THE EFFECT OF SOIL MOISTURE ON RESIDUAL FLUID AND GRANULAR PHOSPHORUS AVAILABILITY

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Abbreviations; monoammonium phosphate (MAP), technical grade monoammonium phosphate (TGMAP), zinc (Zn), phosphorus (P).

ABSTRACT

Fluid and granular fertilizer containing zinc and phosphorus were incubated for four weeks air dry and at optimal moisture in six soils from the cereal growing regions of Southern Australia and Kansas. Following the incubation, measurements were made of fertilizer diffusion, soluble nutrient concentration and labile nutrient concentration. The results demonstrate that a dry incubation inhibits the diffusion of phosphorus and zinc fertilizer and needs to be considered when dry sowing fertilizer and seed simultaneously. The dry incubation also decreased the lability of zinc at the point of fertilizer application indicating that despite the presence of high concentrations of zinc, this zinc has already reacted with the dry soil and the amount of potentially available zinc has reduced.

INTRODUCTION

Laboratory experiments have indicated that fixation reactions for phosphorus (P) slow down in dry soil (Bramley *et al.* 1992), and residual effectiveness of superphosphate decreased as soil water content increased (Bolland and Baker 1987). However, these experiments added P to soil as liquids or powders and uniformly mixed the fertilizer with the soil. Indeed, much of the early glasshouse work on interactions between soil moisture and nutrient availability have used soils with fertilizer P and micronutrients uniformly mixed throughout the plant growth medium rather than banded as fluid or granular fertilizer which is the normal method of application in the field. As a result of these laboratory studies, the common perception is that dry soil means that fertilizers do not react with the soil, and residual fertilizer efficiency in the year following drought is high.

Our recent research has shown that movement of soil water in and around granules can have a marked influence on chemical reactions which control fertilizer effectiveness (Hettiarachchi *et al.* 2006; Lombi *et al.* 2006). When a fertilizer granule is placed in moist soil, it draws soil water towards it and also draws solutes in the soil water into the granule. In a calcareous soil this enhances precipitation of calcium phosphate compounds in and around the granule (Lombi *et al.* 2004a), which reduces granular fertilizer effectiveness markedly (Bertrand et al. 2006; Holloway et al. 2001). We have discovered this is one of the reasons why delivery (into soil) of exactly the same fertilizer formulation in fluid form can enhance fertilizer efficiency markedly compared to granular products, especially in calcareous soil (Lombi *et al.* 2004a). It is therefore evident that changes in soil water status could markedly affect the reactions occurring in and around fertilizer granules in soil, a phenomenon not well reproduced in most laboratory experiments when nutrients are uniformly mixed throughout the soil. The aims of this experiment were to investigate the effect of soil moisture and fertilizer form on the diffusion and lability of P and zinc (Zn) in six different agricultural soils from Southern Australia and the US.

MATERIALS AND METHODS

Six soils were chosen from cereal production areas of Southern Australia and Kansas, USA. The Australian soils were Langhorne Creek (calcarosol), Warramboo (hypercalcic calcarosol), Kangaroo Island (ironstone), and Walpeup (sand). The US soils were Osage county and Wary of Weir, Cherokee county, Kansas (Bates silt loam). Some basic soil properties are shown in Table 1. We have excluded Kangaroo Island and Walpeup from the full data presentation due to space constraints.

Table 1. Soil Characteristics

Test	Units	Langhorne Creek	Kangaroo Island	Walpeup	Warramboo	Osage	Wary
pH	H_2O	8.3	5.9	7.6	8.3	6.0	6.0
$EC_{1:5}$	dS/m	0.23	0.19	0.06	0.16	0.07	0.17
$CaCO_3$	% w/w	2.8	nd	nd	60	*	*d
Clay	% w/w	17.5	9.8	12	9	*	*
TOC	% w/w	2	6.46	0.8	1.1	1.13	0.42
Total Ca	mg/kg	15524	5602	1742	245536	2598	1145
Total Fe	mg/kg	13867	12024	9137	3680	17450	99242
Total Al	mg/kg	15524	25379	14935	4830	21121	942952
Total P	mg/kg	506	537	89	343	310	360
DGT CE_P	µg/L	151	135	197	354	618	739
Total Zn	mg/kg	21	27	25	27	50	34

†EC-electrical conductivity, Al-aluminium, Fe-iron, Ca-calcium, $CaCO_3$- calcium carbonate, TOC-total organic carbon, DGT PCE- diffusive gradient in thin film effective concentration phosphorus.*data not available, nd -not detected.

