

Changes in pH, EC and Concentration of Phosphorus in Soil Solution during Submergence and Rice Growth Period in Some Paddy Soils of North of Iran

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ABSTRACT

Changes in pH, EC and concentration of phosphorus in soil solution during submergence and rice growth period were studied in three paddy soils of North of Iran (one acid and two alkaline-calcareous soils). Also, changes in pH, EC and concentration of phosphorus in soil solution of an alkaline-calcareous soil after addition of 40 mg P/ kg of soil during submergence and rice growth period were studied. The experiment was performed in a set of specially fabricated pots equipped with a perforated sampling tube installed in the root zone area. At different times, pH, EC and concentration of phosphorus in soil solution of cultivated and uncultivated treatments were measured. The results are as follows: 1- After submergence, water soluble P increased initially and then decreased in all three soils in both cultivated and uncultivated treatments. 2- Both pH and concentration of water soluble P in both treatments was not significantly different at early stage of rice growth, but they were significantly lower in cultivated treatment afterward. 3- After submergence, the pH of alkaline soils decreased, while the pH of acid soil increased significantly. 4- The EC of rhizosphere soil solution changed differently in different soils during the rice growth period. In acid soil, the EC of rhizosphere soil was significantly lower than the bulk soil solution, while in one of the alkaline-calcareous soils, it was significantly higher than the bulk soil solution. 5- After P addition, the pH of the rhizosphere soil solution did not change significantly, but the pH of the bulk soil solution increased significantly. 6- Generally, the chemistry of rice rhizosphere was essentially different from the bulk soil.

Keywords: Rice, pH, EC, phosphorus, soil solution, rhizosphere, submergence, paddy soils.

INTRODUCTION

Rice (*Oryza sativa*) is one of the most important crops in the world and Iran that is cultivated under submerged conditions. When a soil is submerged, air is excluded and the soil quickly becomes anoxic and reduced. This phenomenon changes physical, biological, and chemical properties of soil (Ponnamperuma, 1972; Kirk, 2004). Soil pH is probably the most important chemical soil parameter (Bloom, 2000). It reflects the overall chemical status of the soil and influences a whole range of chemical and biological processes occurring in the soil. Because of its implications in most chemical reactions in the soil, knowing the actual value of soil pH and monitoring its changes is critical for understanding the physicochemical functioning of the soil (Jaillard et al. 2003). After soil waterlogging, the pH tends to converge to neutrality irrespective of initial pH, whether acidic or alkaline (Ponnamperuma, 1972; Kirk,

2004). Narteh and Sahrawat (1999), and Dekamedhi and De Datta (1995) found that the soil solution electrical conductivity (EC) increased initially after submergence and then decreased. Also, the chemical behavior of phosphorus can easily be changed by flooding of paddy soils. Some investigations showed that the concentration of phosphorus in soil solution increased initially after submergence and then decreased (Ponnamperuma, 1972; Narteh and Sahrawat, 1999).

Root-soil interactions in the rhizosphere include different processes that have an important influence on the soil solution chemistry (Smiley, 1974). Chemical conditions in the rhizosphere can be very different from those of the bulk soil due to root exudation, nutrient uptake, microbial activity, and differences in water relations (Darrah, 1993; Hinsinger, 2001; Marschner, 1995; Wang et al., 2005). Thus, knowledge of rhizosphere chemistry and rhizosphere processes is essential for characterizing nutrient availability in soils. In the last decade, much progress has been made toward a better understanding of the role of rhizosphere processes in plant nutrition, particularly the root-mediated changes in the chemical, physical, and biological properties of the rhizosphere soil (Darrah, 1993; Gregory and Hinsinger, 1999). However, little attention has been given to the dynamics of rhizosphere solution, and little is known about the influence of rice plant on rhizosphere solution chemistry. Improved understanding of rhizosphere solution chemistry will enhance our ability to model nutrient dynamics and to develop on a broader scale, effective buffers to minimize nutrient movement to surface waters (Wang et al., 2005). In This investigation, Changes in pH, EC and concentration of phosphorus in soil solution during submergence and rice growth period in some paddy soils of North of Iran were studied.

