SIMULATING AND UNDERSTANDING ROOT GROWTH USING ROOTMAP TO GUIDE PHOSPHORUS FERTILISER PLACEMENT IN WIDE ROW LUPIN CROPPING SYSTEMS

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ABSTRACT

Research in Western Australia (WA) for the last few years reveals that in the warm and low rainfall environments of the northern agricultural region, wide rows (50 cm or more) can produce better lupin yields than narrow rows (25 cm or less) due to improved soil-crop water relations. However, in the broader sense the influence of wide row cropping on crop nutrition and nutrient management is still largely unknown in WA cropping systems. The simulation model, ROOTMAP can be used as a tool to understand the interactions between root systems and availability of soil water and nutrient in the rooting environment, and develop research hypotheses that can be tested under field conditions to develop better nutrient management practices for wide row cropping. ROOTMAP was parameterised for a deep yellow sandy soil from Moora, WA to simulate soil water dynamics and lupin root growth. Two contrasting seasons (wet vs. dry) in Moora were chosen when conducting the two simulation case studies. In the first case study, 8 simulated treatments were designed to evaluate lupin root growth in the rows and between the rows and P uptake when the row spacing and P fertilisation rate below seeds were altered in both dry and wet seasons. The second case study was designed to explore root growth response and P uptake, when P fertiliser was banded in the rows and at 8, 13, 18 and 23 cm away from the rows using a 50 cm row spacing. The simulations suggest that in wide row cropping, where lupin plants are planted closely in the seeding rows, having sufficient P supply in the rows is critical to reduce competition among roots for soil P, to improve penetration and proliferation of the roots into deep soil layers, and to encourage root growth and proliferation between the rows. However, in a wide row (= > 50 cm) cropping, banding all P in the rows sometimes could create P toxicity problem for lupins and may result in increased horizontal soil P stratification that could affect nutrient management for following crops (such as wheat) when using a narrow row spacing (< = 25 cm). Thus, to develop best P management in lupin-based rotation systems, there is a need to further explore different P placement strategies (such as banding some P in the rows and some away from the rows at seeding or deep banding > 10 cm).

KEYWORDS

lupin, root architecture and growth, phosphorus uptake, nutrient management

INTRODUCTION

Western Australia (WA) is the biggest lupin production state in Australia, currently producing 500,000 tonnes annually. This is because lupins are well adapted to the deep, acid sandy soils commonly occurring in the WA grain growing areas (French and Buirchell *et al.* 2005). Lupins have traditionally been grown in rows 18 to 25 cm apart but research in the last few years in WA reveals that lupins can be grown in wide rows (> 25 cm) without a grain yield penalty, particularly in the WA northern agricultural region (Harries and French, 2007). The yield benefit of lupins growing at wide row spacings in the low rainfall environments of the northern region is attributed to the greater soil water reserve between the rows and delayed onset of crop water stress during seed fill (French, 2005). Wide row cropping could also bring agronomic benefits such as stubble handling, inter-row spraying to control weeds, less yield variability in poor growing seasons and maybe better disease control.

However, the influence of wide row cropping on lupin nutrition is still unknown. In-row plant densities and fertiliser concentrations are increased when row spacings are wider at constant seed and fertiliser rates. This change will affect crop root growth and the dynamics of crop water use and nutrient uptake from within the row and between the rows. The change in row spacings in rotation systems may significantly increase the uneven distribution of applied fertilisers both vertically and horizontally, and raises questions for crop nutrient management in rotations, particularly for phosphorus (P): Do we need to change P fertiliser rates? Where do we best place P fertilisers? How do we assess the residual value of P fertilisers and sample soils for

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chemical analysis when row spacings are altered from narrow to wide? What are the effects of wide row lupins on the nutrition of following crops? The simulation model, ROOTMAP (Dunbabin *et al.* 2002a, b) can be used as a tool to provide guidance on the likely outcomes of different P fertiliser placement decisions and thus help develop research hypotheses that could be tested under field conditions to develop better crop nutrient management practices for wide row cropping systems.

MATERIALS AND METHODS

ROOTMAP

ROOTMAP simulates a three-dimensional root architecture as well as nutrient and water uptake by roots (Dunbabin *et al.* 2002a, b). The model has a modular structure with the key modules being three-dimensional root growth and structure, water, solute, and the dynamics of resource allocation (Dunbabin *et al.* 2002a). The model is useful for exploring the interactions between root systems, soil and water both vertically and horizontally.

