Phosphorus acquisition characteristics of cotton (*Gossypium hirsutum* L.) plant: a review

Xiaojuan Wang[A], Caixian Tang[A], Christopher N Guppy[B], Peter W G Sale[A]

[A]Department of Agriculture Science, La Trobe University, Bundoora, VIC 3086, Australia, Email x18wang@students.latrobe.edu.au. C.Tang@latrobe.edu.au. P.Sale@latrobe.edu.au
[B]School of Environmental and Rural Science, University of New England, Armidale, NSW 2351, Australia, Email cguppy @une.edu.au

Abstract

This paper provides a review of P acquisition strategies by cotton plants. Except for excretion of phosphatase enzymes, the cotton plant lacks the ability to manipulate its rhizosphere chemistry, and to mobilize non-labile inorganic P sources. Phosphorus acquisition by cotton plants mainly depends on root exploration of relatively labile inorganic P and organic P sources from the surface and subsurface soil layers. Root morphological traits, such as increased root to shoot ratio or AM associations, would result in a high root absorbing surface area. Subsoil P sources could be accessed by cotton plant over time possibly due to the water stress encountered at the topsoil, and the presence of roots in the subsoil. The role that mycorrhizae play with cotton plants in Vertosol soils is worthy of future investigation.

Key Words

Hydraulic lift, P response, Root exudates, Soil depth, Residual P, P placement.

Introduction

Cotton (*Gossypium hirsutum* L.) production is an important agricultural industry in Australia. Lint yields from flood-irrigated cotton crops have increased steadily over the past 25 years and impose a high demand for nutrients (Rochester 2007). Although cotton lint is composed of primarily cellulose, considerable amounts of nutrients can be removed with cotton seed (Dorahy *et al.* 2004; Rochester and Peoples 1998). In Australia, cotton production requires regular P fertilizer inputs (~ 20 kg P/ha) in order to maintain soil P fertility and high lint yields, especially in the last 25 years (Dorahy *et al.* 2004). Nevertheless, the response of cotton to P fertilizers is unpredictable and frequently low. Dorahy *et al.* (2004) reported that only 3 out of 17 cotton field sites in Australia showed increases in lint yield from P fertilizer application. In addition, the reported critical Colwell P concentration for cotton in Vertosols varies from 6 to 12 mg/kg (Dorahy *et al.* 2004; Hibberd *et al.* 1990), which is much lower than those for wheat (21 mg/kg) and barley (18 mg/kg) on similar soils with low P sorption capacity (Reuter *et al.* 1995). This suggests that cotton may be able to access P from stable soil P pools. Such knowledge on P acquisition characteristics of cotton would increase our understanding of P responses by cotton to P fertilizers. This paper reviews possible root strategies adopted by cotton plants in their P acquisition from the soil.

Root morphological and physiological traits

Carboxylates and proton release

Significant exudation of carboxylates was not detected in the rhizosphere of cotton in response to P deficiency (Wang *et al.* 2008). Proton efflux of cotton plant is frequently related to the N uptake as NH_4^+ rather than insufficient P supply. For example, Hylander *et al.* (1999) reported a greater rhizosphere acidification of cotton than maize and soybean when N source was applied as NH_4NO_3. In the case of NO_3^- as the sole N sources, alkalization of the rhizosphere by cotton was detected irrespective of shoot P status (Wang unpublished data). In addition, cotton was not superior in using sparingly soluble P sources such as Al, Fe and Ca phosphates, when compared with both wheat and white lupin (Wang unpublished data). It appears that cotton plants lack the ability to manipulate its rhizosphere chemistry and to mobilize non-labile inorganic P sources, in terms of both carboxylate and proton release. Nevertheless, the enhanced acid and alkaline phosphatase activity in the rhizosphere of cotton could promote the utilization of P from soil organic pools, as demonstrated by the concurrent depletion of NaOH-extractable organic P (NaOH-P_o) in the rhizosphere soil (Wang *et al.* 2008; Figure 1). While Dorahy *et al.* (2004) found a strong correlation between relative P uptake of cotton and Al- and Fe fraction of soil P in a field experiment, these pools in Vertosols normally represent P weakly absorbed with Al and Fe oxides (Holford and Mattingly 1975; Soils and Torrent 1989).