MATERIALS and METHODS

On the basis of soil properties including pH, CCE, available-P, and texture, three soil samples (one acid and two alkaline-calcareous) collected from the surface layer (0-20 cm depth) of paddy soils of north of Iran. The soil samples were air-dried at room temperature, thoroughly mixed, and sieved (2-mm). Then, two greenhouse experiments were conducted. In the first experiment, changes in pH, EC and concentration of phosphorus in soil solution during submergence and rice growth period were studied. The experiment was performed as a 13×2×2 factorial experiment in a randomized complete blocks design, with two replications and three factors of soil at two levels, time at 13 levels, and cultivation at two levels (cultivated and uncultivated). In this Experiment, two soils (one acid and one alkaline-calcareous) with similar available-P contents were selected. The Olsen-P of the both soils was 45.5 mg P/kg of Soil. In the second experiment, changes in pH, EC and concentration of phosphorus in soil solution during submergence and rice growth period were studied after application of 40 mg P per kg of one alkaline-calcareous soil with the initial Olsen-P of 3.8 mg P per kg of soil. The experiment was performed as a 12×2×2 factorial experiment in a randomized complete blocks design, with two replications and three

factors of P fertilizer at two levels (0 and 40 mg P/kg of soil), time at 12 levels, and cultivation at two levels (cultivated and uncultivated). The both experiments were performed in a set of specially fabricated pots equipped with a perforated sampling tube installed in the root zone area. The pots were filled to 20 cm depth with soils. The fertilizers, including 40 mg P as MCP (only in P-fertilized treatment), 140 mg Urea, 100 mg K₂SO₄, and 22 mg ZnSO₄·7H₂O per kg of soil, were added in liquid form and mixed thoroughly with the soil. The soil moisture was held at almost saturation percentage during the first three days, and then five germinated rice seeds (*Oryza sativa* L. cultivar Khazar) were transplanted in each pot (only in cultivated treatments). After 10 days, water was added in sufficient amounts to maintain a water level of five centimeters above the soil surface for a period of three months. At different times, soil solution samples of cultivated and uncultivated pots were gathered using a 50 mL syringe and pH, EC and concentration of phosphorus in soil solution was measured. Inorganic P in the extracts was quantified spectrophotometrically by the ascorbic acid method (Murphy and Riley, 1962; Kuo, 1996). Statistical analysis of data including normality test, analysis of variance, and comparisons of means was performed by using MSTATC and Excel programs. Comparison of means was carried out by Duncan's multiple range test at P≤0.05.

RESULTS AND DISCUSSION

The selected chemical and physical properties of the experimental soils are listed in Table 1. The important data in Table 1 indicate that the three soils studied had a wide range in initial pH (6.2-7.9), organic C (18.9-49.3 g/kg), Calcium carbonate equivalent (0-423.7 g/kg), available-P (3.8-45.5 mg/kg), and texture (loam-sandy clay loam). Soils 628 and 635 are alkaline-calcareous and soil 650 is acidic. Soils 628 and 650 have similar available-P.

Table 1. Some chemical and physical properties of the soils used in the study.

Soil No.	pH _{1:1(H₂O)}	CCE (g/kg)	OC (g/kg)	Olsen-P (mg/kg)	Sand (g/kg)	Clay (g/kg)	Texture
628	7.9	115.7	18.9	45.5	427	214	L
635	7.7	423.7	25.3	3.8	460	255	L
650	6.2	nil	49.3	45.5	492	275	SCL

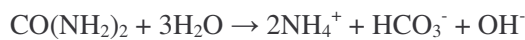
CCE: Calcium carbonate equivalent, OC: Organic carbon, L: Loam, SCL: Sandy clay loam.

Changes in pH of Soil Solution after Submergence

The results of two experiments showed that after submergence in uncultivated treatments, pH of alkaline-calcareous soils decreased initially and remained almost constant, then increased again (Figures 1, 2, 3), while pH of acidic soil 650 increased initially and then remained almost constant (Fig. 4). Following submergence, CO₂ formed in respiration, escapes from the soil only very slowly, and it

therefore accumulates. As CO₂ continues to accumulate during anaerobic respiration and fermentation, large partial pressures develop, typically in the range of 5 to 20 kPa. The accumulation of CO₂ lowers the pH of alkaline soils (Kirk, 2004).

The observed increase in acidic soil solution pH as a result of submergence into water is well known (Ponnamperuma, 1972) and attributed to the consumption of protons during reduction processes (Narteh and Sahrawat, 1999; Kirk, 2004). The subsequent increase in soils pH after 50 days can be attributed to the predominance of reduction processes and pH increase by urea hydrolysis. In this study nitrogen fertilizer added as 100 mg urea/ pot (four times) to both rice cultivated and uncultivated pots during rice growth period. The pH increases during urea hydrolysis (Kirk, 2004):



Changes in pH of Soil Solution after Rice Cultivation

Comparisons of means indicated that the pH of the rhizosphere (rice cultivated treatment) in all three soils studied was significantly lower than bulk soil (uncultivated treatment) solution (Figures 1, 2, 3, 4). The following processes may be expected to modify soil conditions near rice roots growing in submerged soil which lead to a considerable acidification of the rhizosphere (Kirk et al. 1993; Kirk, 2004):

- The oxidation of ferrous iron by rice root-released O₂ which leads to both an accumulation of Fe(OH)₃, and an acidification:



- The direct release of H⁺ ions from the roots to balance cation-anion intake, Because the main form of plant-available N in anaerobic soil is NH₄⁺, the root absorbs an excess of cations (NH₄⁺, K⁺, Na⁺, Ca²⁺, Mg²⁺) over anions (H₂PO₄⁻, Cl⁻, SO₄²⁻). Consequently H⁺ is released by the root to maintain electrical neutrality, tending to further decrease the rhizosphere soil pH.
- The release of organic acids from the root into the soil.
- The release of CO₂ from roots during respiration which reacts with water to form carbonic acid.