The two soil moisture treatments were air dry (to simulate dry fertilizer application) and 80% of field capacity (to simulate optimal moisture conditions for sowing and fertilizer application).

The two fertilizer treatments were granular uncoated monoammonium phosphate (MAP, 10:22:0) manually coated with a zinc chloride solution, and fluid technical grade monoammonium phosphate (TGMAP, 12:26:0) with zinc chloride in solution. For the granular treatment, fertilizer granules were selected based on their weight in order to add 8.8 mg P per petri dish and coated with 3µL of zinc chloride solution to add 0.6 mg Zn per petri dish. For the fluid treatment aliquots containing 8.8 mg P were diluted to 200 µL with distilled water.

Soils were packed to an approximate bulk density of 1.3 g/cm^3 in 15cm diameter petri dishes, wet to the appropriate moisture content and allowed to equilibrate for 24 hrs. Following this equilibration, a Zn coated MAP granule or 200µL of Zn-TGMAP blend was applied to the very centre of the petri dish, and the petri dishes were incubated at 20°C for four weeks, at the two different moisture potentials. At the end of the incubation concentric rings of soil with increasing radius were removed from the dish at the moisture at which they were incubated.

The soils were then dried down at 35°C and subsamples were used to measure the pH, diffusion and lability of Zn and P. The percentage of P (or Zn) from fertilizer in the soil sections collected from the point of fertilizer application was calculated as follows %Padded = [Psec x Wsec]/ sum of [Psec 1-4 x Wsec1-4] where sec is the soil section, Psec and Wsec are the concentration of fertilizer P and the soil weight of each section respectively. Psec is calculated by subtracting the P concentration of untreated soil from the concentration of the fertilized soil. A subset of all data will be presented in this paper. Gentstat® 10th Edition was used for all statistical analyses.

RESULTS AND DISCUSSION

Phosphorus Diffusion and Solubility

The most important effects of the treatment regime on phosphorus diffusion was the effect of incubation moisture on P diffusion. A dry incubation resulted in little or no diffusion of fertilizer P (displayed as P % of added) away from the first section (0-7.5mm) of the petri dish where the fertilizer was added (Figure 1.1,1.3 and 1.4.). A moist incubation resulted in improved diffusion with the second petri dish section (7.5-13mm) having a greater amount of P than the first section for the non-calcareous soils (Langhorne Creek, Osage and Wary). In contrast there was not the same difference between incubation moistures for the calcareous Warramboo soil suggesting that fertilizer diffusion is severely restricted even when this soil is incubated wet (Figure 1.2). There was a small diffusion advantage in the second section (7.5-13mm from application point) for the fluid P source when incubated wet in the Warramboo soil. We suspect that we have not observed the large differences between fluid and granular forms in the Warramboo soil because we used uncoated fertilizer in order to layer Zn on the fertilizer granule in the laboratory before adding it to the petri dish.

