



Research Article

ISSN 2320-4818

JSIR 2021; 1(1): 5-12

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Received: 13-02-2021

Accepted: 21-03-2021

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Effect of labile carbon on iron reduction and phosphorus availability in two paddy soils

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Abstract

Phosphorus (P) limitation in acidic tropical paddy soils is thought to be contributed by the affinity of iron oxides and hydroxides for phosphorus. However, the addition of labile carbon (C) compounds appears to be stimulated iron (Fe) reduction which can release occluded P through Fe cycling. The aim of this study was to investigate the phosphorous mobilization triggered by labile C coupled to iron (Fe) cycling during flooding anaerobic conditions in two P limited paddy soils. Two concentrations (low and high) of equal mixture of glucose and oxalate were added to soil microcosms and they were incubated for one month under flooded condition. During the 30-day experiment, replicate microcosms were destructively harvested for five times and measured total Fe, Fe II, available P and pH. It was found that labile C addition significantly increased total Fe and Fe II in soil solution at early incubation period although the changes were not significant in soil. Available P in soil was not increased and steady throughout the incubation period because the added labile C may not be enough to enhance the P solubilization or available P was dissolved in soil water which we did not measure in this experiment. High amount of labile C addition significantly decreased pH at the start of incubation. pH and available P are negatively correlated at day 7 which is compatible with decreased pH can increase available P. Our results suggest that reducing conditions coupled with labile carbon inputs can stimulate iron reduction and corresponding decreased pH which can triggered soil phosphorus mobilization in P limited paddy soils.

Keywords: Acidic soil; Phosphate limited soil; labile carbon; phosphate solubilization; iron reduction.

I. INTRODUCTION

Some tropical paddy soils are acidic and abundant in iron (Fe) and aluminum (Al) oxides, which result in a considerable role to adsorb phosphate [1]. Even if total phosphate are rich in soil, moderately low concentrations of phosphorus (P) are available to plants because a large proportion of it is strongly held by diverse soil minerals such as Fe and Al [2]. However, Fe is redox active and the reduction of Fe minerals tends to liberate P. Therefore, the redox dynamics of Fe may play an important role in P cycling in soil [3]. Reduced availability of P in soils decreased the biomass and yield of rice. Therefore, enhancement of P availability in tropical weathered soils and magnification of P uptake in rice plants is crucial to meet the rising demand for rice to feed the population of world [1].

In tropical soil, most P are bound to redox-sensitive Fe minerals and under reducing conditions, P release occurs through desorption of P from Fe and other clay minerals and the dissolution and hydrolysis of Fe and Al phosphate [4] because Fe can be easily solubilized and re-precipitate/crystallize in response to local redox conditions [5]. Soils which are rich in total P, but possessed low contents of available P are called P limited soils. Studies with P fertilization described that P limitation had effect on soil respiration, microbial activity, litter decomposition and net primary productivity [3]. In a previous study, it was shown that the addition of organic matter such as green manures makes the iron and phosphorus more soluble and the solubility of iron and phosphorus increases when ferric iron becomes reduced to ferrous iron [6].

Iron reduction is a source of CO₂ via heterotrophic respiration during anoxic periods [7], therefore, Fe and C cycles are also linked. Several factors may control the rates of Fe reduction in soils. The addition of anthraquinone-2,6-disulfonate (AQDS), a humic acid analog, has been found to stimulate Fe reduction in soils [8] because they can shuttle electrons from the organisms to solid phase Fe minerals [9]. Also, the addition of labile C compounds such as acetate or glucose appears to be stimulated Fe reduction because it is a heterotrophic process [8]. Root exudates contain abundant dissolved organic matter, which can serve as an effective carbon source and rhizosphere processes could offer suitable redox condition for Fe

reduction [10] and redox fluctuations due to labile C inputs can release occluded P through Fe cycling. However, investigations on the impact of C on Fe reduction, soil P availability in P limited paddy soils are still rare. Therefore, we incubated two P-limited paddy soils with two common components from root exudates to better understand the role of labile C in Fe reduction and P-solubilization in paddy soils. We hypothesized Fe reduction will increase the solubility of Fe minerals and therefore the P availability.

MATERIALS AND METHODS

Sampling and characteristics of soils

The soil samples (0–20 cm) were collected from two P limited paddy soils. Three replicates were collected from each soil and for each replicate, five soil cores were combined and mixed thoroughly. In the lab, soils were homogenized by manually mixing and removing visible plant debris, rocks, and soil micro-fauna. The soil samples were air-dried and ground to pass through a 2-mm sieve. Both soils are acidic soils with pH around 5. Total P contents of both soils are nearly same (0.4 g/kg soil). However, Olsen P (available P) contents are different, the available P content of soil1 is 0.3 mg/kg soil while soil2 contained 8.1 mg/kg soil of available P. Microbial biomass carbon of two soils were nearly same, around 1g/kg soil.