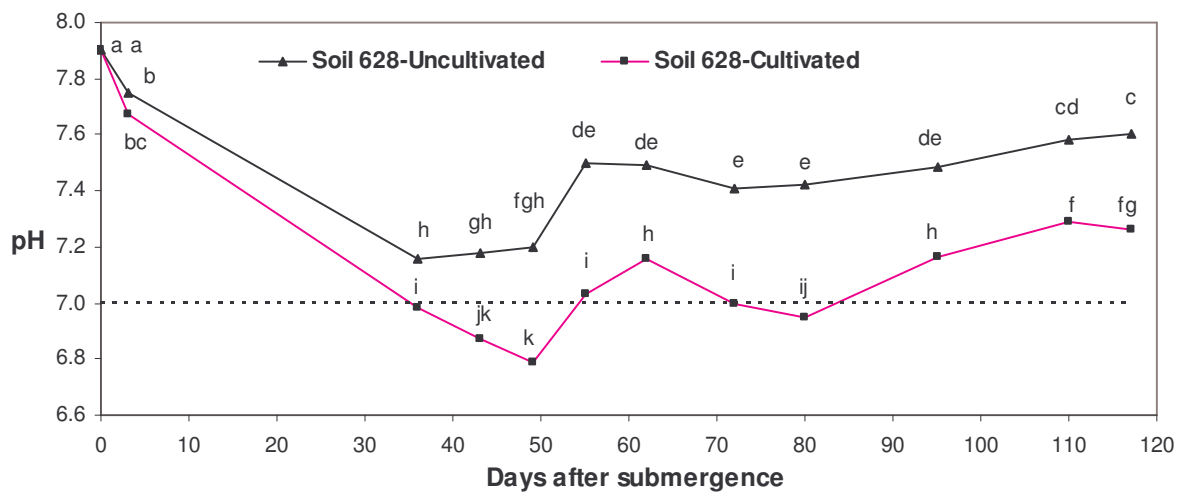


Fig.1. Changes in pH of soil 628 after submergence in both rice cultivated and uncultivated treatments.

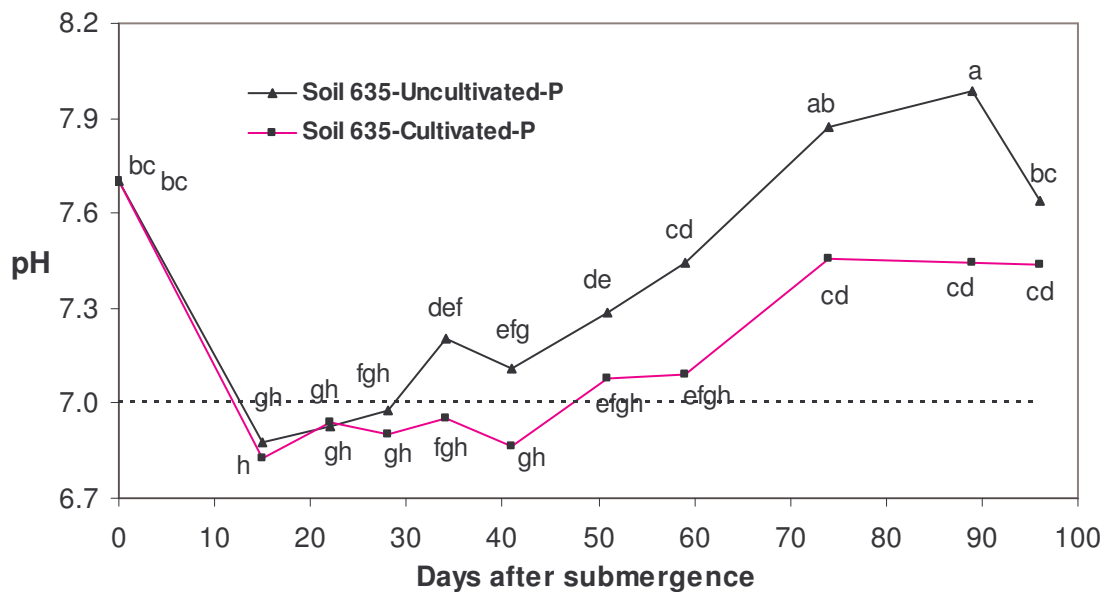


Fig.2. Changes in pH of soil 635 after submergence in both rice cultivated and uncultivated treatments (without P addition).