Root to shoot ratio
Like many species, P stress causes a preferential distribution of dry matter and P content to the roots of cotton (Gill *et al.* 2005; Maqsood *et al.* 2005; Wang *et al.* 2008). Indeed, P-deficient cotton plants can retain 35% of total P in its roots, compared with only 14% in P-sufficient cotton (Ahmad *et al.* 2001). Cotton plants have the peak consumption of P later in the growing season (first peak bloom) when the root system is fully developed (Schwab *et al.* 2000), which possibly indicates that P acquisition of cotton mainly depends on its root morphological exploration of labile P sources. Ahmad *et al.* (2001) also found that the tolerance of cotton genotypes to P deficiency was due to their efficiency in absorption of soluble P and P utilization for biomass synthesis. Thus, the greater allocation of assimilates to root growth due to P stress by cotton could confer a significant advantage in soluble P acquisition by cotton.

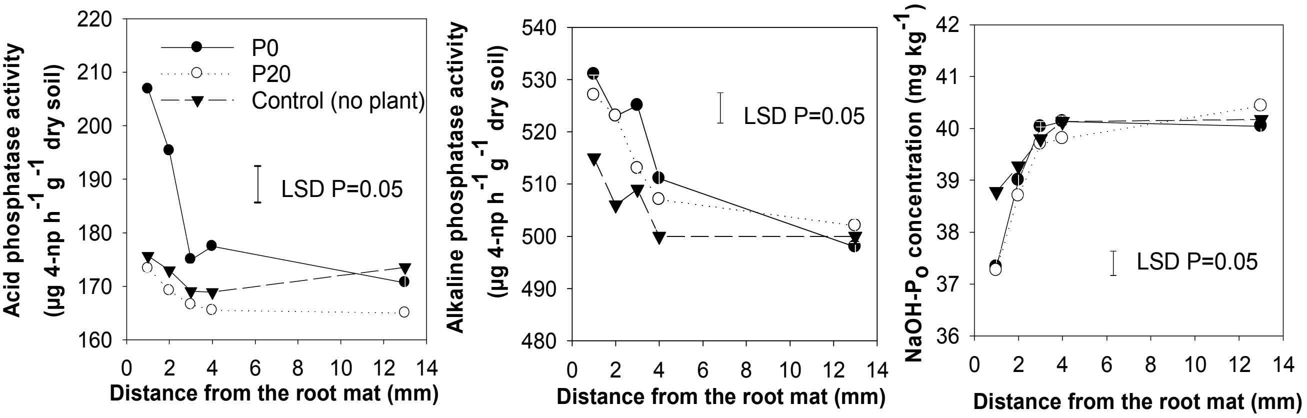

Figure 1. Changes in acid and alkaline phosphatase activity, and concentration of NaOH-P_o with distance from the root mat of cotton with 0 and 20 mg/kg P application. For each panel, the vertical bar indicate the LSD (P=0.05) for the treatment × distance interaction (Wang *et al.* 2008).

AM fungi
Cotton crops grown in Australian are known to be well infected with arbuscular mycorrhizae (AM) fungi (Rich and Bird 1974). The external hyphae of AM fungi contribute to an increased P uptake due to an increased surface area for absorption and decreased distance for P diffusion (Bolan 1991; Schnepf *et al.* 2008). Poor P uptake of cotton on virgin soil in tropical Australia had been related to the lack of an association with AM (Duggan *et al.* 2008). Graham and Syvertson (1985) suggested that plant species like cotton with less branched and coarse root systems could be highly dependent on mycorrhizal association for P acquisition compared to that of species with finely branched roots.

Hydraulic lift
As a tropical species, cotton is normally cultivated in warm to hot climates. Rapid drying of furrow-irrigated soils due to evaporation is quite common under cotton production (Muchow and Keating 1998; Singh *et al.* 2006). Redistribution of water from wet subsoil layers into drier topsoil through plant root systems, a phenomenon known as hydraulic lift, could be a desirable strategy for P acquisition by cotton plants from surface soil that experienced frequent dryness. Hydraulic lift would enhance shallow root survival and P availability at the topsoil (Bauerle *et al.* 2008; Huang 1999). By using gamma densitometry, Baker and van Bavel (1988) detected an overnight movement of water from wet to dry soil through the cotton root system. Wang *et al.* (2009) also demonstrated the occurrence of hydraulic lift by cotton plant grown on a Vertosol. Nevertheless, the detected hydraulic lift did not aid P uptake from the drying topsoil (Wang *et al.* 2009). Higher root mortality and lower P diffusion rate in the Vertosol, compared with sandy soil, could account for the negligible P uptake from water-stressed surface soil (Wang *et al.* 2009).