Soil flooding and incubation

Before the onset of incubation, air dried soil samples were pre-incubated under flooded condition at 25 °C for 3 days to re-constitute microbial activity. Subsequently, 50 g of soil microcosms were prepared and then pre-incubated under submerged conditions to overcome the disturbance effects that might have occurred due to soil handling and homogenizing. Each treatment was replicated three times. Stock solutions of mixture of oxalate and glucose were added to each microcosms at two concentrations; 0.25g/kg soil (low) and 1g/kg soil (high). The soil was incubated for one month under flooded condition. During the 30-day experiment, replicate microcosms were destructively harvested on days 1, 3, 7, 14 and 30, respectively. The destructive sampling was carried out to determine soil pH, total Fe (TF) and Fe (II) in soil and soil solution, available P (Olsen P) in soil. Soil without any added compound were designated as control.

Soil analysis

Soil pH was measured by using a combined electrode and pH meter (Mettler Toledo, Switzerland) in a soil suspension. 0.5 M HCl were used to extract Fe (II) and Fe (III) from soil solution and soil. The extracted Fe (II) was determined by ferrozine method [11]. The same procedure were used to extract total Fe with the exception that hydroxylamine hydrochloride was added to the soil extracts to transform Fe (III) to Fe (II). The absorbance was read immediately on a spectrophotometer (Perkin Elmer, Germany) at 510 nm. To measure Olsen P, 5 g of soil were shaken with 80 ml NaHCO₃ at 180 rpm for 1 hour. After that the samples were filtered and added ammonium molybdate and ascorbic acid and then measured with spectrophotometer at 830 nm [12].

Statistical Analysis

The data shown and discussed are the means of three replicates, with standard errors of the mean as error bars in the figures. One-way analysis of variance (ANOVA) were used to compare the differences in soil properties treated with two concentration of labile C compounds (glucose and oxalate). Differences were considered to be significant if $p < 0.05$. Statistical analyses was conducted using the SPSS 16.0 software package.

RESULTS

Total Fe concentration in soil

In soil 1, a little increase in total Fe concentrations in soil was found while a pronounced decrease occurred in total Fe concentrations in soil solution as compared to control (Fig. 1 A and B). In soil1, Fe reduction in soil

solution occurred sharply starting from day 3 and then gradually decreased until day 30 (Fig. 1B). In soil2, at day 1, high amount of labile C addition can decrease total Fe in soil, while highest amount of total Fe was observed in soil solution of soil2-high (Fig. 2A and B).

Fe (II) accumulation

For soil1, Fe II in soil increased with incubation time while Fe II in soil solution decreased gradually (Fig 3A and B). However, for soil2, Fe II concentration in soil was fluctuated throughout incubation period showing increased trend from day 1 to day 3, and decreased at d7, after that increased again at day 14 and day 30. Fe II in soil solution increased from day1 to day 3 and decreased steadily until day 30 (Fig 4A and B). High amount of labile C addition significantly accumulated Fe II in soil solution than low amount of labile C addition in soil1 until day 14. Similar phenomenon was found in soil2 until day 7.

Changes in Available P

For soil1, high amount of labile C addition showed significant increased available P at day 3 although it was decreased after that (Fig. 5A). For soil2, available P at day 7 was the highest during 30 day incubation. At day 30, the amount of available P was significantly decreased than other days (Fig. 5B).

Changes in pH

Labile C compounds instantly decreased soil pH in both soils at the start of incubation (Fig, 6A and B). The magnitude of the pH decrease at day 1 and 3 was in the order of control > low C input > high C input for soil1. However, lowest pH was observed under low C input in soil2 at day 1, 3 and 7. Control soil showed the highest pH throughout incubation period.

Correlation of Fe reduction, pH and available P

For soil1, available P at day 3 was positively and significantly correlated with Fe II in soil at day3 and 30; with FeII in soil solution at day 1, 3, 7 and 14 (Fig. 7A). pH at day 1, 3, 7, 14 was positively and significantly correlated with available P at day 7. pH at day 30 significantly correlated with available P at day 14. For soil2, pH at day 30, Fe II in soil at day 14, Fe II in soil solution at day 1, 3, 7 and 14 were significantly correlated with available P at day 7 (Fig. 7B). Fe II in soil at day 30 and Fe II in soil solution at day 3 were significantly correlated with available P at day 30.

DISCUSSION

Previous investigations presented that labile C compounds like oxalate and acetate can stimulate Fe (III) reduction and Fe (II) accumulation in soils [13]. In this experiment, soil Fe (II) concentrations increased at day 14 and day 30 although it was steady at earlier incubation time. However, higher amount of Fe (II) in soil water was found at day 1, day 3 and day 7 under high C input. It was shown that Fe reduction was formed in soil water at early incubation time, after 7 days, Fe (II) was decreased in soil water and increased in soil. At day 30, the amount of total Fe in soil solution in all treatment showed no significant different in both soil because added labile C was used up. High amount of labile C addition significantly decreased total Fe in soil solution than low amount of labile C addition in both soil. Similar phenomenon was found in other study [14] which described higher Fe (II) accumulation due to excellent capacity of oxalate and propionate to transfer electrons to Fe (III) oxides. Accordingly, the faster Fe (II) mobilization during first week (day 1, 3 and 7) in both soils revealed that the higher labile C addition facilitated an efficient Fe (III) reduction and associated Fe (II) mobilization. It was shown that a large amount of available C was adsorbed or co-precipitated by Fe- oxides in soil. This is evident that the C availability is vital in determining the magnitude of microbially-mediated Fe (III) reduction [15].

