of pe were observed in the morning and afternoon in the rhizosphere as compared to noon and evening but at maturation stage pe values were comparatively stable during the whole day. In fact, in the morning climatic conditions are favourable to the opening of stomata and photosynthesis that result in the nutrients absorption and oxidization of soil waters in rhizosphere while at noon and evening stomata get close and photosynthesis stops due to either intensive light or insufficient light respectively, so, increased respiration and lower transfer of oxygen in rhizosphere resulted in more reducing conditions (lower pe values). The results also showed that at vegetation stage plant roots were more active in nutrients absorption and injected more oxygen as compared to maturation stage. These results are in accordance with Ramanathan & Krishnamoorthy (1973). However, comparatively more oxic conditions in the presence of roots can be attributed to oxidizing capability of rice plant roots in the rhizosphere.

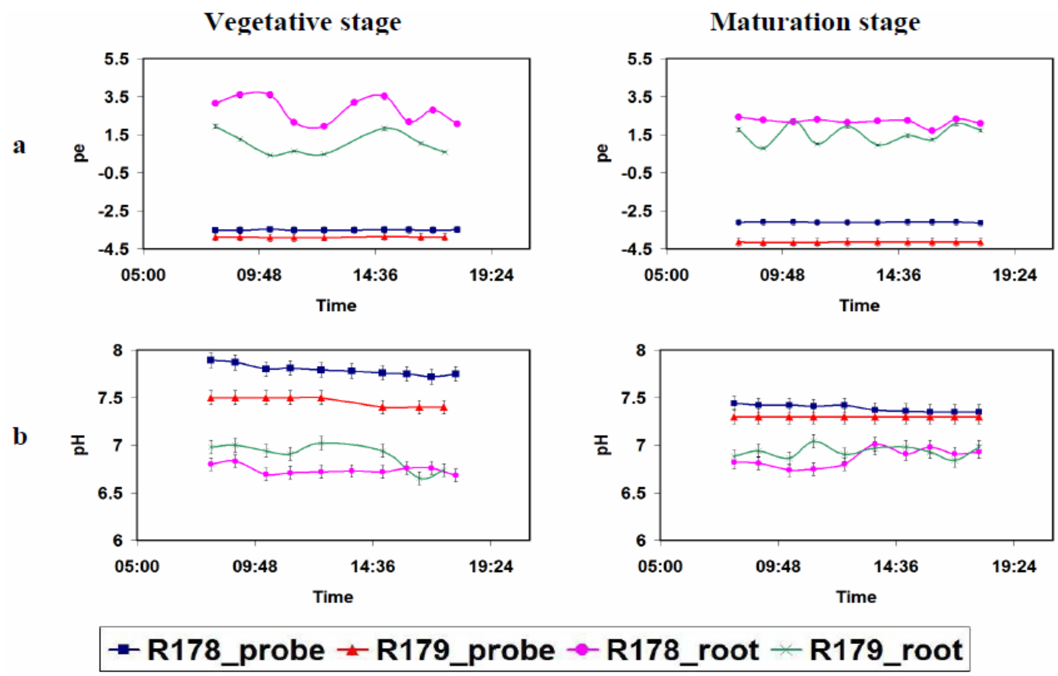

Fig. 2. Comparison between evolutions of pe (a) and pH (b) measured in the presence of roots (R178_root and R179_root)) and without roots (R178_probe and R179_probe).

