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Short communication

Effect of drying and rewetting on phosphorus transformations in red brown soils with different soil organic matter content

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Abstract

In this study, the effect of drying and rewetting on native P transformations in two red brown soils with different management history was investigated. Three treatments, T1 (constantly moist), T2 (dried for 4 days and then kept dry), T3 (rewetted after 4 days drying) were used. Drying and rewetting caused a rapid increase in microbial P (Pm) and labile organic P (labile Po) within 1 day and a gradual increase in available inorganic P (Colwell). These increases were only temporarily, as Pm and labile Po decreased with time and were at the same level as in the constantly moist soil by the end of the incubation period of 21 days. The effect of drying and rewetting on P transformations strongly depended on soil organic matter content, being more pronounced in the soil with high organic matter content, compared to the soil with low soil organic matter content.

Keywords: Availability; Biomass P; Drying; Labile organic P; Phosphorus; Rewetting; Soil; Transformations

Phosphorus is a very important nutrient in agricultural production. In soils, it is rapidly transformed from one pool to another and the transformation rates are affected by a large number of factors. Of these, drying and rewetting has been reported to significantly influence soil P availability. However, this effect is dependent on soil properties and thus differs between soils. The effects of drying and rewetting can be separated into biological, chemical and physical effects.

Van Gestel et al. (1993) indicated that up to 58% of the total microbial biomass may be killed by soil drying and rapid rewetting. Turner et al. (2003) confirmed that lysed bacterial cells are the source of a large proportion of the increase in water-extractable organic P after soil drying. A portion of the microorganisms survives drying by accumulation of cytoplasmic solutes that serve as osmoregulators in the cells. Upon rapid rewetting, the cells of some microorganisms will burst caused by the influx of water into the cells, while others will survive by release of intracellular solutes to maintain the proper cell turgor pressure and subsequently rapidly mineralise the compounds released by the dead micro-organisms (Birch, 1958, 1959; Halverson et al., 2000).

Wiklander and Koutler-Andersson (1966) proposed three chemical processes that decrease P availability in dry soils. Drying would (i) increase the ion concentration in the soil solution, leading to P fixation; (ii) decrease the solubility of many compounds, including Fe, Al and Ca phosphates; and (iii) induce oxidation, for example of Fe^{2+} to Fe^{3+}, which would lead to formation of less soluble P compounds. On the other hand, drying and rewetting may result in chemical breakdown of organic matter thereby increasing P availability (Laura, 1975). The physical changes induced by drying and rewetting can also have opposing effects. Disruption of bonds between organic compounds may increase mineralisation and thereby P availability. On the other hand, aggregate breakdown may expose more P adsorption sites, which would decrease P availability (Raveh and Avnimelech, 1978). The aim of this study was to investigate the effects of drying and rewetting in two soils with different organic matter content. Our hypothesis was that effects of drying and rewetting would be more pronounced in the soil with the higher organic matter

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content due to the higher biomass and thus greater magnitude of biological effects.

The investigation was conducted with Urrbrae fine sandy loam (red brown soil 20% clay, 33% silt, 41% fine sand and 3% coarse sand; after Tisdall, 1980). The climate is mediterranean with cool moist winters and hot, dry summers. Two plots of the long-term rotation trial at Waite Campus, University of Adelaide were sampled (0–10 cm) at the end of summer (after more than 3 months without significant rainfall): permanent pasture (PP) covered by a mixture of grasses and wheat fallow (WF) in the phase of fallow. The management regime (PP or WF), which included regular addition of mineral fertilizer (N, P and K), has been applied since 1924. Soils from these two plots differ in carbon content, which was 3.0% in PP, and 1.3% in WF. The soil was sieved to 2 mm and filled into 24 shallow plastic trays (10 cm × 20 cm by 5 cm height) with 1.2 kg soil per tray. The trays were placed randomly in a temperature-controlled room at 20 °C and re-randomised after each watering. Field capacity was 43 and 28% gravimetric water content for PP and WF soils, respectively.

All soils were pre-incubated at field capacity for 7 days. Then the following three treatments were started (four replicate trays per treatment): T1 (moist treatment): constant moisture at field capacity maintained by daily watering for 23 days; T2 (drying treatment): the soil was dried with a low powered fan at 30 °C for 4 days, then kept dry for 19 days; and T3 (drying and rewetting): the soil was dried with a low powered fan at 30 °C for 4 days, then rapidly rewetted to field capacity and kept moist for another 18 days.

By the end of the 4-day drying period soil moisture content of the treatments T2 and T3 was approximately 5% gravimetric water content for WF and 9% for PP. Soil moisture in T1 and T3 after rewetting was controlled by monitoring the weight of the trays daily and adding the appropriate amount of distilled water when necessary.

