Phosphorus placement for wheat and lupins in WA cropping systems

Wen Chen[1, 2], **Richard Bell**[1], **Ross Brennan**[2] and **Mike Bolland**[2]
[1]School of Environmental Science, Murdoch University, Western Australia
[2]Department of Agriculture and Food, Western Australia

KEY MESSAGES

In a soil-crop modelling study, placing phosphorus (P) fertiliser at 8 cm depth often produced higher wheat grain yields than placing it at 4 cm, particularly when growing season rainfall was less than 300 mm together with the dry conditions early in the season. There were no further grain yield responses when P was placed deeper in the soil profile (14 cm).

Lupins responded differently to the P fertiliser placement depths. In the seasons with below-average growing seasonal rainfall, and thus low grain yield potential, the lupin grain yield differences when P was placed at different depths were small, but in the seasons with above-average growing seasonal rainfall, lupins seemed to benefit from deep P placement (14 cm), particularly if it was dry in the spring. As lupins have a demand for P late in the growing season, maintaining P fertiliser in moist soils (through deep banding) late in the season would be important to meet the P demand by lupins, particularly if the potential yield was high but spring conditions were dry.

AIMS

Significant vertical stratification of soil nutrients, particularly soil immobile nutrients (such as phosphorus (P)) in long-term zero-till fields has been reported in both Australia and overseas (White 1990; Howard et al. 1999). Soil nutrient vertical stratifications could have a significant impact on availability of nutrients to crops, as soil immobile nutrient availability, root growth and activity are more vulnerable to drought in the surface soil layer than those in sub-surface layers. Placing fertiliser deeper in soil may improve nutrient uptake by crops in soils with nutrient stratification. However, the reported crop grain yield (GY) responses from deep P fertiliser placement in the field experiments being conducted across different states in Australia have been inconsistent. This paper combines analysis of literature data and APSIM simulations to evaluate the key factors (such as crop type, season and, etc.) driving the crop GY responses from deep P placement so that site-specific P placement advice could be developed to improve crop P use efficiency.

METHOD

The **A**gricultural **P**roduction **S**ystems S**im**ulator (APSIM) software system simulates cropping systems at the point-scale, accounting for soil chemical, physical and crop physiological growth processes on a daily time step. In this study, the APSIM-wheat and APSIM-lupin modules were parameterised with the maximum and minimum P concentrations in the different parts of wheat (*Triticum aestivum*) and narrow-leaf lupin (*Lupins angustifolius*) based on the literature (Elliott et al. 1997, Bolland and Brennan 2005), and they were then used as reference levels to define optimal and minimal P concentrations and to calculate P stress factors to modify wheat or lupin growth by combining with corresponding water and N stress factors (law of minimum). In the parameterisations of the maximum and minimum P concentrations in the lupin module, late (post-flowering) P uptake and demand by lupin was assumed based on the previous field observations.

The simulations were set up using a duplex soil and long-term climatic data (1957–2006) from Merredin, Western Australia to explore the impact of P placement at the different soil depths (4, 8 and 14 cm) on P uptake and crop GY. The long-term annual average rainfall in Merredin is 323 mm and varies greatly between years (ranging from 178 mm to 591 mm). The growing season rainfall (April to October) is 237 mm making up 72 per cent of the annual rainfall and it also varies significantly (140–418 mm). Soil properties used for specifying the simulations are summarised in Table 1. Low labile P was used to ensure P uptake by the crop would respond to added fertiliser P in most seasons. The labile P and P sorption in the top 15 cm of the soil were assumed to be constant to remove any confounding effect of soil depth on soil P availability. During the simulations, soil water content and labile P were re-set to the crop low limit (CLL) and background level, respectively on the first day of each year to avoid any carryover effects.

Table 1 **Soil properties used for specifying APSIM simulations**

Soil layer (cm)	Soil Wat parameters[1]				Soil P parameters	
	BD (g cm^3)	DUL	CLL	SWCON	Labile P (mg kg^1)	P sorption (mg kg^1)[2]
0–5	1.72	0.17	0.08	0.80	3	100
5–10	1.80	0.18	0.08	0.80	3	100
10–15	1.82	0.22	0.10	0.70	3	100
15–25	1.66	0.24	0.13	0.70	1	200
25–35	1.64	0.28	0.17	0.70	1	200
35–45	1.66	0.29	0.18	0.60	1	200
45–55	1.74	0.29	0.18	0.60	1	200
55–65	1.78	0.29	0.19	0.60	1	200
65–85	1.79	0.29	0.19	0.60	1	200
85–245	1.79	0.29	0.19	0.60	1	200

[1] BD is soil bulk density, DUL (cm cm^{-1}) is drained upper limit, CLL (cm cm^{-1}) is crop lower limit of water extraction, and SWCON is the proportion of water in excess of DUL that drains in 1 day. The values adopted in the table are based on previous modelling studies for a standard duplex soil.