For soil1, high amount of labile C addition showed significant increased available P at day 3 although it was decreased after that (Fig. 5A). Other study showed that Labile C addition significantly increased available P as a result of Fe (III) reduction and associated Fe (II) mobilization. They

described P occluded to Fe (III) oxides solubilize during Fe reduction [3]. Anoxic condition like paddy field can cause Fe (III) reduction which resulted the release of obstructed P on Fe (III) mineral surfaces, resulting in a considerable increase in labile P in the soil solution [15]. The significant positive relationship of Fe (II) contents in soil solution and available P confirmed that the reduction and dissolution of Fe (III) released their adsorbed P (Fig 7A and B). This indicates that labile C inputs acts as the main electron donors to release substantial amounts of P. When the input labile C used up, the Fe (II) amount in soil solution decreased significantly. However, the positive correlation of Fe (II) and available P in soil 1 and soil2 were in different times (day 3 for soil 1 and day 7 for soil 2). The reason of the differences seems to be because of difference in soil physicochemical parameters which we need to investigate more.

Moreover, available P contents decreased after 14 day in both soils (Fig. 5 A and B) although previous work described that soluble P in two wetland soils peaked until 30 days after the start of anoxic incubation as a result of desorption, but then fell back to its initial level due to re-adsorption and precipitation [16].

Labile C compounds instantly decreased soil pH in both soils at the start of incubation (Fig. 6A and B). In soil1, pH was decreased in low and high treatments. The sharp initial decline in pH likely dependent on H⁺ dissociation of the labile C compounds [17]. pH at day 1, 3, 7, 14 was positively and significantly correlated with available P at day 7. pH at day 30 significantly correlated with available P at day 14. In other studies, lower pH can enhance phosphate solubilization, however, in this study, decreasing the pH can decrease P mobility as suspected by the positive correlation between pH and available P in both soils (Fig. 7A and B).

Other studies found that decreasing in pH should result in a stronger retention and hence in a decreased mobility of inorganic P from Fe and Al oxides [18].

Most farmers in tropical regions use chemical P fertilizer to supplement P deficiency, however, the soil is not able to hold the added P. About 75–90% of the added chemical P fertilizer is precipitated by metal-cation complexes and rapidly becomes fixed in soils and has long-term impacts on the environment in terms of eutrophication, soil fertility depletion [19]. Therefore, further research is needed to address these issues and to stop depletion of P stocks for enhanced P demands of plants in subtropical and tropical ecosystems.

CONCLUSION

Although most P are bound to redox-sensitive Fe minerals in tropical soil, P release can occur through desorption of P from Fe under reducing conditions because Fe can be easily solubilized and re-precipitate in response to local redox conditions. Labile C primarily controls redox-driven biogeochemistry of these soils which lead to Fe reduction with the concomitant release of Fe-P. In this study, labile C addition, which mimic root exudation, significantly increased total Fe and Fe II in soil solution at day 1, 3, 7 and 14 in soil1 and day 1, 3 and 7 in soil 2 although the changes were not significant in soil. Available P in soil was not increased and steady throughout the incubation period because the added labile C may not be enough to enhance the P solubilization or available P was dissolved in soil water which we did not measured in this experiment. Further research is needed to investigate the effect of labile C on P solubilization by adding high amount of labile C, and available P and MBP should be measured in both soil solution and soil.