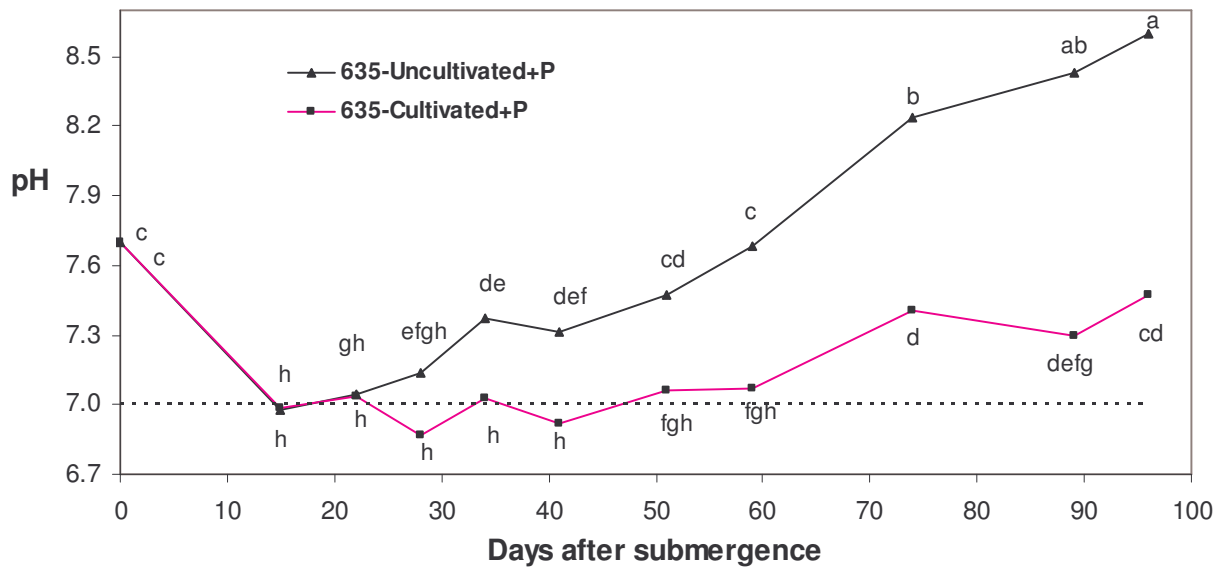


Fig.3. Changes in pH of soil 635 after submergence and P addition in both rice cultivated and uncultivated treatment.

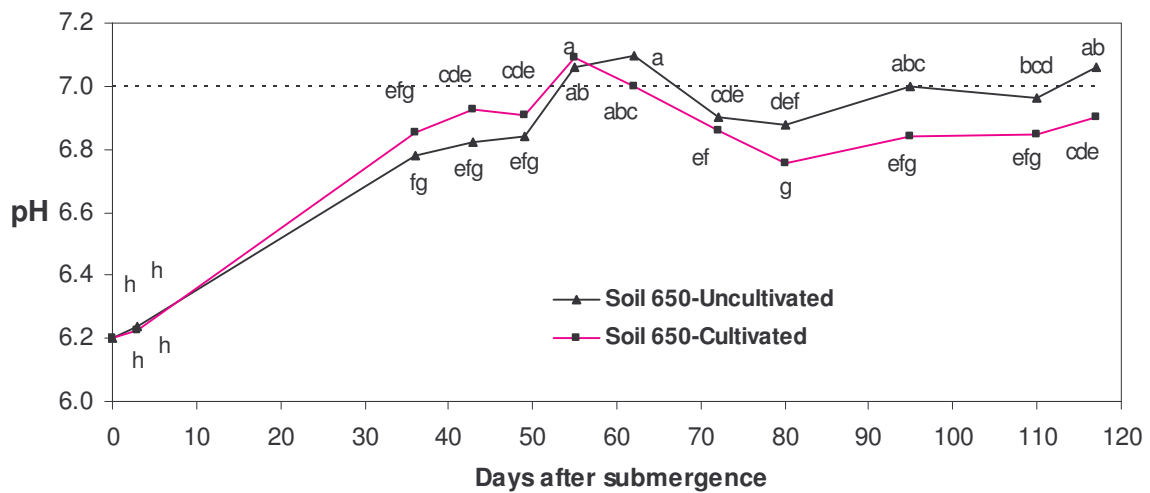


Fig.4. Changes in pH of soil 650 after submergence in both rice cultivated and uncultivated treatments.