[2] P sorbed at 0.2 mg L^{-1} in solution (also referred to as O&S value).

RESULTS AND DISCUSSIONS

Wheat

P placement at 8 cm depth often improved GY, particularly when GY was < 2500 kg/ha, compared with the placement at 4 cm (Figure 1a). The GY differences between the placements at 8 cm and 4 cm ranged from 0 to 700 kg/ha and varied significantly among the seasons (Figure 1a). The results presented in Figure 1b suggested that the GY benefits from P placement at 8 cm depth were more likely when growing seasonal rainfall was less than 300 mm. The GY differences between the placements at 8 cm and 14 cm were small (≤ 100 kg/ha) in most years (Figure 1a), suggesting no yield benefits when deep banding (14 cm) of P was compared with the current banding practice (about 8 cm) for wheat. This study (Figure 1a, b) reveal that in this winter rainfall-dominant environment, alternating wetting up (rain) and drying (soil evaporation) through individual rainfall events determine soil P availability for crop uptake and thus GY responses when P is placed at the different soil depths.

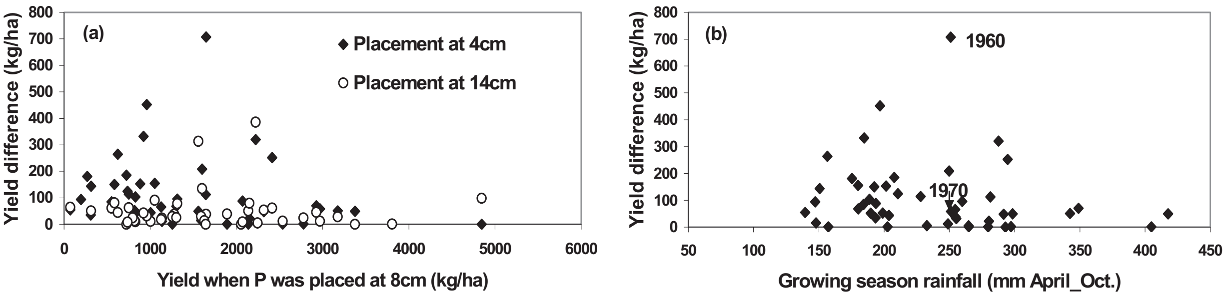

Figure 1 (a) **The grain yield differences for wheat (simulated yields when P placed at the 8 cm minus simulated yields when P placed at the 4 cm and 14 cm, respectively) in relation to simulated yields when P placed at the 8 cm, (b) the grain yield differences (simulated yields when P placed at the 8 cm minus simulated yields when P placed at the 4 cm) in relation to growing seasonal rainfall.**

The daily P uptake simulated for the rainfall of 1960 and 1970 (Figure 2) also highlight the importance of soil P availability for wheat P uptake early in the growing season and its impact on P demand and GY potential. In 1960 and 1970, similar growing seasonal rainfall was received but in 1960, the GY when P was placed at 4 cm was only 942 kg/ha compared with 1649 kg/ha when P was placed at 8 cm. This difference was due to the dry surface soil and thus low soil P availability early in the growing season in that year. However, in 1970, which had favourable early season rainfall, similar grain yields of 2912 and 2969 kg/ha were obtained when P was placed at both 4 cm and 8 cm, respectively. This observation is consistent with the published literature showing that P deficiency early during wheat growth can greatly reduce GY potential.

Unlike field studies with wheat in the winter rainfall-dominant areas (Alston 1980, Jarvis and Bolland 1990, Ma et al. unpublished data), wheat tended to respond positively to deep placement of P fertiliser in the summer rainfall-dominant areas where the crop was grown from profile-stored soil water (Singh et al. 2005). Alston (1980) suggested that in winter rainfall-dominant environments, P uptake by wheat took place early during the growth when the topsoil remained wet due to in-crop rain but in the summer rainfall-dominant environments, the topsoil more likely remained dry due to little in-crop rain and high soil evaporation.