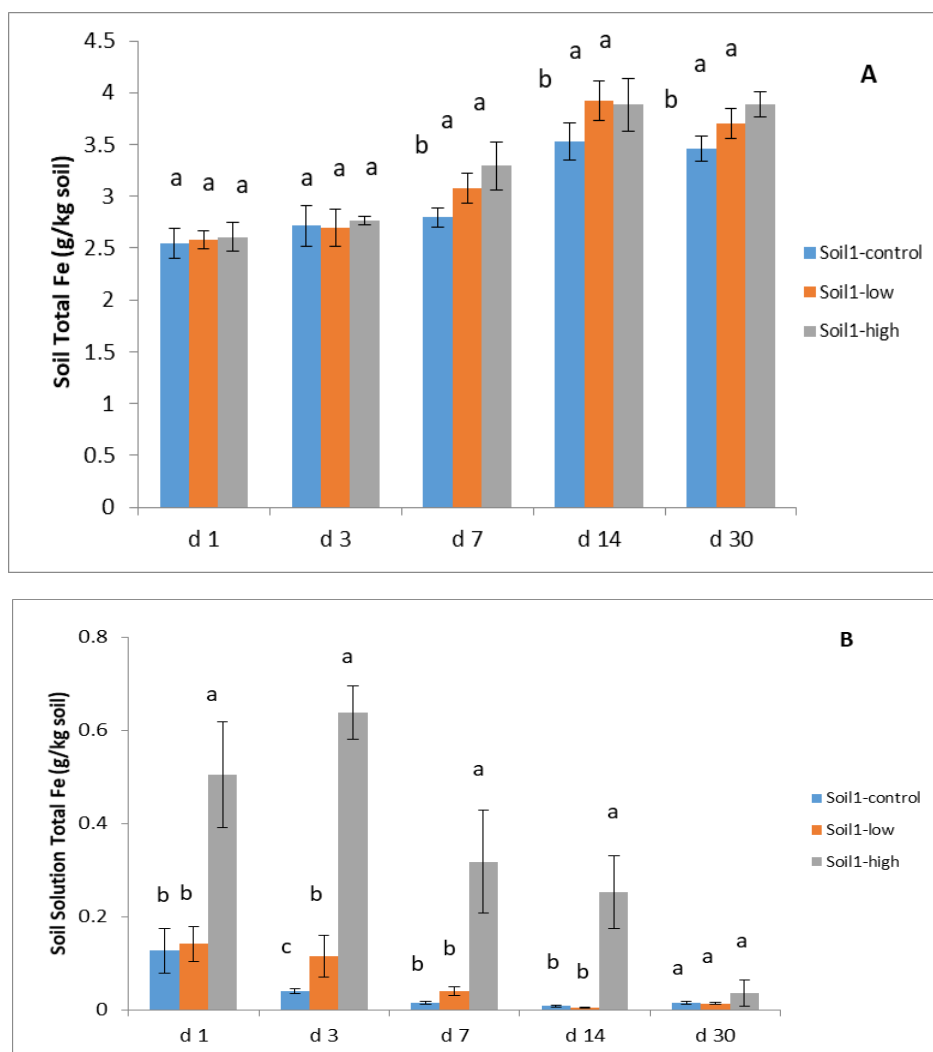


Figure 1: Total Fe concentrations in soil (A) and soil solution (B) for control (water only); low (0.25 g glucose+oxalate per kg soil); high (1 g glucose+oxalate per kg soil) for 30 day incubation for soil1

