Density-dependent wheat allelopathy: effectiveness for weed control, associated root interaction and morphology changes

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Summary A laboratory-based root exudates bioassay was conducted to assess the density-dependent allelopathic potential of wheat against annual ryegrass (*Lolium rigidum* Gaud.) Results showed that increasing the density of wheat plants significantly inhibited the seedling growth of annual ryegrass. Root and shoot dry biomasses of annual ryegrass were reduced by up to 80% and 70%, respectively. At lower wheat densities the dominant root diameter of annual ryegrass (>50% of roots) was between 0.000 and 0.018 mm. As wheat density increased the diameter of annual ryegrass fibrous roots was increased as well and gradually dominated by the root diameter between 0.018 and 0.270 mm (>50% of roots). Total allelochemical level in the wheat root exudates was linearly correlated with wheat density (r^2 = 0.988**). These results suggest that strong allelopathic effects from allelochemicals exuded from wheat plant roots might have contributed to increased wheat competitiveness at high densities and ultimately led to the suppression of annual ryegrass growth and development.

Keywords Weed management, root exudates, allelopathy, annual ryegrass, *Lolium rigidum*.

INTRODUCTION

Weeds cost over $4 billion per annum to Australian farmers. They have evolved herbicide resistance that threatens environmental sustainability and the viability of crop production (Peltzer *et al.* 2009). Australia is facing the severe challenge of running out of synthesised herbicide options for effective control of crop weeds, such as annual ryegrass and wild radish, and alternative means of weed control are urgently required.

Allelochemicals produced by plants could have potential to control weeds in the field as biological herbicides and work as alternative means (Khanh *et al.* 2005). Wheat is an important cereal crop worldwide and a potential crop that can be explored for allelopathic weed control because of its ability to produce and exude allelochemicals in the field (Bertin *et al.*2003, Wu *et al.* 2001). Wheat residues significantly reduced weed density and biomass (Putnam *et al.* 1983). Growth of annual ryegrass could be suppressed by wheat (Wu *et al.* 2002), and seed germination and seedling growth of *Amaranthus retroflexus*, *Stellaria media* and *Digitaria ciliaris* were reduced by wheat extracts (Ma 2005). Allelochemicals, such as phenolic compounds, are often associated with allelopathic effects of wheat (Bertin *et al.* 2003). Wu *et al.* (2002) reported that phenolic compounds of *p*-hydroxybenzoic, vanillic, and *trans*-ferulic acids were negatively related to root length of annual ryegrass. DIMBOA (2,4-dihydroxy-7-methoxy-1,4-benzoxazin-3-one) was also an effective allelochemical produced by wheat (Wu *et al.* 2002), and the amounts of DIMBOA produced by wheat ranged from 238–560 mg kg^{-1} dry matter in shoot and 551–612 mg kg^{-1} dry matter in root (Ma 2005). Generally, more than one allelochemical was responsible for the allelopathic effect of wheat. Allelopathic potentials in rice are reported to be strengthened by increasing the total amount of phenolic compounds produced (Lee *et al.* 2008) as well as by increased rice density (Seal *et al.* 2004).

The aims of the present study were to: (1) assess the effectiveness of density-dependent crop allelopathy in weed control; (2) examine associated root mechanisms by using wheat-annual ryegrass (*Lolium rigidum*) interaction as a model system.

MATERIALS AND METHODS

The allelopathic potential of crop wheat was investigated by employing a laboratory-based root-exudate bioassay, the 'equal-compartment-agar method' (ECAM), developed in our laboratory (Wu *et al.* 2000). Since phenolic compounds and benzoxazinoids are the most common allelochemicals reported in wheat root exudates (Wu *et al.* 2002) a colorimetric method, Folin-Ciocalteu, was used to measure the total allelochemicals present in wheat root exudates (Belz *et al.* 2005, Yang *et al.* 2009). Root morphologic parameters were measured by WinRhizo 2005 root scanner.