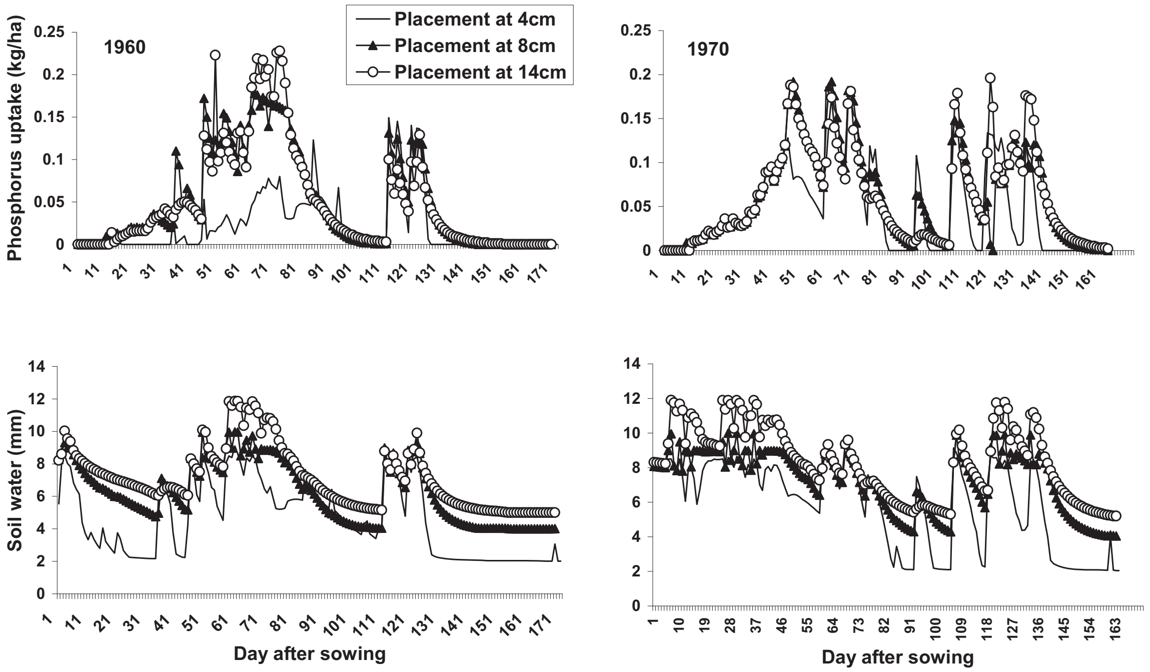

Figure 2 **Daily phosphorus uptake by wheat (kg/ha/day) from the soil layer where fertiliser P was banded, and soil water content in the fertilised soil layer (0–5 cm, 5–10 cm, 10–15 cm) when P was banded at the three different depths (4, 8 and 14 cm respectively) on a duplex soil using 1960 and 1970 rainfall for simulations.**

Lupin

Simulated lupin GY varied significantly depending on season and fertiliser placement depths. In most years when P was placed at 8 cm, the GY varied between 200 and 1800 kg/ha, and was positively related to growing seasonal rainfall (Figure 3a). The simulations also suggested that GY differences when P was placed at different depths varied among seasons (Figure 3b). In the seasons with below-average growing seasonal rainfall, and thus lower GY potential, the GY differences when P was placed at the different depths were small (< 100 kg/ha). However, in the seasons with above-average growing season rainfall, and thus higher GY potential, placing P deeper (14 cm) in the soil profile tended to improve GY compared with P placements at 4 and 8 cm (Figure 3b).

The detailed simulations for the 1963 season indicated (data not shown) that lupin benefited most from deep P placement (14 cm) in the seasons with above-average growing seasonal rainfall but drying in the spring. In this type of seasons, P fertiliser placed at 14 cm depth remained in moist soil longer than P placed at 4 or 8 cm and was therefore more available for crop uptake later in the season. Maintaining P fertiliser in moist soils (through deep placement) late in the season (or post-flowering) would be important to meet the P demand by lupin, particularly if the potential yield was high but spring was dry.

CONCLUSION

Placing P at 8 cm depth often produced better wheat yield than placing at 4 cm, particularly in dry years (growing season rainfall less than 300 mm) together with the dry conditions early in the growing season. But there was no further wheat yield benefit when P was placed deeper (14 cm) in the soil profile.