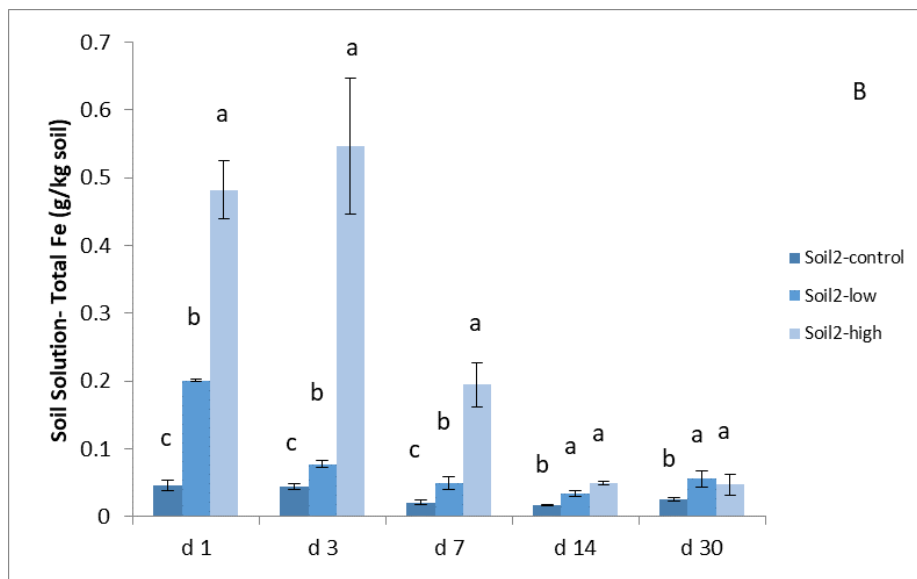
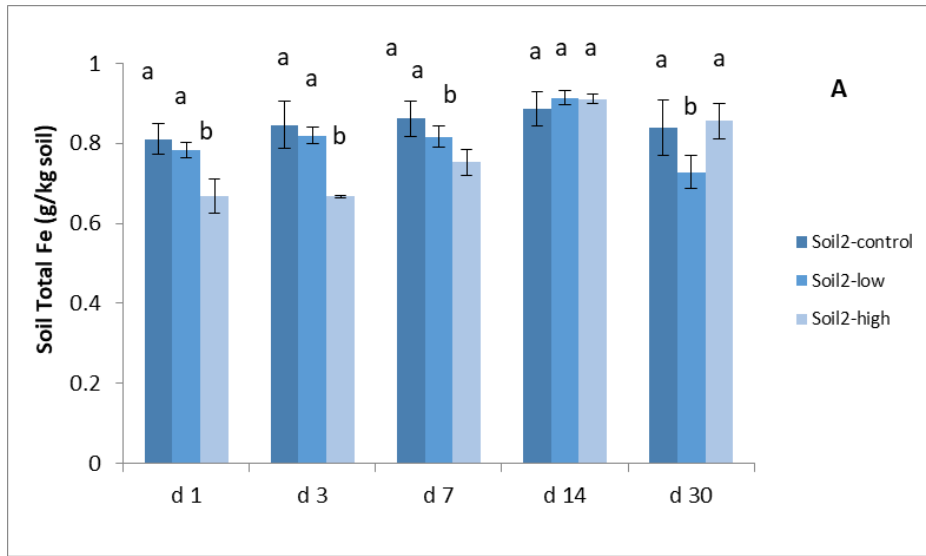
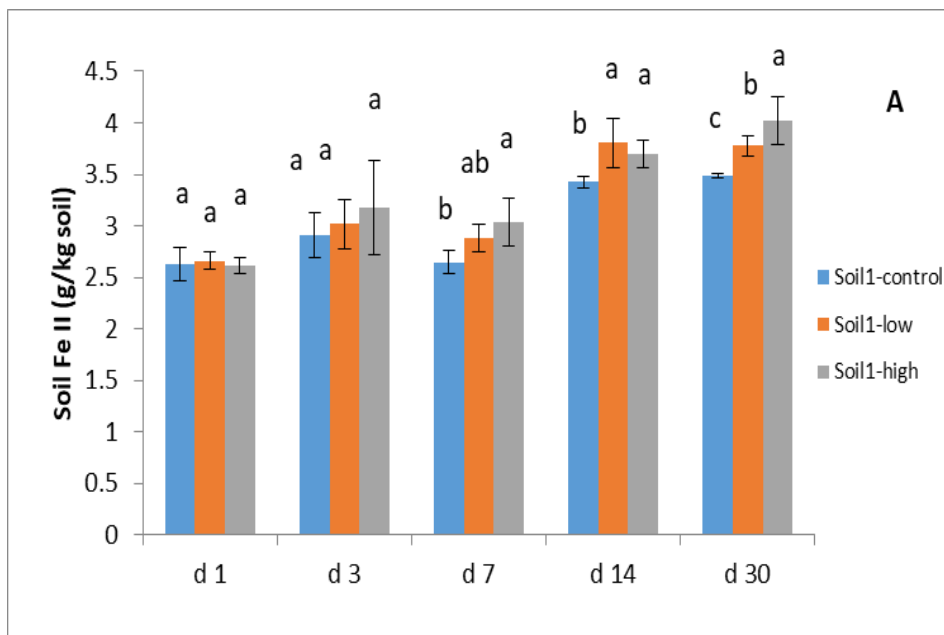


Figure 2: Total Fe concentrations in soil (A) and soil solution (B) for control (water only); low (0.25 g glucose+oxalate per kg soil); high (1 g glucose+oxalate per kg soil) for 30 day incubation for soil2



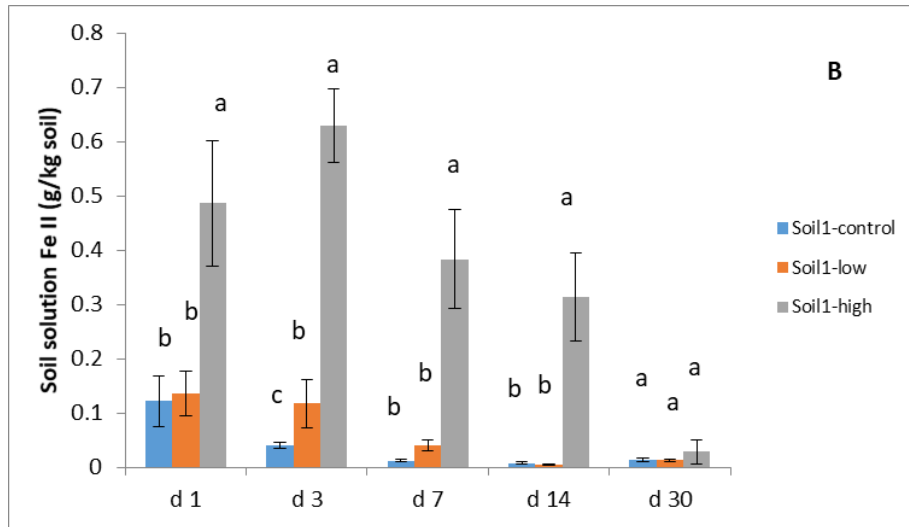


Figure 3: Fe II in soil (A) and soil solution (B) for control (water only); low (0.25 g glucose+oxalate per kg soil); high (1 g glucose+oxalate per kg soil) for 30 day incubation for soil1