Changes in Water Soluble Phosphorus after Submergence and P Addition

The results of two experiments showed that after submergence, water soluble-P of alkaline-calcareous soil 628 increased initially and then decreased, while water soluble-P of alkaline-calcareous soil 635 and acidic soil 650 increased initially and then remained constant and afterwards decreased in both rice cultivated and uncultivated treatments; the water soluble-P of three soils studied finally remained almost constant (Figures 5, 6, 7, 8). The highest concentration of P in soil solution (3 mg P/L) was

recorded by alkaline-calcareous soil 628 and acidic soil 650 that had similar available-P (45.5 mg P/kg), while the highest concentration of water soluble-P of alkaline-calcareous soil 635 with available-P of 3.8 mg P/kg was 0.22 mg P/L. After P addition and submergence, water soluble-P of soil 635 decreased, and then remained almost constant and finally increased in uncultivated treatment (Fig. 7). Ponnampereuma, (1965), Ponnampereuma (1972), Islam and Islam (1973), Willet (1986) and Narteh and Sahrawat (1999) reported that soil water soluble-P increased initially after submergence and then decreased. The initial increase in soil solution P in submerged soils is particularly linked to the transformations of Fe and changes in pH. The main processes are (Ponnampereuma, 1965; Kirk, 2004):

- Reduction of Fe(III) compounds holding P on their surfaces and within their crystal lattices;
- Dissolution of Ca-P compounds in alkaline soils as the pH decreases and desorption of P held on variable-charge surfaces in acid soils as the pH increases;
- Displacement of sorbed P by organic anions and chelation of metal ions that would otherwise immobilize P; and
- Mineralization of organic P.

The subsequent decline in soluble P is caused by re-sorption or precipitation on clays and oxides as soil conditions continue to change, and decomposition of organic anions chelating P or chelating Al and Fe with which it would otherwise react. Following submergence soils often release more P to solutions low in P but adsorb more P from solutions high in P. This apparent paradox can be explained by the reduction of Fe(III) oxides to poorly ordered gel-like Fe(II) compounds with large surface areas. Phosphorus solubilized in soil reduction is sorbed on the amorphous surfaces and desorbed when P is removed from the soil solution; but fresh P added to the soil is removed from solution by sorption onto the Fe(II) surfaces. Consequently many soils do not show significant increases in P solubility during flooding (Willett, 1991), and with prolonged flooding the P may become re-immobilized in less soluble forms (Kirk, 2004).

Changes in Water Soluble Phosphorus after Rice Cultivation

Comparisons of means indicated that the water soluble-P of the rice rhizosphere (cultivated treatment) in all three soils studied was significantly lower than bulk soil (uncultivated treatment) (Figures 5, 6, 7, 8). In other words, the uptake of phosphorus by roots resulted in a depletion of phosphate ions in the rice rhizosphere. So that the concentration of water soluble-P of the rice rhizosphere in all soils studied was lower than critical concentration (0.2 mg P/L) for optimum rice growth that has been reported by Khalid et al. (1977) and Roy and De Datta (1985). Jianguo and Shuman (1991) and Yuan and Huang (1995) concluded that the water soluble-P of the rice rhizosphere was lower than the bulk soil. Movement of phosphate ions to root by diffusion and mass flow is an important factor in supplying P to plants. Most of the P moves to the root by diffusion. When rice plant roots absorb phosphate ions from the surrounding

soil solution, the P concentration at the root surface decreases compared with the bulk soil solution concentration. Therefore, a P concentration gradient is established that causes phosphate ions to diffuse toward the plant roots (Havlin et al. 1999). When P supplying rate by diffusion and mass flow to plant roots is lower than P uptake rate by plant roots, the concentration of P in the rhizosphere soil solution will be lower than the bulk soil solution.