Lupins responded differently to P fertiliser placement depths. In the seasons with below-average growing seasonal rainfall, and thus low yield potential, lupin yield differences when P was placed at the different depths were small (< 100 kg/ha). However, in seasons with above-average growing seasonal rainfall, and thus high yield potential, the model predicted lupins benefited from deep P placement (14 cm), particularly if it was dry in the spring. Maintaining P fertiliser in moist soils (through deep placement) late in the growing season (or post-flowering) would be important to meet the P demand by lupins, particularly if the potential yield was high but spring was dry.

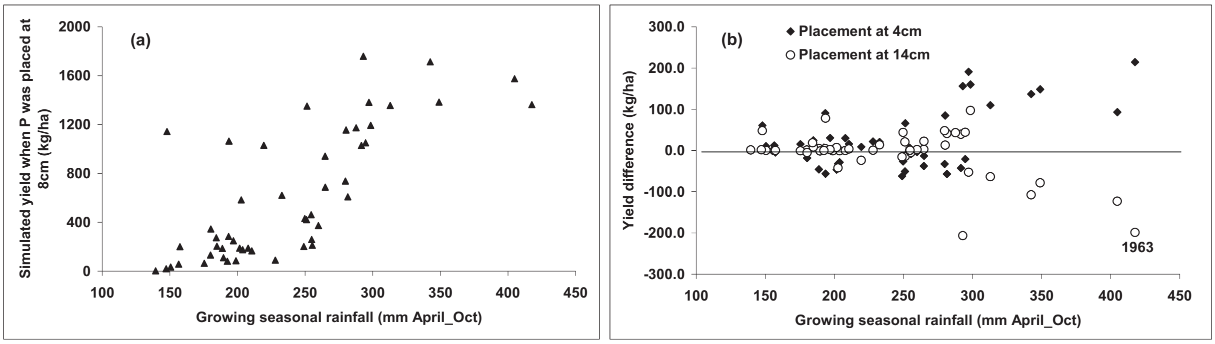

Figure 3 (a) **Simulated lupin grain yield when P was placed at 8 cm in relation to growing seasonal rainfall, (b) yield differences (simulated yield when P was placed at 8 cm minus simulated yield when P was placed at 4 or 14 cm, respectively) in relation to growing seasonal rainfall.**

REFERENCES

Alston, AM 1980, ‘Response of wheat to deep placement of nitrogen and phosphorus fertilisers on a soil high in phosphorus in the surface layer’, *Aust. J. Agric. Res.*, **31,** 13–24.

Bolland, MDA & Brennan, RF 2005, ‘Critical phosphorus concentrations for oats, barley, triticale, and narrow-leaf lupin’, *Comm, Soil Sci. and Plant Anal.,* **36,** 1177–1186.

Elliott, DE, Reuter, DJ, Reddy, GD & Abbott RJ 1997, ‘Phosphorus nutrition of spring wheat (*Triticum aestivum* L.) 4. Calibration of plant phosphorus test criteria from rain-fed field experiments’, *Aust. J. Agric. Res.*, **48,** 899–912.

Howard, DD, Essington, ME & Tyler D 1999, ‘Vertical phosphorus and potassium stratification in no-till cotton soils’, *Agron. J.*, **91,** 266–269.

Jarvis, RJ & Bolland, MDA 1990, ‘Placing superphosphate at different depths in the soil changes its effectiveness for wheat and lupin production’, *Fert. Res.*, **22,** 97–107.

Singh, DK, Sale, PWG & Routley, RR 2005, ‘Increasing phosphorus supply in subsurface soil in northern Australia: rationale for deep placement and the effects with various crops’, *Plant Soil*, **269,** 35–44.

White, PF 1990, ‘The influence of alternative tillage systems on the distribution of nutrients and organic carbon in some common Western Australian wheatbelt soils’, Aust. J. Soil Res., **28,** 95–116.

KEY WORDS

soil nutrient stratification, zero-tillage, crop P use efficiency, wheat, lupins

ACKNOWLEDGMENTS

The studies were funded by the Grains Research & Development Corporation, Department of Agriculture and Food Western Australia and Murdoch University. We thank Dr Merv Proberts for his advice on the APSIM-P model.

Project No.: Profitable and sustainable nutrient management in the WA grains industry (UWA 00084) and Making Better Fertiliser Decisions in WA cropping systems (UMU 00030).

Paper reviewed by: Art Diggle and Bill Bowden, Department of Agriculture and Food, WA.