ROOTMAP PARAMETERISATION AND SIMULATION STUDIES

ROOTMAP was parameterised for yellow deep sandy soil in Moora, WA (Table 1) since the model was validated previously against observed data on soil water and lupin root growth on this soil type and at this site (Dunbabin *et al.* 2002b). Two simulation case studies were conducted. In the first case study, 8 simulated treatments were designed to evaluate lupin root growth in the rows and between the rows and P uptake when the row spacing and P fertilisation rate below seeds were altered in both dry and wet seasons (Fig. 1). The treatment details are; 2 row spacings (25 cm and 50 cm), 2 P fertiliser rates (10 and 30 kg P ha-), and 2 seasons (wet and dry, Fig. 1). The second case study was designed to explore root growth response and P uptake, when P fertiliser (20 kg P ha-1) was banded in the rows and at 8, 13, 18 and 23 cm away from the rows using a 50 cm row spacing in both dry and wet seasons (Fig. 1). In all studies, the information on P fertiliser rates and rows m-2 (which vary with row spacing) were used to accurately calculate P concentrations banded below seeds on each row. Lupins were seeded on 20th May each season at the depth of 30 mm for all treatments. Crop density was 45 plants m^{-2} for all treatments.

Table 1. Summary of soil parameters used to set up simulations (deep sand).

Soil depth (cm)	Bulk density (g cm^{-3})	DUL[1] (v v^{-1})	WP[2] (v v^{-1})	Soil Water (v v^{-1})	Mineral N (kg N ha^{-1})	Total P (mg kg^{-1})	Colwell extractable P (mg kg^{-1})	PRI[3]
0- 5	1.58	0.18	0.03	0.03	11.1	60	6	10
5- 10	1.68	0.13	0.03	0.03	5.9	50	5	10
10- 20	1.67	0.12	0.06	0.06	6.8	40	4	10
20- 30	1.78	0.11	0.06	0.06	0.4	30	< 2	10
30- 50	1.85	0.10	0.06	0.06	0.7	20	< 2	10
50- 70	1.80	0.10	0.07	0.07	0.7	20	< 2	10
70- 90	1.80	0.10	0.08	0.08	0.7	20	< 2	10
90-120	1.80	0.11	0.09	0.09	0.7	20	< 2	10
120-150	1.80	0.12	0.11	0.11	0.7	20	< 2	10

[1]Drained upper limit.
[2]Wilting point.
[3]Phosphorus retention index.

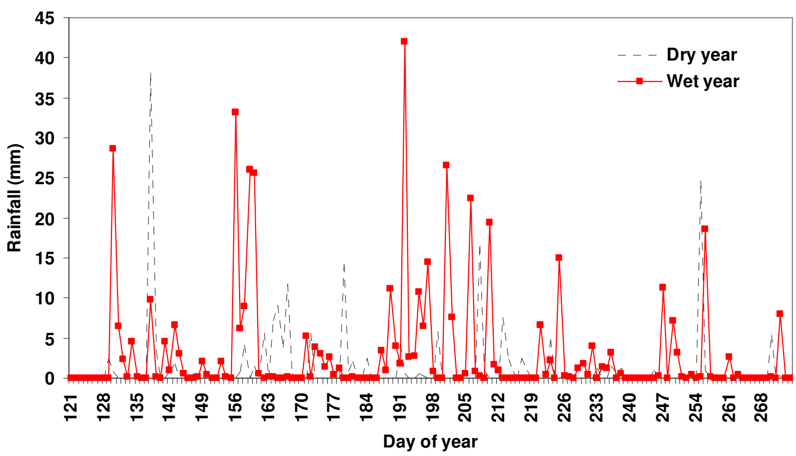

Fig. 1. Daily rainfall during May-October in the dry (1969) and wet (1995) years in Moora, WA.

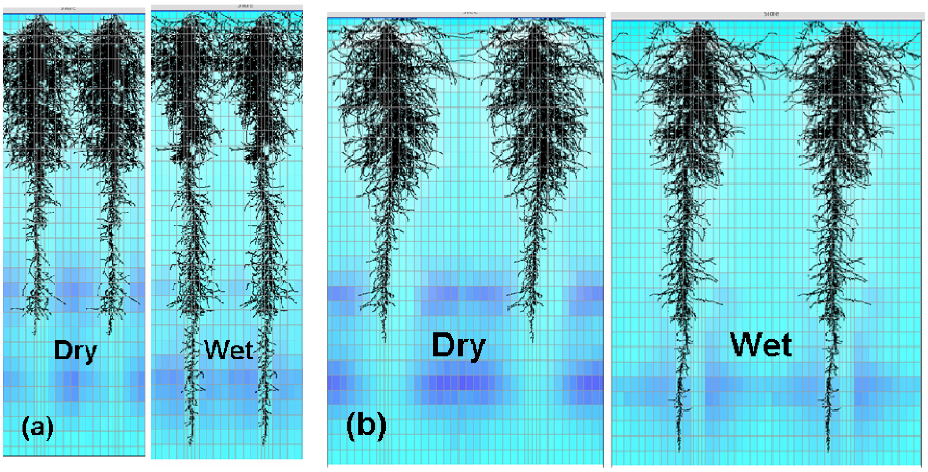

Fig. 2. Impact of the season (dry vs. wet) on root architecture when lupins were sown at 25 (a) and 50 (b) row spacings.