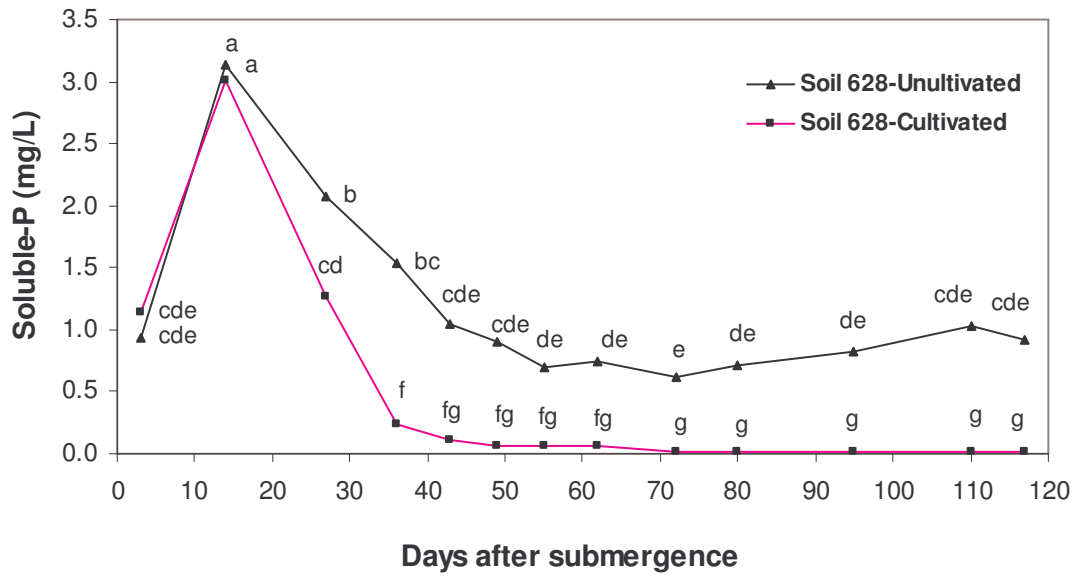


Fig. 5. Changes in water soluble-P of soil 628 after submergence in both rice cultivated and uncultivated treatments.

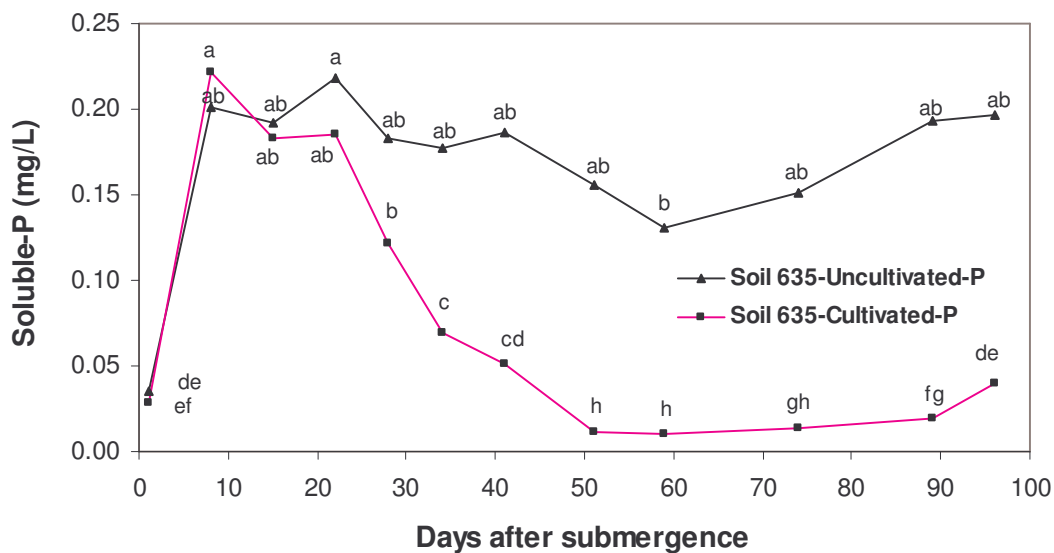


Fig. 6. Changes in water soluble-P of alkaline-calcareous soil 635 after submergence in both rice cultivated and uncultivated treatments (without P addition).