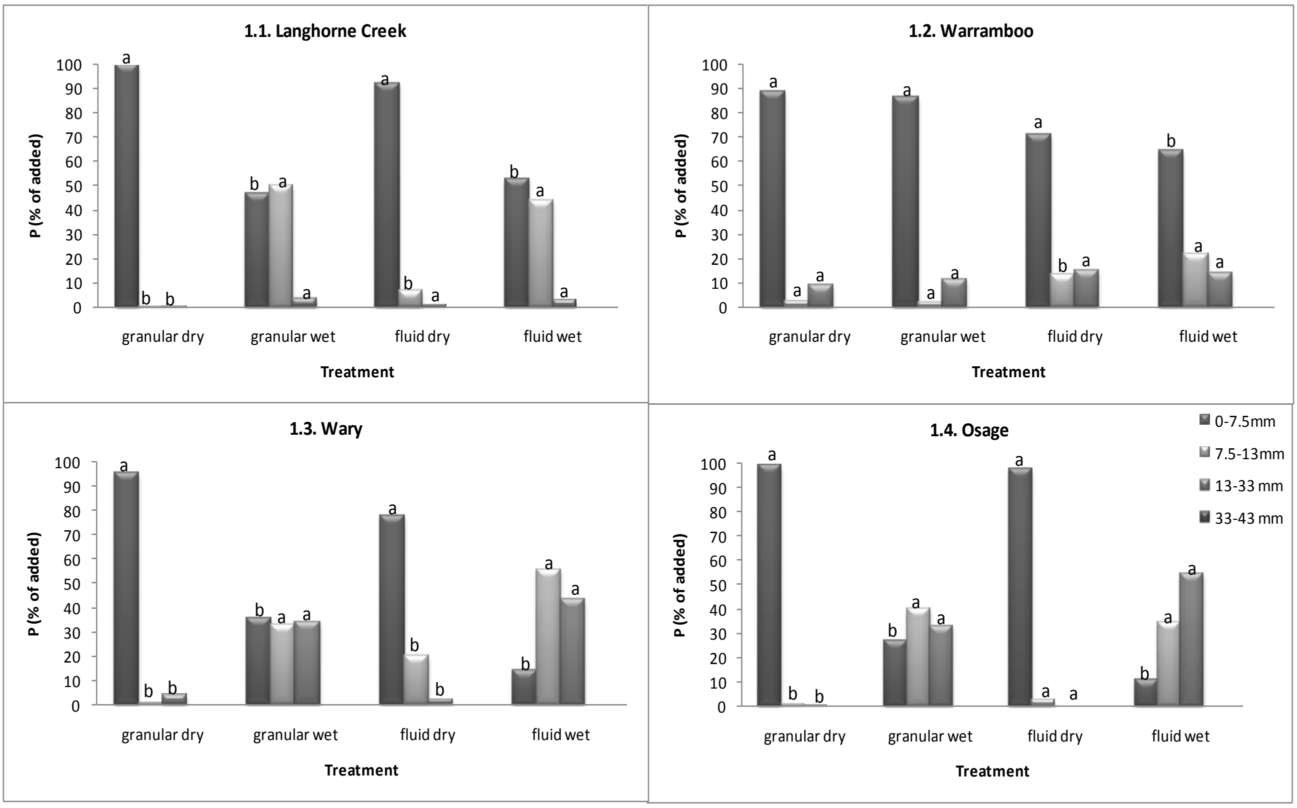

Figure 1.1 Langhorne Creek, 1.2 Warramboo, 1.3 Wary and 1.4 Osage. Percentage of P derived from fertilizer in petri dish soil sections. Within a fertilizer and section, a column appended with a different letter represents a different P % of added (i.e. Fig 1.1. section 0-7.5mm dry is greater than wet and section 7.5-13 mm wet is greater than dry).
$P<0.001$ LSD section 0-7.5mm=7.4, section 7.5-13mm=3.52, section 13-33mm=2.80 section 33-43 mm not significant.

The issue with the restriction of diffusion is the increased probability of excessive P concentrations at the point of addition which then participate in precipitation reactions reducing the lability of fertilizer (Lombi *et al.* 2004b). This reduced diffusion effect, regardless of fertilizer form, needs to be considered when making decisions about dry sowing, especially in soils with high levels of calcium, iron or aluminium.

The water soluble P data closely follows the diffusion data (Figure 2.1-2.4). The highest concentration of water soluble P is in the first (0-7.5mm) section and diminishes away from the point of application. The wet incubation had the effect of increasing the amount of water soluble P in the second (7.4-13mm) section in all cases except for the calcareous Warramboo soil where there is no difference between treatments in this section. In this second section, the Langhorne Creek and Wary soil had more water soluble P for the fluid treatment than the granular, but the opposite was true for the Osage soil. The implications of the soluble P data will be better defined with the labile P data which is currently being analysed and will be provided during the oral presentation.