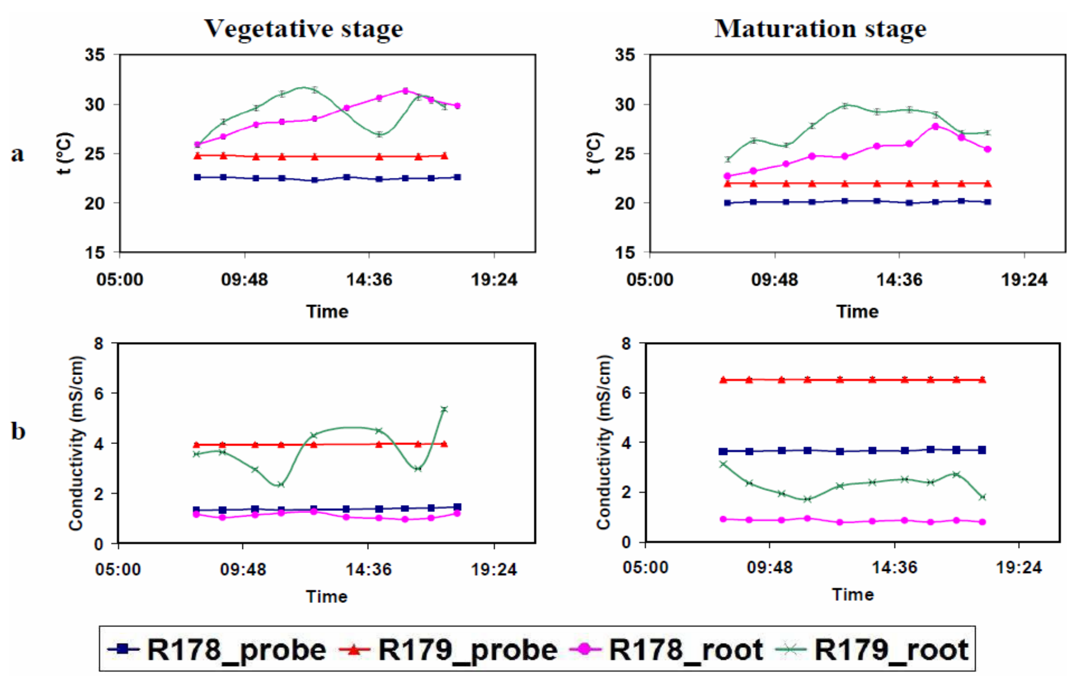

Fig. 3. Comparison between evolutions of Temperature (a) and Electrical conductivity (b), measured in the presence of roots (R178_root and R179_root)) and without roots (R178_probe and R179_probe).

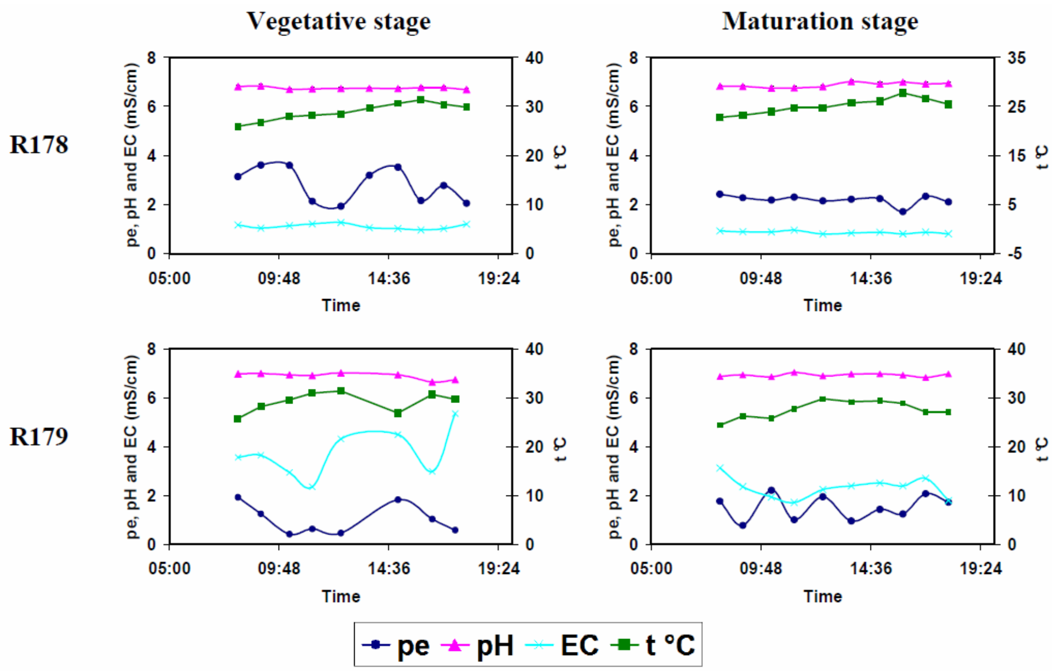

Fig. 4. Evolution of Temperature; pe, pH and Electrical conductivity (EC), measured in the rhizosphere under different post harvest practices. R-178; where rice straw was burnt, R-179; where rice straw was incorporated.

Table 1. Summary of measured parameters in two plots (Mean values with standard deviation).

	R178		R179	
	Without roots	**With root**	**Without roots**	**With roots**
pe	-3.31 ± 0.21	2.5 ± 0.58	-4.03 ± 0.13	1.3 ± 0.59
pH	7.59 ± 0.21	6.8 ± 0.1	7.37 ± 0.09	6.91 ± 0.98
t °C	21.31 ± 1.23	26.97 ± 2.54	23.22 ± 1.4	28.28 ± 1.99
EC (mS/cm)	2.52 ± 1.18	0.98 ± 0.14	5.39 ± 1.3	2.94 ± 0.99