The soils were sampled immediately before drying and during the incubation period on days 0, 1, 2, 4, 7, 10, 14, 18. Soil organic carbon (SOC) was determined according to Walkley and Black (1934). Available Pi was measured by the Colwell method (1963). Total available P (Pta) in Colwell extracts was estimated using the procedure proposed by Tiessen and Moir (1993). Labile organic P (labile Po) was calculated by the difference between Pta and Pi. Biomass P (Pm) was determined by the fumigation–extraction method after Kouno et al. (1995). The P concentration in the extracted solutions (available Pi, total P and biomass P) was measured colorimetrically by autoanalyser based on Murphy and Riley (1962).

The SOC content was higher in the PP soil (3%) than the WF soil (1.3%) before and after incubation and it slightly decreased during incubation. There were no significant differences in SOC content between treatments after incubation (data not shown). The soil with high SOC content (PP) had higher concentrations of available Pi and labile Po than the soil with low SOC content (WF)

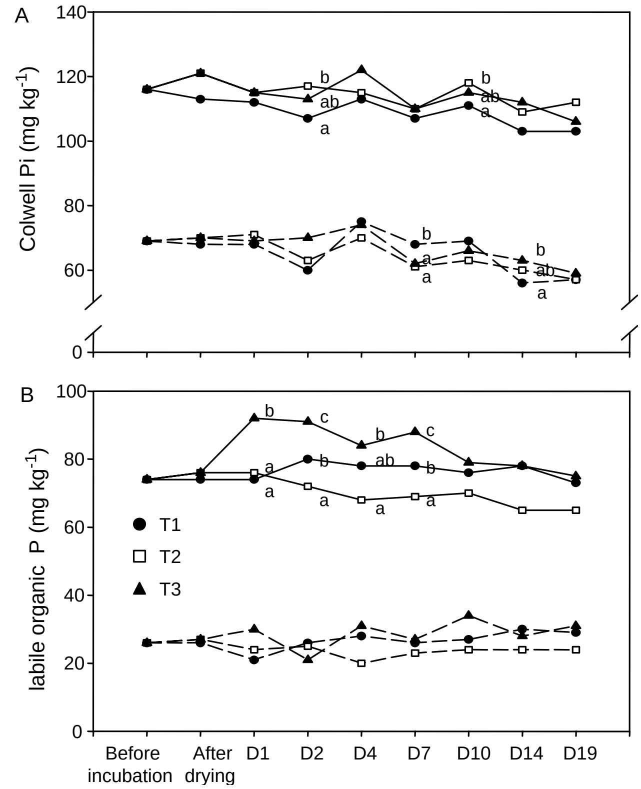

Fig. 1. Changes in Colwell P pools (A) available Pi and (B) labile Po during the incubation period in two soils PP (solid lines) and WF (dashed lines) and three treatments, T1 (constantly moist), T2 (dried for 4 days and then kept dry), T3 (soil being rewetted after 4 days drying). Data are means of four replicate samples. Data of each soil (PP and WF) at a given sampling date followed by different letters are significantly different ($P \leq 0.05$).

(Fig. 1A). Differences in Colwell P pools between treatments were more pronounced in the PP soil with higher SOC content than in the WF soil with lower SOC content. Drying alone (T2) and drying and rewetting (T3) caused a significant increase in available Pi, compared with T1 (constant moist) in the PP soil while there were no significant differences between the three treatments in the WF soil (Fig. 1A, Table 1). Colwell Pi concentrations in both soils were high.

Drying had no effect on the labile Po concentration in the PP soil (Fig. 1B). However, rewetting of the dried soil (T3) resulted in a rapid increase of labile Po within one day. The labile Po concentration then slowly decreased during incubation in T3. The effect of rewetting on labile Po lasted less than 14 days; after 14 days the labile Po concentration in T3 was similar to the level before incubation. In the constantly moist treatment (T1), labile Po remained relatively stable during incubation. In the WF soil, the differences in labile Po between the treatments were less pronounced than in the PP soil (Fig. 1B, Table 1).

The soil with high SOC content (PP), had a higher biomass P (Pm) concentration than WF, the soil with low SOC content, and the effect of the treatments on Pm

Table 1
Significance of *t*-test comparisons between treatment pairs in available Pi, labile Po and biomass P in two soils (PP and WF) during incubation $n=7$ (7 sampling times after drying); ns, not significant; *, **, ***significant at $P\leq 0.05$, $P\leq 0.01$ and $P\leq 0.001$, respectively