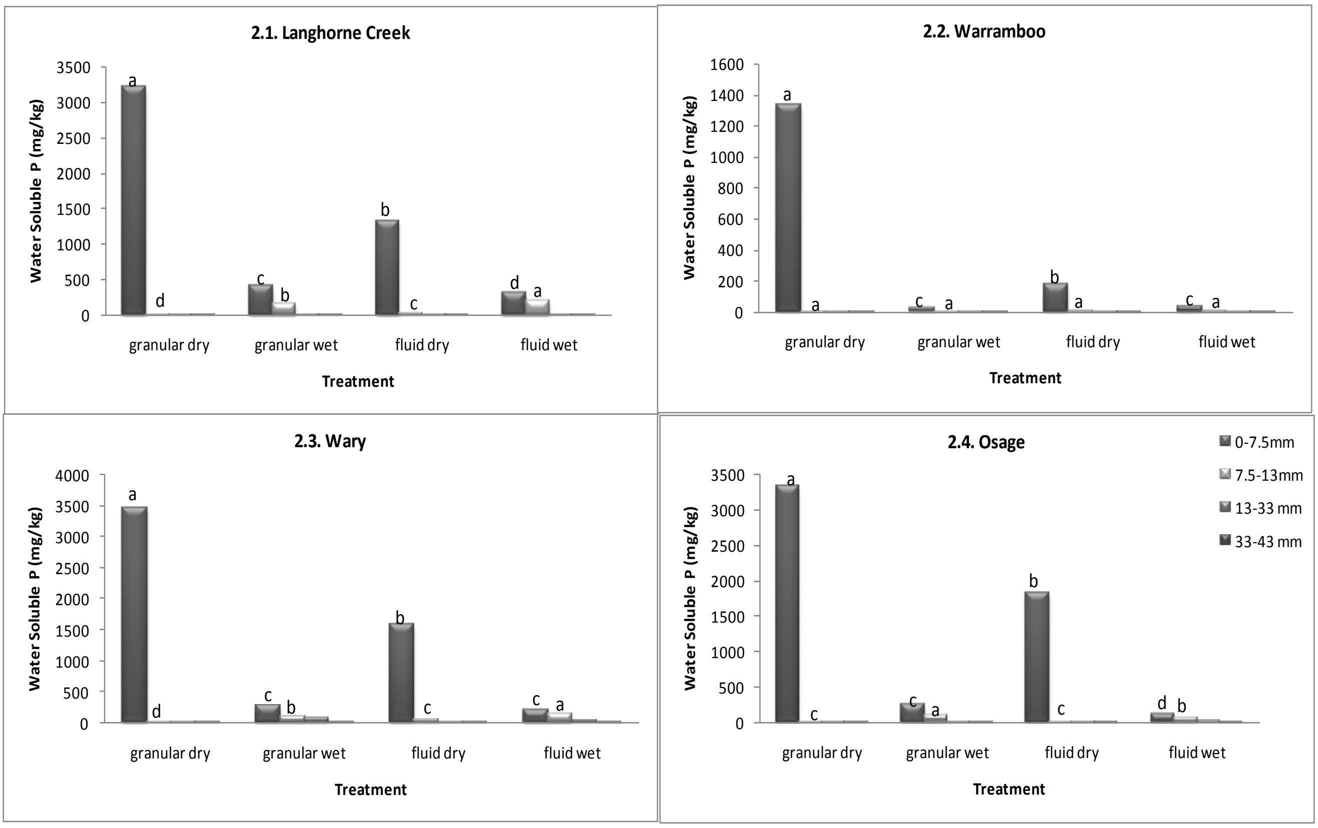

Figure 2.1 Langhorne Creek, 2.2 Warramboo, 2.3 Wary and 2.4 Osage Water soluble P (mg/kg). Within a section, a column appended with a different letter represents a different Water soluble P. (i.e. Fig 2.1. section 0-7.5mm granular dry > fluid dry >granular wet> fluid wet). Water x fertilizer interaction P<0.001 LSD section 0-7.5mm=104.4, section 7.5-13mm=15.14, section 13-33mm= not significant section 33-43 mm not significant.

Zinc Diffusion and Lability

When the Osage and Wary soil was incubated dry, there was virtually no diffusion of Zn away from the point of application. In comparison there was some diffusion of Zn when incubated wet and therefore a greater % of Zn added was located in the second (7.5-15mm) and third (13-33mm) sections. In contrast, in the highly calcareous Warramboo soil, the wet and dry incubated Zn fertilizer behaved in the same way with a small amount of Zn measured in the second and third sections in both cases. The Langhorne Creek data is difficult to interpret as the granular wet treatment data is not available.