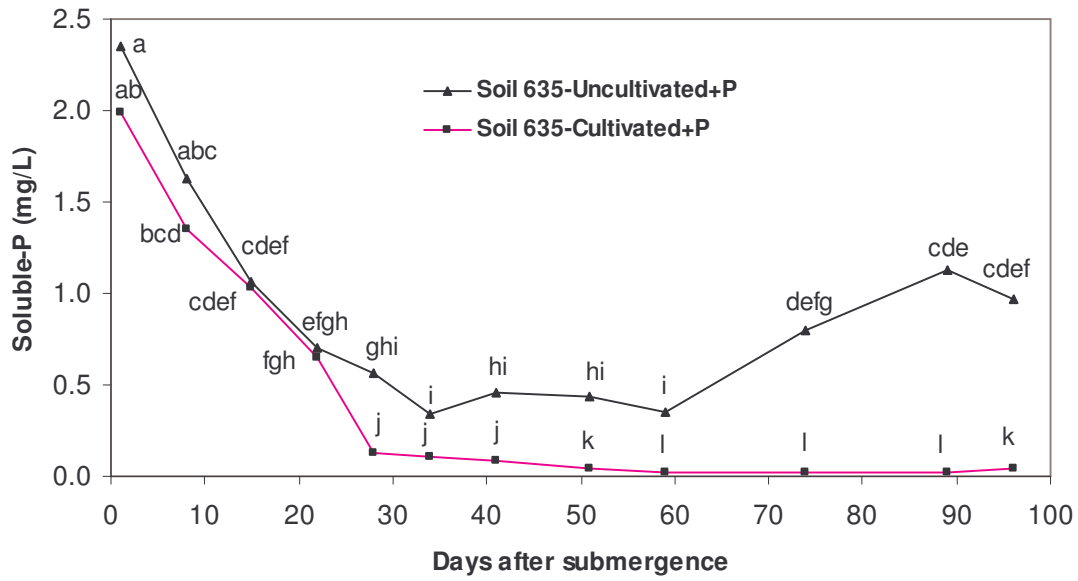


Fig. 7. Changes in water soluble-P of alkaline-calcareous soil 635 after submergence and P addition in both rice cultivated and uncultivated treatments.

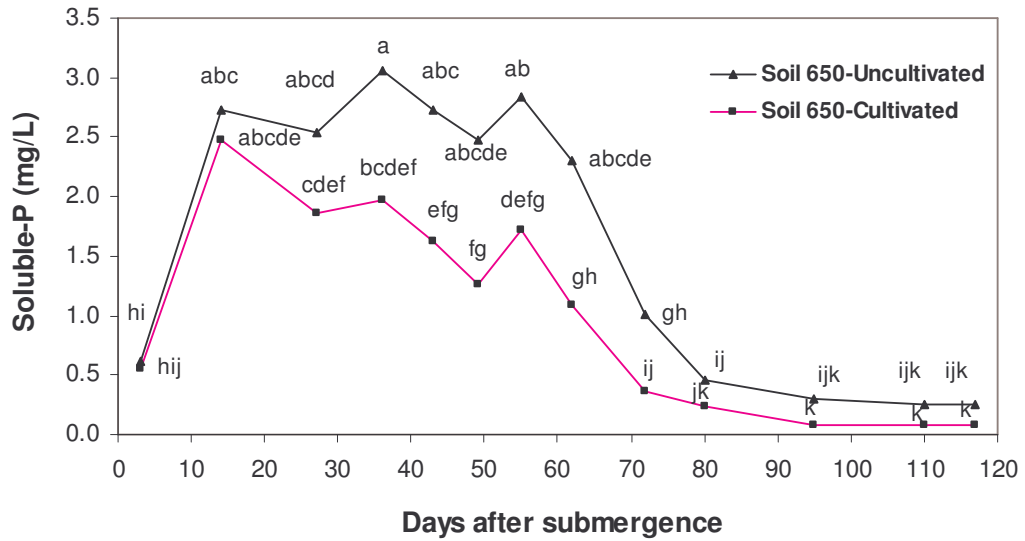


Fig. 8. Changes in water soluble-P of acidic soil 650 after submergence in both rice cultivated and uncultivated treatments.

Changes in EC of Soil Solution during Rice Growth Period

Comparisons of means indicated that the electrical conductivity (EC) of rhizosphere soil solution changed differently in different soils during the rice growth period (figures 9, 10, 11, 12). In alkaline soil 628, the EC of rhizosphere soil solution was significantly lower than the bulk soil solution until 108 days after rice cultivation; afterwards it was not significantly lower than the bulk soil solution (Fig. 9). In alkaline soil 635, the EC of rhizosphere soil solution was not significantly different from the bulk soil solution until 50 and 40 days after rice cultivation respectively in without and with P addition treatments; afterwards it was significantly higher than the bulk soil solution (Figures 10, 11). In acid soil 650, the EC of rhizosphere soil solution was significantly lower than the bulk soil solution during the rice growth period (Fig. 12). The following processes may be expected to modify the EC of rhizosphere soil solution:

- Simultaneously uptake of cations and anions by rice roots (e.g. H^+ and NO_3^- ; Marschner, 1995); that decreases the EC of rhizosphere soil solution.
- Precipitation and adsorption reactions; that probably decrease the EC of rhizosphere soil solution.
- Water uptake rate as compared with nutrients uptake rate; when water uptake rate is higher than the nutrient uptake rate, the EC of rhizosphere soil solution is higher than the bulk soil solution (Barber, 1995).
- The pH changes; when the pH of rhizosphere soil solution decreases, the EC of rhizosphere soil solution increases, because proton has the highest equivalent conductance between ions (Pazandeh, 1992).