P pools	Soils	Treatments	T1	T2
Available Pi	PP	T2	0.0010**	
		T3	0.0008***	0.7455 ns
	WF	T2	0.6031 ns	
		T3	0.5302 ns	0.0664 ns
Labile Po	PP	T2	0.0166*	
		T3	0.0132*	0.0007***
	WF	T2	0.0786 ns	
		T3	0.2898 ns	0.0312*
Biomass P	PP	T2	0.0006***	
		T3	0.0323*	0.0035**
	WF	T2	0.0000***	
		T3	0.1565 ns	0.0053**

depended on SOC content (Fig. 2, Table 1). In the PP soil, drying soil for 4 days resulted in a reduction in Pm. Rewetting of the dried soil rapidly and significantly increased Pm within 1 day. This effect was also observed in the WF soil, but the differences between treatments were not as obvious as in the PP soil. The increased Pm in T3 was maintained throughout the incubation period in the PP soil, while in the WF soil it was no longer observed 14 days after rewetting. Biomass P was quite low; representing only 10% of Colwell Pi. Similar biomass P concentrations (10 mg kg^{-1}) were found in a cropping soil from Western Australia (McNeill et al., 1998).

The results of this study confirm the hypothesis that soil organic matter content is important for the effect of drying and rewetting on soil P transformations. The increase in labile Po, Pm and available Pi as a result of drying

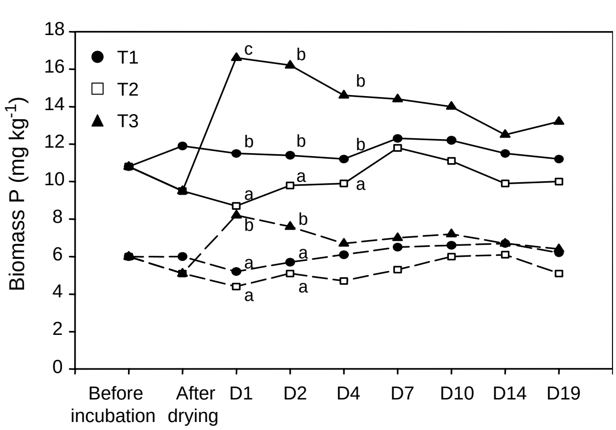

Fig. 2. Changes in Pm with time in two soils PP (solid lines) and WF (dashed lines) and three treatments, T1 (constantly moist), T2 (dried for 4 days and then kept dry), T3 (soil being rewetted after 4 days drying). Data are means of four replicate samples. Values for each soil (PP and WF) at a given sampling date followed by different letters are significantly different ($P\leq 0.05$).

and rewetting (T3) compared with T1 (constantly moist) was more pronounced in the soil with high organic matter content (PP) than in the soil with the low organic matter content (WF).

In the present study, drying and rewetting had no significant effect on SOC. This is in agreement with Magid et al. (1999). On the other hand, it has also been reported that drying and rewetting may result in higher SOC turnover (Denef et al., 2001). Organic matter content and size of microbial biomass are positively correlated (Banu et al., 2004). As a consequence, biomass P was higher in the PP soil than in the WF soil (Fig. 2). After the 4-day drying period, biomass P was reduced by 12% in PP and by 15% in WF. Pm was reduced after drying because drying may cause cell lysis (Turner et al., 2003) or death of organisms (Sparling et al., 1985; Van Gestel et al., 1993). Rewetting of the dried soil rapidly increased labile Po (Fig. 1) within 1 day. This occurs when rapid rehydration follows a period of drying and intracellular solutes from soil microorganisms are released by cell lysis or in order to avoid excessive turgor pressure (Halverson et al., 2000; Fierer and Schimel, 2003).

Although many soil organisms are killed by drying and rewetting, a proportion of the microbial biomass survives. Due to the increase in available nutrients (C, N and P) after rewetting the surviving microorganisms will be able to multiply rapidly. In the present study this is indicated by the increase in biomass P (Fig. 1). This rapid increase in biomass after rewetting is in agreement with other studies (Mondini et al., 2002; McNeill et al., 1998). The rapid increase in biomass P in this study had little effect on the available P concentrations, which may be explained by the relatively small biomass P compared to available P concentrations. The increase in labile Po may also be explained by an increase in solubility of organic matter by disruption of soil aggregates thus exposing organic matter that was previously inaccessible to micro-organisms (Haynes, 1986). With the decrease in concentration of easily decomposable substances as a result of decomposition and mineralization, labile Po and Pm gradually decreased in both soils. This decrease was slower in the PP soil than in the WF soil. Available P concentrations also decreased over time and were probably due to adsorption of available P to freshly exposed organic matter and mineral surfaces and net immobilisation of P by the microbial biomass.

In conclusion, this study showed that drying and rewetting had a stronger effect on P transformations than drying alone. After rewetting, biomass P and labile organic P increased rapidly while available Pi increased more slowly. The effect of drying and rewetting was more pronounced in the soil with high SOC content than in the soil with low SOC content. These results emphasize the importance of biological processes on P transformations during drying and rewetting.

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