The pH in both plots (Fig. 2b) was observed more acidic (between 6.65 and 7.04) at two different stages in the presence of roots as compared to pH values in the absence of roots (between 7.3 and 7.89). The pH in both plots (R178 and R179) was observed larger at vegetative growth as compared to during maturation stage in the absence of roots while in the rhizosphere pH values were less or more stable at both stages. Furthermore, the pH was relatively more alkaline in R178 than R179 in the absence of roots and opposite is observed in the presence of roots (in rhizosphere). From the evolution of pH during the whole day it was noticed that maximum pH of soil solutions were observed in early morning (Fig. 2b) then the pH continued to decrease progressively and was observed minimum at late evening (about 17h00). The acidic pH in the rhizosphere is evident and is directly related to the roots activity and exudation of acids by roots (López-Bucio *et al*., 2000; Hinsinger *et al*., 2006). The decrease in the pH can also be due to H^+ liberation in the root absorption processes as rice plant absorbs more cations (especially ammonium) than anions and maintain equilibrium between cations and anions by releasing the H^+ in the soil (Nye, 1981; Begg *et al*., 1994). This zone is so well regulated by roots activity that, perhaps, it has even masked the difference of the post harvest practices in the rhizosphere of different plots R178 and R179. Similar to pe values, diurnal patterns of pH values in the rhizosphere are directly related to variable root activity during a complete day depending upon light factor. Variability in the pH values in the absence of roots is directly related to temperature variability according Nernst equation.

Temperatures in the rhizosphere were observed higher than in the absence of roots (Fig. 3a). Furthermore incorporation of rice residuals resulted in higher temperatures in R179 in both cases: absence or presence of roots. Normally temperatures of surface waters in rice culture are largely influenced by solar cycles: in the morning the temperature start rising and in the evening it starts falling. In spite the fact that the temperatures were measured at the depth of 5-10 cm, they followed well the air temperatures, but this trend is more obvious in the presence of roots and rather stable temperatures were observed in the absence of roots. According to Bossio & Scow (1997) higher temperatures in R179 can be attributed to larger microbial biomass as the result of incorporation of rice residuals.

More EC values at vegetative and maturation phase in R179 as compared to R178 were due to saline soils of the plot R179 (Fig. 3b). At vegetative phase electrical conductivity (EC) values were at the average same during the complete day in the presence or absence of roots while at maturation stage higher EC values were observed in the absence of roots in both plots. The probe measured EC (in the absence of roots) showed no variations during the complete day at different stages in both R178 and R179 while a huge variation was observed in the rhizosphere measured EC. Electrical conductivity is the ability of soil solution to transmit an electrical current and directly affected by its molar concentrations (Marion & Babcock, 1976). EC is directly affected by the presence of major dissolved inorganic solutes in the aqueous phase consisting of soluble and readily dissolvable salts in soil, including charged ions (like Na^+, K^+, Mg^{2+}, Ca^{2+}, Cl^-, HCO_3^-, NO_3^-, SO_4^{2-}, and CO_3^{2-}), non-ionic solutes, and ions that can exist in the form of ion pair (Corwin & Lesch, 2003; Jamil *et al.*, 2012). Increase of EC in the absence of roots at maturation stage seemed to be not affected by the roots activity but is under direct influence of evapotranspiration or ground water salinity while low EC in rhizosphere at maturation stage can be the result of uptake of major elements by plant roots. As the result of diurnal changes, the absorption of major elements by plant roots and/or micro-organism and restoration of these elements by diffusion or dissolution process can be the responsible of these remarkable variations in the EC during the complete day (Fig. 3b).

When electro-physico-physical parameters were measured in the absence of roots, no relation was observed in diurnal patterns among electro-physico-chemical properties of soil waters such as temperature (t°C), pH, pe and electrical conductivity. But in the presence of roots, measured parameters showed that increase in temperature most often resulted in decrease the pH, pe and EC in both plots (R178 and R179) especially at the vegetative stage (Fig. 4). When temperature (t°C) is low in the morning the values of all the other parameters are comparatively high and *vice versa* for the evening.

Air temperatures and light intensity influence on the photosynthetic activity, evapotranspiration and ultimately, absorption of nutrients. In rice plants, higher air temperatures result in the closure of stomata to avoid thermal stress which reduces the transpiration. Furthermore, photosynthetic activity having strong relation with stomata conductance is also reduced at maximum temperatures but it is not essential that maximum photosynthetic activity corresponds well to maximum stomata conductance (Ishihara & Saito, 1987). This reduction in the photosynthetic activity can also result in the reduction of absorption of different elements.

In the rice plants, as major part of photosynthesis and absorption is carried out in vegetative phase so effect of air temperatures on physical parameters and chemical parameters is more obvious during vegetative phase. During latter stages of rice growth, this effect of the temperature on the pH, redox potential and conductivity is less evident due to largely decreased photosynthetic activity and decreased absorption of rice roots. But precise knowledge about the presence of other forms of life and their activities depending on the temperatures and solar cycles can make all interpretations more accurate and precise.

Conclusion

Rhizosphere of rice plants is very dynamic region that is dependant of plants activity, so, physico-chemical parameters in this area are changed very rapidly. In our study, it is concluded that rice plant activity during a day is largely regulated directly by solar cycles and indirectly by atmospheric temperature and light variation which in turn affect the roots activity of these plants. When roots are active, in the morning and afternoon, acidic pH, low EC values and larger pe values (potential redox) were observed and *vice versa*. Furthermore, incorporation of rice residues resulted in more anaerobic conditions either in the presence or in the absence of the roots. These results can be of utmost importance while deciding for post harvest management practices in rice culture.

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