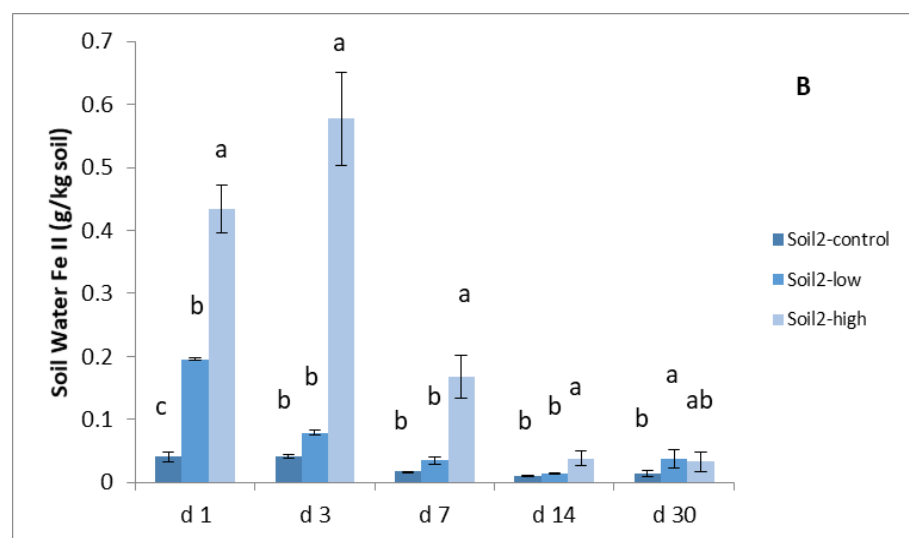
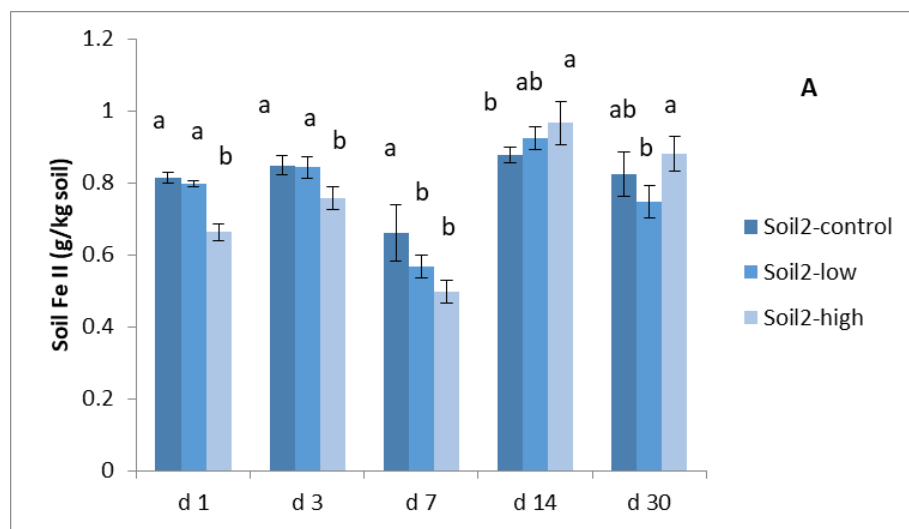


Figure 4: Fe II in soil (A) and soil solution (B) for control (water only); low (0.25 g glucose+oxalate per kg soil); high (1 g glucose+oxalate per kg soil) for 30day incubation for soil2

