Precision placement increases crop phosphorus uptake under variable rainfall: Simulation studies

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KEY MESSAGES

- Placing phosphorus (P) at 8 cm depth consistently produced better crop yield than placing P at the 4 cm, particularly in the dry seasons. There was no further yield benefit when P was placed deeper in the soil profile.
- Alternating wetting up (rain) and drying (soil evaporation) of the soil determined soil P availability to crop uptake and thus crop yield benefits when P was placed at the different soil depths. Soil P availability to crop uptake early in the season was critical to achieving potential yield for wheat.

AIMS

The objective of this paper was to evaluate soil and climatic factors affecting crop P uptake and yield when P was placed at different soil depths using APSIM. Nutrient stratification, particularly soil immobile nutrients such as phosphorus (P), could have a significant impact on availability of nutrients to crops, as soil immobile nutrient availability, root growth and root activity in the surface layer are more vulnerable to drought than those in sub-surface layers. Placing P fertiliser deeper in the soil was demonstrated in the early field studies to improve crop P uptake and yield in a water-limited environment of Western Australia (Jarvis and Bolland 1990). However, soil and climatic factors (and their interactions) driving the benefits of deep P fertiliser placement are not well understood.

METHOD

APSIM soil P module and parameterisation of the APSIM-wheat module

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. The model has been developed using a modular software structure so that different modules can be easily linked to adapt to different applications. The soil P module is a representation of the availability of phosphorus in soil. It simulates soil's ability to supply P to crops and can be linked with crop modules to modify growth processes under P limiting conditions. The principle processes considered in the soil P module are illustrated in Figure 1 (see Probert 2004 for the details). The dominant processes considered by the soil P module are:

- loss of plant availability through time;
- removal by crops;
- addition by crop residues;
- mineralisation/immobilisation of soil organic P.

The routines introduced into the wheat module to restrict growth under P limiting conditions were similar to those used in the nitrogen routines. The APSIM-wheat module was parameterised with the maximum and minimum P concentrations through time, in the different organs of wheat based on literature information. These are then used as the reference to define optimal and minimal P concentrations and to calculate P stress factors to modify wheat crop growth by combining with corresponding water and N stress factors using the law of minimum.

Simulation studies

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 yield of wheat. The long-term annual 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% of the annual rainfall and it also varies significantly (140-418 mm).

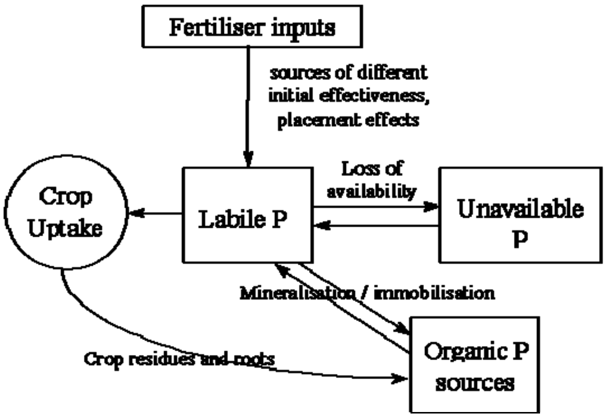

Figure 1. Schematic representation of the Soil P module showing the principal processes considered in the APSIM (Probert 2004).

The APSIM soil P module was parameterised using a duplex soil. Soil properties used for specifying the simulations are summarised in Table 1. The low labile P was used to ensure that wheat crop would respond, to added fertiliser P, for the P uptake in most seasons. The medium P sorption was used to prevent any P leaching. During the simulations, soil water content and labile P were reset to crop low limit (CLL) and background level (Table 1), respectively on the first day of each year to avoid any carry over effects.

Table 1. Soil properties used for specifying APSIM simulations

Soil layer (cm)	SoilWat 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 is drained upper limit, CLL is lower limit of water extraction by wheat, and SWCON is the proportion of water in excess of DUL that drains in one day. The values adopted in the Table are based on the previous modelling studies for a standard duplex soil.

