INCREASED PHOSPHORUS SUPPLY ENHANCES WATER UPTAKE AND WATER USE EFFICIENCY IN WHITE CLOVER UNDER DRY CONDITIONS

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ABSTRACT
A glasshouse experiment was carried out to determine how increasing rates of P supply (0, 33, 100 and 300 kg P ha^{-1}) influenced the water use efficiency of white clover grown in a P-deficient soil under dry conditions. Increasing the P supply enhanced both shoot dry matter yield and water use by the clover plants. The relatively greater dry matter response meant that water use efficiency also increased with added P. High rates of water extraction by these high-P clover plants resulted in a marked drying of soil. Despite these dry soil conditions there was no adverse effect on growth or any notable display of water stress symptoms for high-P clover plants.

KEYWORDS
Phosphorus, water uptake, water use efficiency, white clover, dry conditions

INTRODUCTION
White clover (*Trifolium repens* L.) is highly regarded for its impact on the quality and the productivity of the temperate pastures (Robinson and Lazenby, 1976), but is intolerant of moisture stress (dry conditions) because of shallow rooting and poor stomatal conductance (Hart, 1987). The use of this legume in rainfed pastures is therefore limited if dry spells and irregular rainfall occur during the growing season. Singh *et al*. (1996) were able to show that increased P supply could improve the ability of white clover plants to tolerate moisture stress by improving the water uptake rate from drying soils and thereby maintain their internal water status. Radin and Eidenbock (1984) reported similar results for cotton plants supplied with high P rates. These studies indicate that increasing the P supply will result in greater water use, but the question of the efficiency with which this extra water was used, in terms of dry matter yield per mm of water used, was not determined. A glasshouse experiment was therefore conducted to quantify the effect of P supply on the total water uptake and dry matter yield of white clover plants in drying soil, and thereby determine the effect of added P on water use efficiency.

METHODS AND MATERIALS
The experiment was laid out in a randomised complete block design with four replicates, on benches in a temperature-controlled glasshouse in Melbourne, Australia (latitude 37° 20' S). The experimental unit was 5.5 kg air dried, homogeneously-mixed Krasnozem soil, packed in a cylindrical PVC pot (30 cm long and 16 cm in diameter) that was closed at one end. Treatments included the factorial combination of four P rates (0, 33, 100 and 300 kg P ha^{-1} equivalent), two defoliation frequencies (plants defoliated every 14 and 28 days over a 28 day experimental period), and two water regimes (where the total moisture content of the soil in the pot was maintained gravimetrically between 75% and 100%, and 0% to 45% of field capacity, for the wet and dry treatments respectively).

Two stolons with 2 to 3 developed leaves and nodal roots were selected from mini-swards of white clover (cv. Kopu) that had been established from the same clonal material. The rooted stolons were grown for 10 weeks with soil water maintained at 80% field capacity. The surfaces of the pots were covered with 3 cm of polystyrene beads, which restricted the soil surface evaporation. The required amount of water for the respective water regimes were determined gravimetrically, and applied to the pots. Leaf plus petiole fractions were harvested at respective defoliation frequencies, oven dried and weighed. Water use efficiency was determined as the ratio of the dry matter yield to the total water added, which was considered to be the water transpired by the clover plants. Data were pooled for the two defoliation frequencies and presented for the dry soil treatments only.

RESULTS AND DISCUSSION
Both water use and clover yield increased with increasing rates of added P, although the responses diminished at the highest P rate (Fig. 1, a and b). The magnitude of the dry matter yield response to added P was more marked than that for water uptake. For example the dry matter yield increased 8 times compared to only a 3 fold increase in the total water uptake, between the P_0 and P_{300} treatments. This differential effect of P on the water uptake and shoot dry matter yield resulted into an improved water use efficiency by the clover plants with increased P supply (Fig. 1c). Clover plants supplied with 300 kg P ha^{-1} equivalent used only 955 g of water to produce one g of dry matter compared to the use of 2191 g water (130% more) by the P0 plants for the similar amount of dry matter production (data not presented).

Increases in clover growth with higher P supply was not surprising, as P-deficient plants are known to have lower photosynthetic rates, and decreased growth (Jacob and Lawlor, 1991). What was surprising was the beneficial effect of the highest P rate (P_{300}) on clover growing in the dry soil, as one could imagine that a negative, toxic effect of high P rates might occur for plants growing in dry soil (Cerda *et al*., 1977). Another highlight of the study was the substantial improvement in the water use and water use efficiency by the clover plants. The extra P enabled the clover plant to extract more water from the dry soil, suggesting that there was probably an increase in root growth with high P supply (Ogata *et al*., 1960). The findings from this study have important implications for clover pastures top-dressed with phosphate fertilisers: the data show that high rates of added P should enable potentially limiting rainfall to be more efficiently used to produce clover forage.

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Figure 1
Response of white clovers growing in dry conditions to P supply for (a) dry matter yield (leaf+petiole), (b) total water uptake, and (c) water use efficiency. Error bars represent ± standard error of mean.