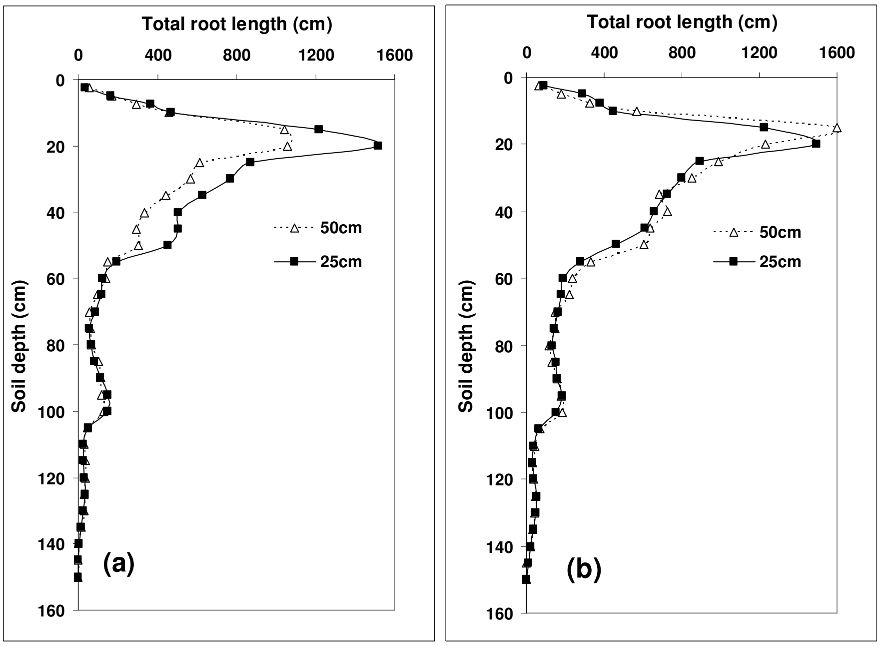

Fig. 3. Impact of P fertiliser banding rates: (a) 10 kg P ha^{-1}, (b) 30 kg P ha^{-1} on total root length per plant when lupins were sown at 25 and 50 cm row spacings.

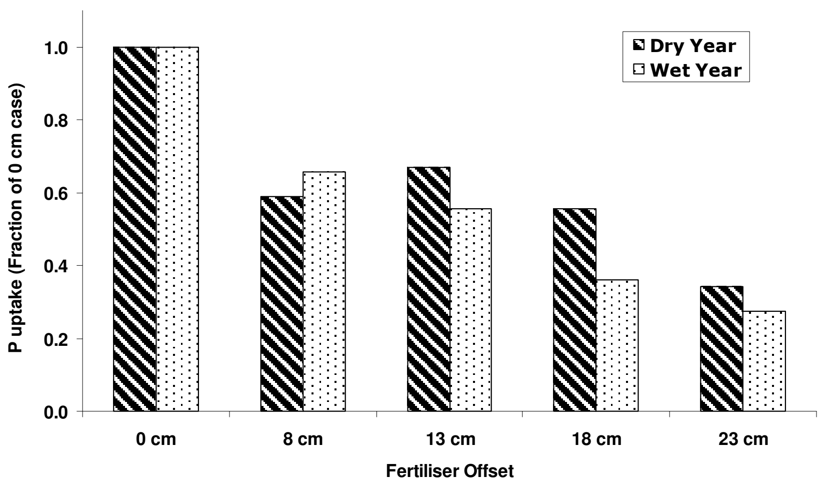

Fig. 4. Impact of the P fertiliser banding away from the seeding rows (offset, cm) on relative P uptake.