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

RESULTS

Wheat grain yield when P fertiliser was placed at different depths

The P placement at 8 cm depth consistently improved grain yield, particularly when grain yield was < 2500 kg/ha, compared with the placement at 4 cm (Figure 2a). The yield differences between the placements at 8 and 4 cm ranged from 0 to 700 kg/ha and varied significantly between the seasons (Figure 2a), and they were not related to growing season rainfall (Figure 2b). However, the results presented in Figure 2b suggested that the yield benefits of banding P at 8 cm depth were more likely when growing season rainfall was lower than that in the average season. The yield differences between the placements at 8 cm and 14 cm were small (= < 100 kg/ha) in most years, suggesting no yield benefits when deep banding (14 cm) of P was compared with the current banding practice (5-10 cm).

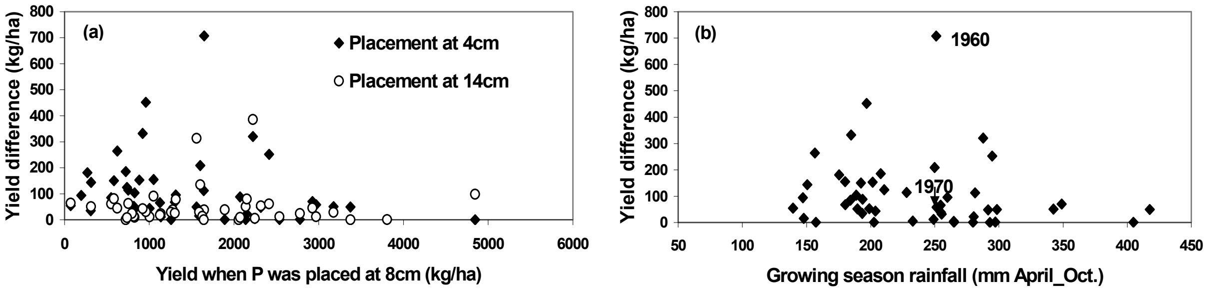

Figure 2. (a) Relationship between wheat yield simulated when P was placed at 8 cm and the yield differences between the placements at 8 cm and 4 or 14 cm, and (b) relationship between the yield differences simulated when P was placed at 8 cm and 4 cm and growing season rainfall.

P placement effects on dry matter, daily P uptake and soil water dynamics

The poor correlation between the yield differences and growing season rainfall (Figure 2b) suggested that alternating wetting up (rain) and drying (soil evaporation) through individual rainfall events determined soil P availability to crop uptake and thus yield benefits when P was placed at the different soil depths. This was supported by the follow up detailed simulations (Figure 3). In 1960 and 1970, similar growing season rainfall was received (Figure 2b), but the different daily rainfall distributions led to the very different soil water dynamics (between two years) and thus daily crop P uptake, particularly early in the season, and final biomass when P was placed at 8 and 4 cm depths (Figure 3). The simulations also highlighted the importance of soil P availability to crop uptake early in the season and its impact on P demand and yield potential. Early plant growth is particularly dependent on P because of the needs for rapid cell division and expansion. The primordia for future stems, roots, leaves, flowers and seed are produced very early in plant growth so P deficiency early during the growth of plants can greatly reduce yield potential.

CONCLUSION

Placing P at 8 cm depth consistently produce better crop yield than placing at 4 cm, particularly in the dry season. There was no further yield benefit when P was placed deeper in the soil profile. Alternating wetting up (rain) and drying (soil evaporation) of the soil determined soil P availability to crop uptake and thus yield benefits when P was placed at the different soil depths. The simulations also highlighted the importance of soil P availability to crop uptake early in the season and its impact on potential yield. However, for the crops (such as lupins and canola) that were reported to have P demand late in the season, the dry surface soil (due to soil evaporation) could also affect P availability to uptake and thus final grain yield, and this needs to be explored further using APSIM.