RESULTS AND DISCUSSION

Our results showed that increasing the density of wheat plants significantly inhibited the seedling growth of annual ryegrass. Root dry biomass of annual ryegrass was reduced by up to 80% at high wheat densities and shoot dry biomass by up to 70% (Figure 1). By examining the associated root interaction, it was found that both total root length and total root surface area of ryegrass steadily decreased as the wheat density increased, while the average root diameter of ryegrass steadily increased. Annual ryegrass roots consisted of fibrous roots with diameters between 0.000 and 0.270 mm. Their distribution and dominance was uneven and wheat density dependent. At a lower wheat density (0–5 plants per container) the dominant root diameter of annual ryegrass (>50% of roots) was 0.000–0.018 mm (Figure 2). As wheat density increased the proportion of ryegrass roots in the 0.018–0.270 mm range

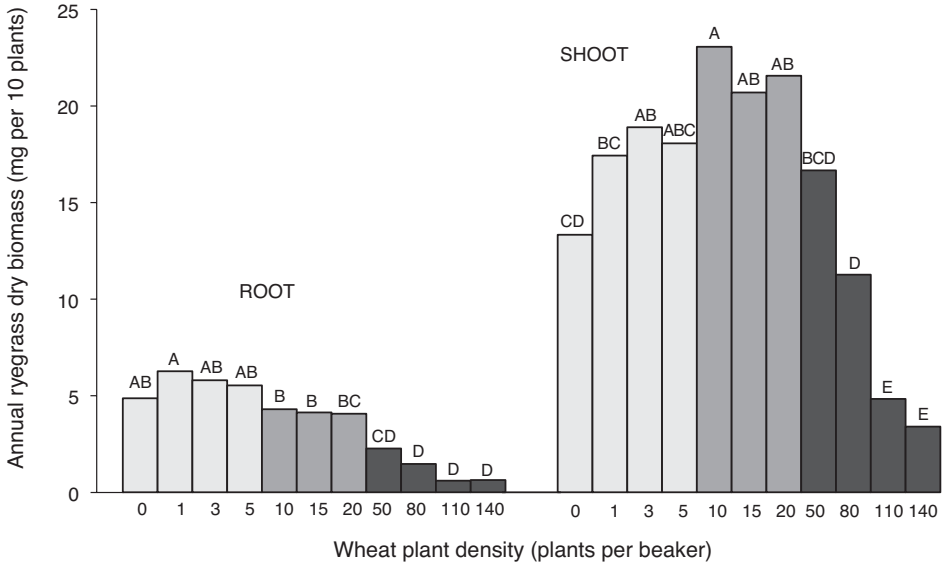

Figure 1. Biomass of annual ryegrass growing in beakers with different densities of wheat seedlings. Values with different letters indicate a significant difference at P <0.05.

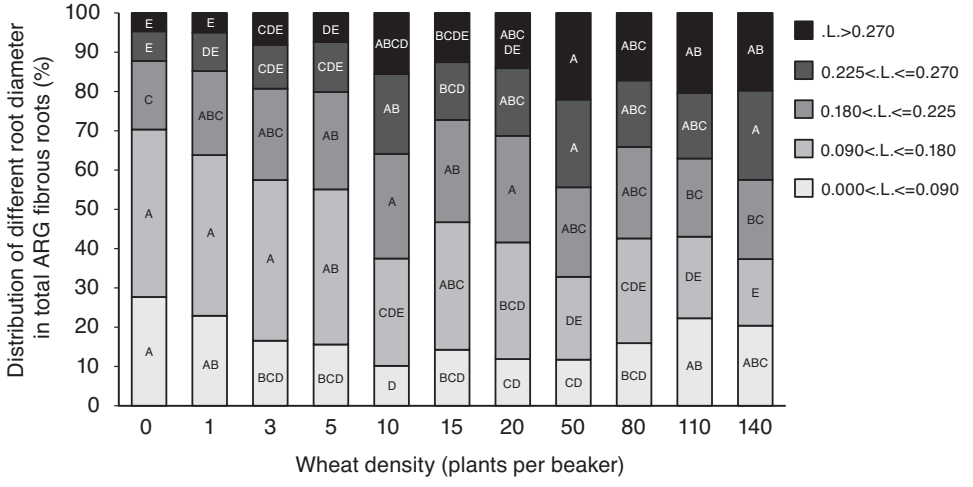

Figure 2. Distribution of different diameter roots in total ARG fibrous roots as affected by wheat plant density. Values with different letters indicate a significant difference at P <0.05.

gradually increased to reach 60%. There was a significant linear correlation between the wheat density (X) and total allelochemical levels (Y) in the wheat root exudates, $Y = 0.1459X - 0.909$ ($r^2 = 0.988$**). It was postulated that increased root diameter and decreased root biomass of annual ryegrass might have resulted from strong allelopathic effects from allelochemicals being exuded from wheat plant roots at high densities. This might have ultimately led to the suppression of annual ryegrass growth and development. These findings suggest that density-dependent crop allelopathy may have agronomic potential in integrated weed management programs for the effective control of weeds in the field.

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