Phosphorus acquisition depth

Top soil
The cotton seedlings had been reported to derive most of its P from the fertilizer band applied to the top 10 cm layer (Dorahy *et al.* 2008). Nevertheless, at a later growth stage (36 days after sowing), soil P pools beyond the fertilizer band showed a significant contribution (more than 90%) to the total P uptake by cotton (Dorahy *et al.* 2008). Poor responsiveness of cotton to shallow P placement had been attributed to the decreased soil moisture at the topsoil (Hibberd *et al.* 1990; Singh *et al.* 2005), which is in consistent with findings from Wang *et al.* (2009) that P uptake from the Vertosol was strictly regulated by its soil water content.

Subsoil

Approximately half of the root system of the cotton plant lies below the surface 15 cm soil layer (Schwab *et al*. 2000). Under frequent drought conditions, seed cotton yield in northern Australia showed a significant increase (17%-67%) to the P applied in subsurface (10-15 and 25-30 cm deep) over that applied at shallow depth (7-10 cm) (Singh *et al*. 2005). In addition, subsoil P pools e.g. residual and total organic P, showed a depletion following long-term cotton cropping (Wang unpublished data, Figure 2). Exploration of subsoil P by cotton roots may act as an important root morphological adaptation to the water stress-induced unpredictable availability of P at the topsoil. The contribution of subsoil P sources to plant P uptake would depend on many factors, including the moisture level of the topsoil, soil texture and the presence of root and P sources in the subsoil (Kuhlmann and Baumgartel 1991; Wang *et al*. 2007; Wang *et al*. 2009). Deep P placement is effective in increasing cotton yield under field conditions possibly because of an enhanced contact between root and fertilizer during the later stages of growth, and also a sustained P availability under periodic surface drought conditions.

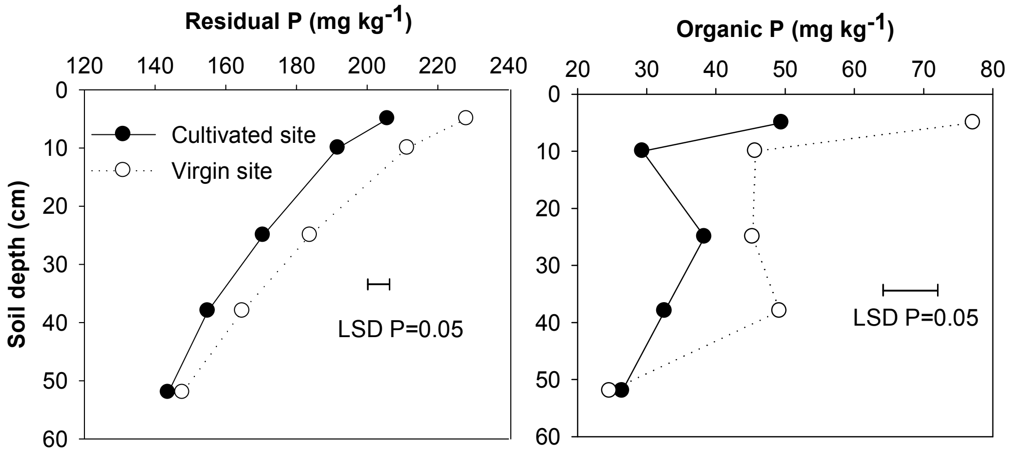

Figure 2. Residual and total organic P concentration (mg/kg) pooled from three sites cultivated with continuous cotton for more than 20 years, and from adjacent three virgin sites, at soil depth of 0-5, 5-10, 10-20, 20-30, 30-45 and 45-60 cm on a Vertosol in northern NSW and southern Queensland. Bars are LSD values at P=0.05 (Wang unpublished data).

Conclusion

Evidences suggest that P acquisition by cotton plants mainly depends on its ability to access relatively labile inorganic P, and organic P from both topsoil and subsoil layers. In this respect, the role that mycorrhizae play with cotton plants in Vertosol soils is worthy of future investigation. Routine soil P tests using alkaline bicarbonate extraction solution (Colwell P) on soil samples collected from the topsoil layers (above 10 cm) do not adequately estimate P responsiveness of cotton to the application of P fertilizers. Low responsiveness of cotton to P fertilizers applied in the soil with low soil test values would indicate that cotton was able to meet their P requirement from the P pools not defined by bicarbonate extractants, such as organic P and subsoil P sources, without the need for P fertilizers.

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