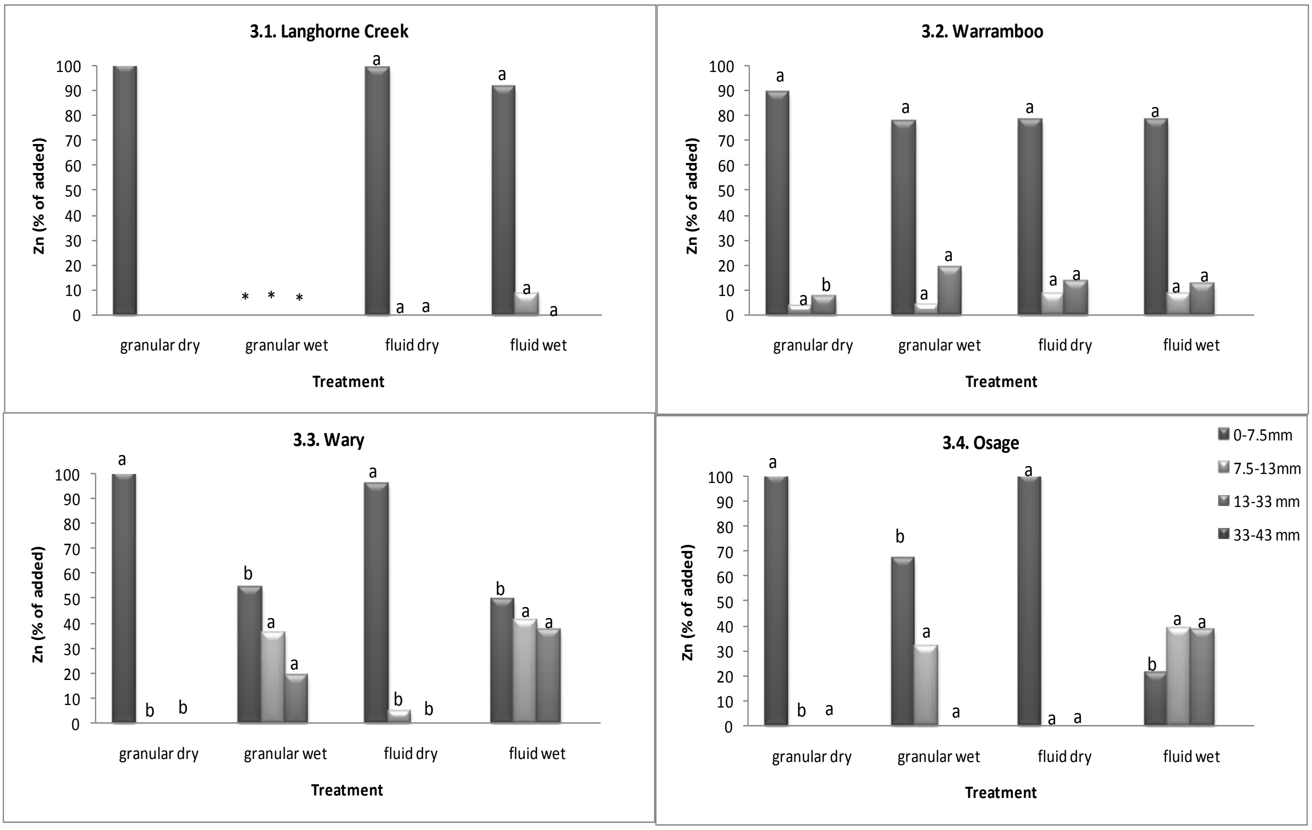

Figure 3.1 Langhorne Creek, 3.2 Warramboo, 3.3 Wary and 3.4 Osage. Percentage of Zn derived from fertilizer in petri dish soil sections. Within a fertilizer and section, a column appended with a different letter represents a different % Zn added (i.e. Fig 3.3. section 0-7.5mm dry is greater wet and section 7.5-13 mm wet is greater than dry).
P<0.001 LSD section 0-7.5mm=13.7, section 7.5-13mm=5.12, section 13-33mm=4.14 section 33-43mm not significant.* data not available.