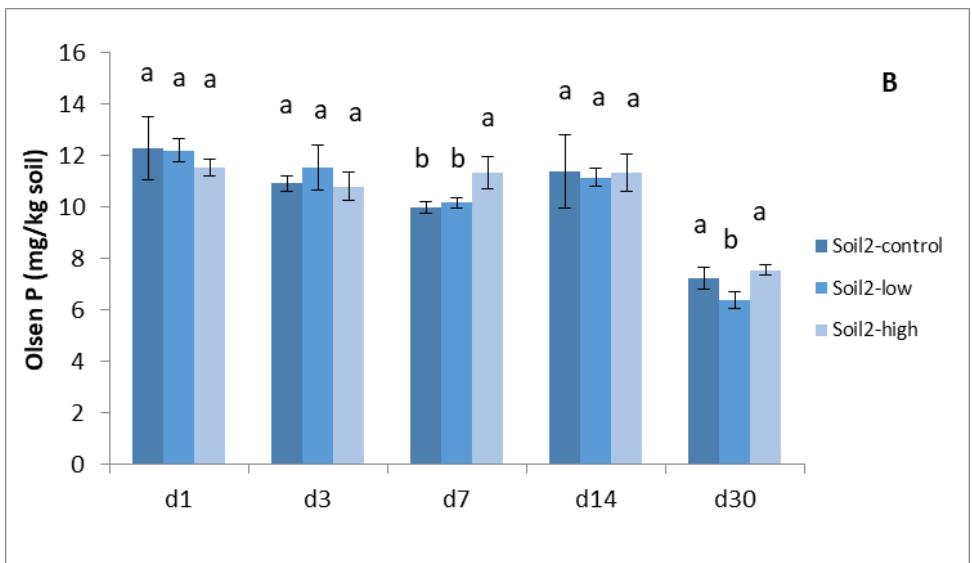
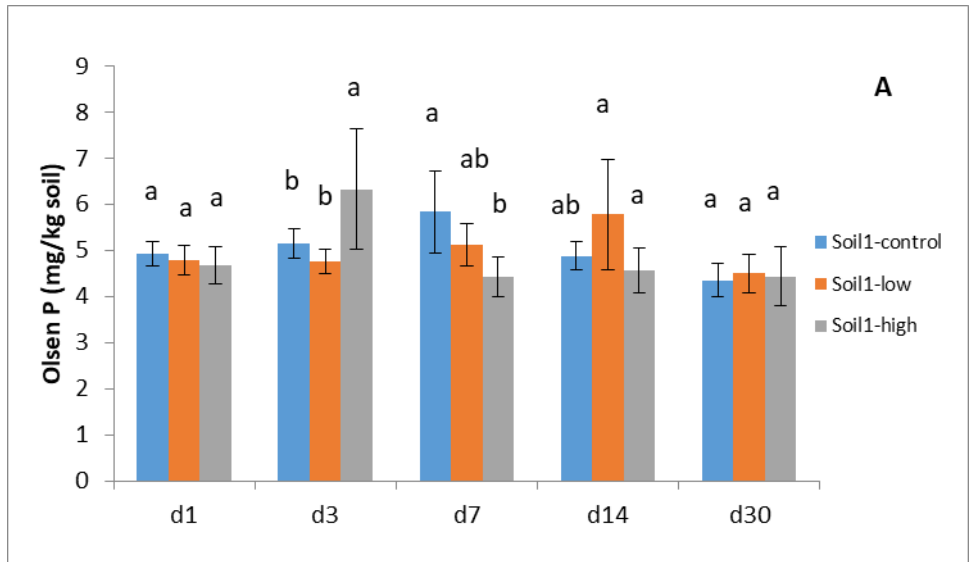
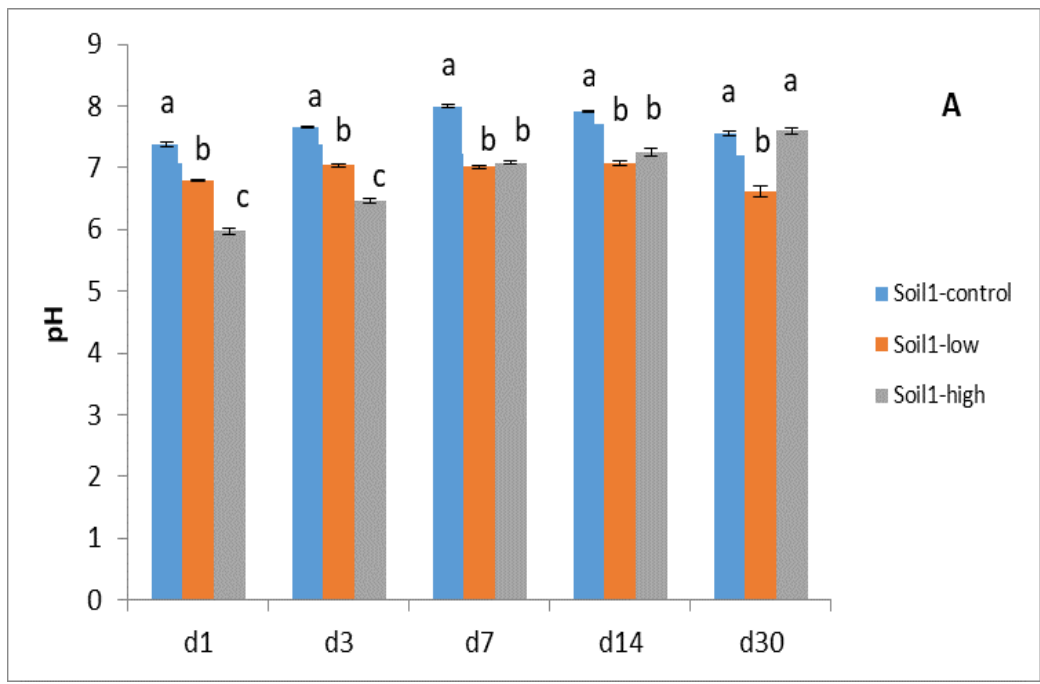


Figure 5: Available P (Olsen P) in soil1 (A) and soil2 (B) for control (water only); low (0.25 g glucose+oxalate per kg soil); high (1 g glucose+oxalate per kg soil) for 30 day incubation