REFERENCES

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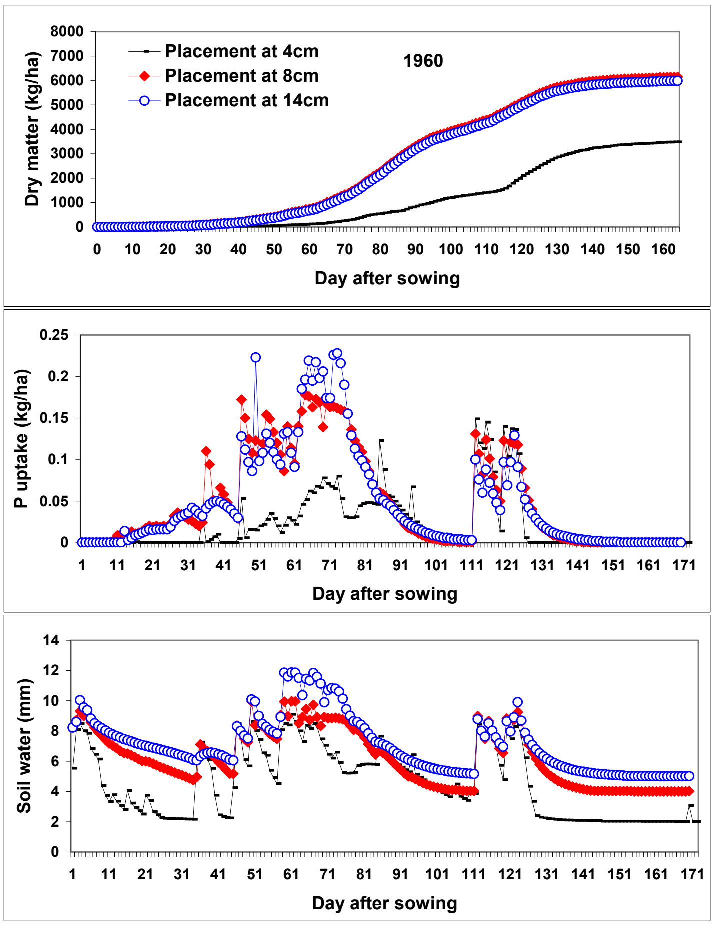

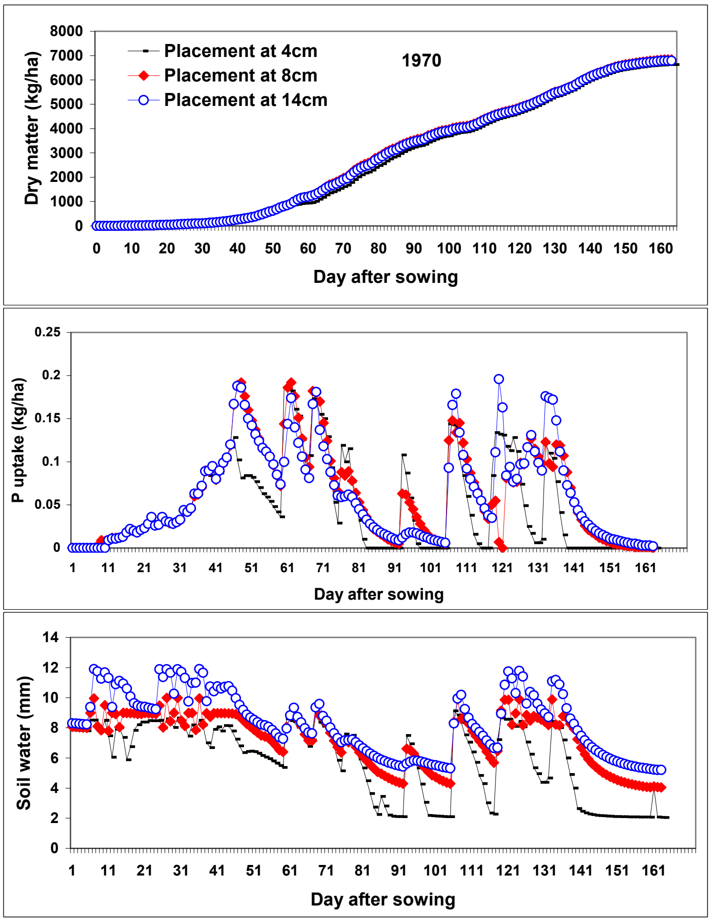

Figure 3. **Wheat dry matter accumulation (kg/ha), daily P uptake (kg/ha/day) from the soil layer where fertiliser P was banded, and soil water content in the fertilised soil layer (0-5 cm, 5-10 cm, 10-15 cm) when P was banded at the three different depths (4, 8 and 14 cm respectively) on a duplex soil in 1960 and 1970.**