The labile Zn in the first 0-7.5mm petri dish section is presented in Figure 4 (the lability of Zn in the remaining sections is so low that it is not presented). The effect of fertilizer was not significant therefore data is compared on a wet incubation vs. dry incubation basis. The data show that for two of the non-calcareous soils (Langhorne Creek and Osage) the amount of labile Zn at the point of fertilizer application is higher when fertilizer is incubated moist while there was no effect of soil moisture in the Wary soil. In the calcareous Warramboo soil the amount of labile Zn is higher when the soil was incubated dry suggesting rapid fixation and/or precipitation reactions in the presence of moisture. Detection of Zn is an issue, especially for the Warramboo which has a very high fixation capacity for Zn. The higher level of labile Zn when wet suggests that while there may be high concentrations of Zn when incubated dry, the lability of this nutrient is diminished and must be assumed to be reacting with the soil.

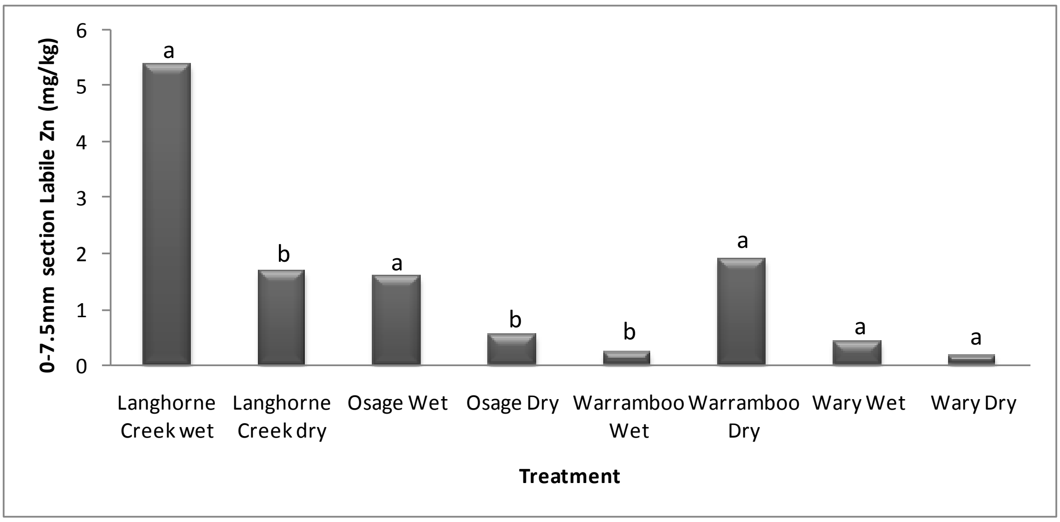

Figure 4.Labile Zinc (mg/kg) in the first section (0-7.5mm from point of application) of the petri dish. Different letters indicate a significantly different labile Zn within a soil type (P=0.003, LSD=0.526).

CONCLUSIONS

The major finding of this study is that the diffusion of both fluid and granular forms of P and Zn are inhibited when incubated dry. In the highly calcareous soil, the diffusion of Zn and P were inhibited regardless of whether the soil was wet or dry. Labile Zn was found to be higher at the point of application when incubated wet suggesting that while there may be high concentrations of Zn at the point of fertilizer application when incubated dry, the lability of this nutrient has been restricted. The purpose of this experiment was to simulate the conditions of wet vs. dry sowing (where fertilizer is assumed to be provided at the time of sowing). Given the effect of soil moisture, filling in the continuum between wet and dry sowing with testing of scenarios such as ‘false starts’ where there is wet sowing followed by an abrupt dry spell and dry sowing but with optimum moisture conditions ensuing will make a significant contribution to our ability to manage fertilizer additions for optimal availability.

This work suggests to us that there are three important areas requiring further clarification which are;

1. The effect of co-locating vs. physically separate application of Zn and P on fertilizer diffusion and lability;
2. The effect of using uncoated vs. coated fertilizer granules on diffusion and solubility; and
3. The effect of wet-dry cycles on diffusion and solubility.

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