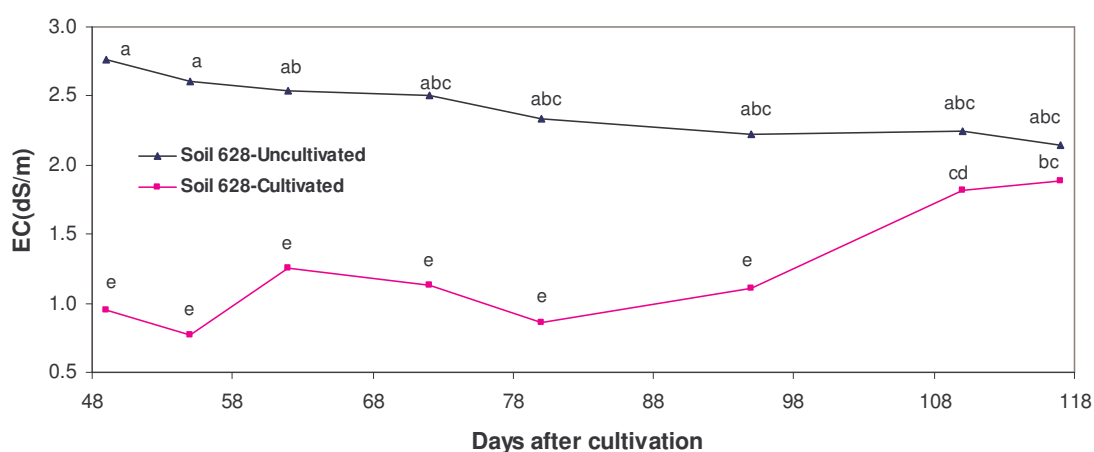


Fig. 9. Changes in EC of soil 628 in both rice cultivated and uncultivated treatments.

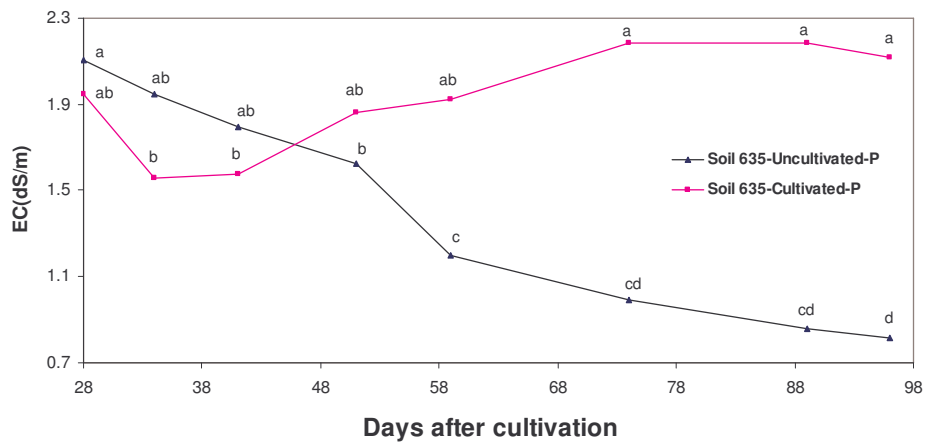


Fig. 10. Changes in EC of soil 635 in both rice cultivated and uncultivated treatments (without P addition).



Fig. 11. Changes in EC of soil 635 in both rice cultivated and uncultivated treatments (with P addition).

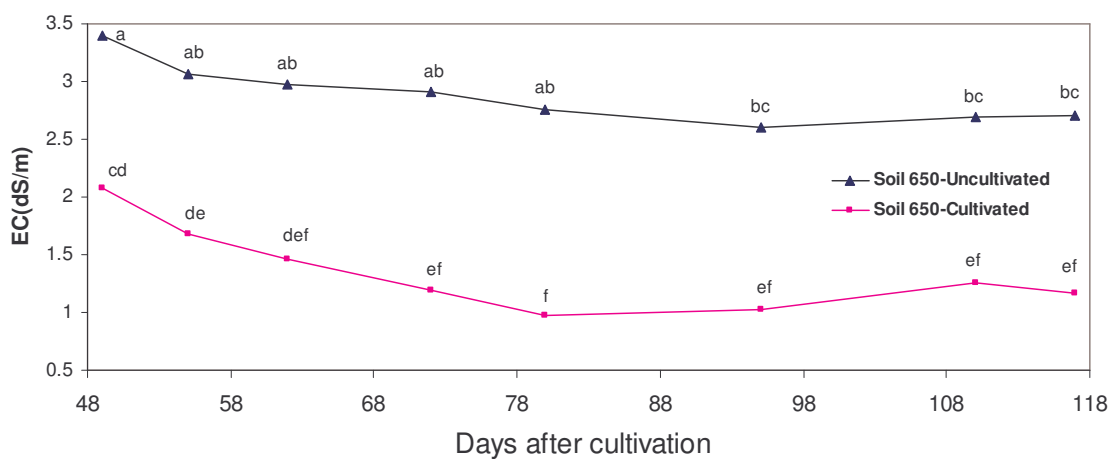


Fig. 12. Changes in EC of soil 650 in both rice cultivated and uncultivated treatments.

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