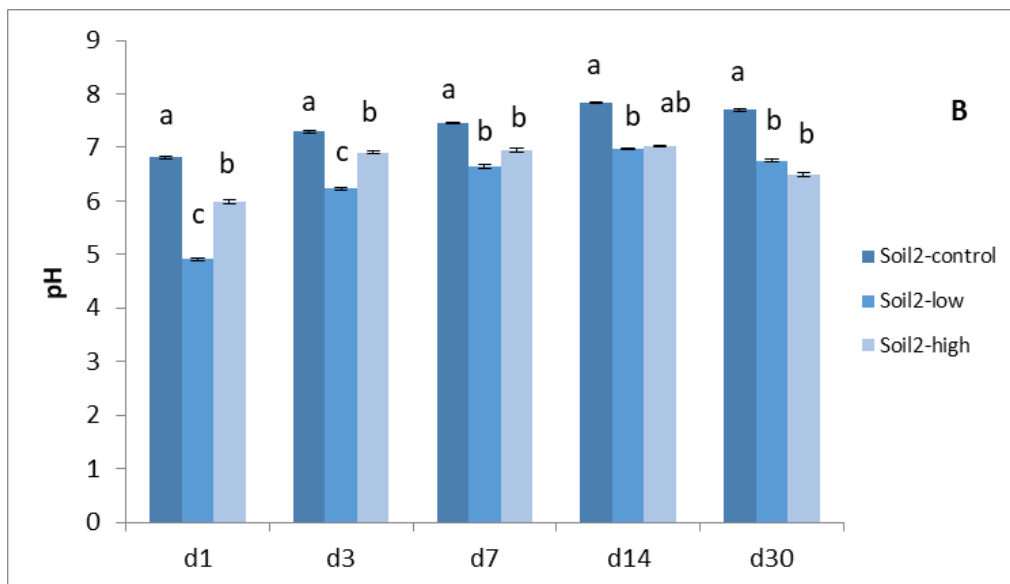


Figure 6: Changes of pH in soil1 (A) and soil2 (B) for control (water only); low (0.25 g glucose+oxalate per kg soil); high (1 g glucose+oxalate per kg soil) for 30 day incubation

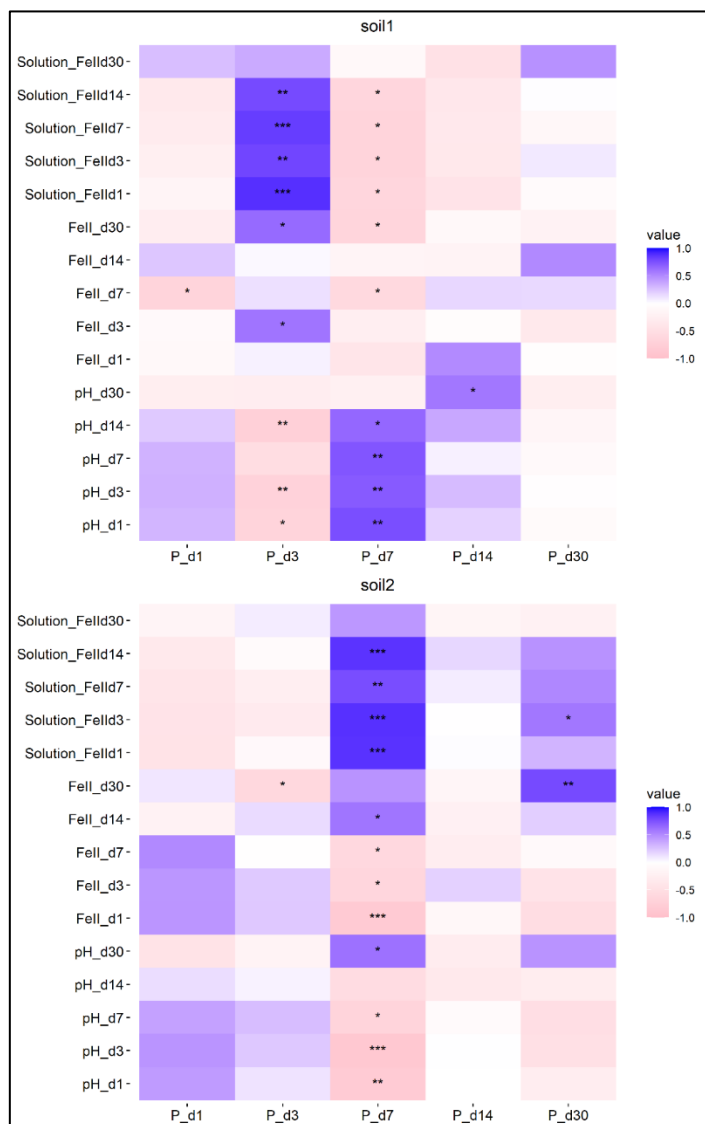


Figure 7: Correlation of Fe II in soil and soil solution with available P and pH in soil 1 and soil 2 for 30 day incubation

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