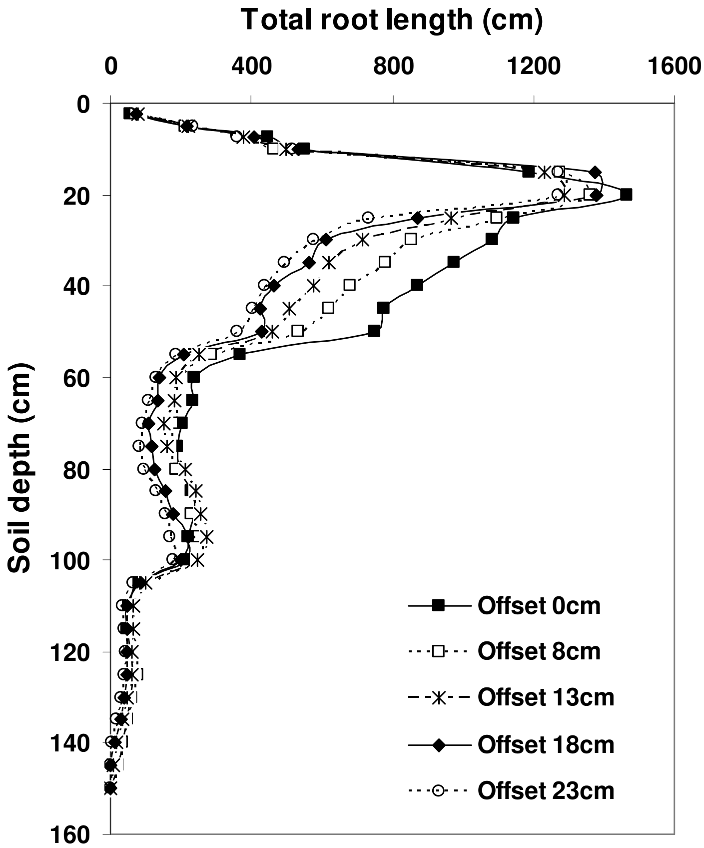

Fig. 5. Impact of the P fertiliser banding away from the seeding rows (offset, cm) on total root length per plant.

RESULTS AND DISCUSSION

SEASON

The annual rainfall was 297 and 662 mm for 1969 (dry) and 1995 (wet), respectively. Despite these large differences in annual rainfall, at the beginning of the season there was enough rainfall to ensure lupin crop establishment in both years (Fig. 1).

CASE STUDY 1

The season had a significant impact on root growth and distribution down the soil profile. For example, the rooting depth was restricted in the dry season compared with the wet season (due to shallow wetting front), thus a greater proportion of the total root length was present in the top soil profile in the dry season than in the wet season (Fig. 2). The simulation also showed that when row spacing was increased from 25 cm to 50 cm (resulting in closer plants in the row), total root length per plant was reduced both vertically (Fig. 3a) and horizontally (data not shown). The reduced total root length per plant in the wide (50 cm) row treatment also led to low P uptake (data not shown) by the roots compared with the narrow (25 cm) row spacing. This is because plant P uptake is sensitive to the density and number of roots present and reduction in root system size usually leads to reduced P uptake. The model also showed that in wide row cropping systems, having sufficient P supply in the seeding rows could reduce root competition for soil P and encourage root growth and proliferation per plant (Fig. 3b).

CASE STUDY 2

P fertiliser banding position had a significant impact on total root length and P uptake by roots per plant (Figs4 and 5). In general, increased P fertiliser banding distance away from the seeding rows reduced total root length per plant both vertically (Fig. 5) and horizontally (data not shown), and thus P uptake in both dry and wet seasons (Fig. 4). This was because at zero offset in P fertiliser from the rows, the roots had full access to the added P but as the banded P was placed further away from the seeding rows, the chance of the roots encountering the P declined, and thus resulted in the decline of total root length and P uptake. However, the simulations suggested that the P fertiliser being banded away from the rows was more likely taken up by the roots in the dry season than in the wet season (Fig. 4), possibly because of the greater proportion of the total root length being present in the top soil in the dry season than in the wet season observed in the case study 1 (Fig. 2).

The above simulation studies suggest that in wide row cropping, where lupin plants are planted closely in the seeding rows, having sufficient P supply in the rows is critical to reduce competition among roots for available soil and fertiliser P, improve penetration and proliferation of the roots into deep soil layers, and encourage root growth and proliferation between the rows. However, in a wide row (= > 50 cm) cropping, banding all P in the rows sometimes could create P toxicity problem for lupins and may result in increased horizontal soil P stratification that could affect nutrient management for following crops (such as wheat) when using a narrow row spacing (< = 25 cm). Thus, to develop best P management in lupin-based rotation systems, there is a need to explore different P placement strategies (such as banding some P in the rows and some away from the rows at seeding or deep banding > 10 cm and, etc.) to improve crop productivity and water use in the rotation systems.

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