Ion uptake and respiration of dry bean roots subjected to localized anoxia

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Summary  Ion uptake by dry bean root systems was examined during a three day treatment period. Three aeration treatments were applied to split root systems where both halves were aerated, both halves were nonaerated and one half aerated and the remaining half nonaerated (localized anoxia). Ion absorption was similar for the aerated control and localized anoxia treatments. The nonaerated control absorbed 2, 40, and 60 percent of the aerated control for K⁺, Ca²⁺, and NO₃⁻, respectively. Ion absorption by stressed plants appeared to increase directly with root growth in the aerated portions of the localized anoxia treatments. Localized anoxia resulted in greater potassium ion uptake per unit root weight and in greater root respiration rates of the aerated half of the Pinto III cultivar root system. Transpiration rates of Seafarer subjected to localized anoxia were 135% of the aerated control. The additional water use may have contributed to greater ion uptake, by mass flow, in the nonaerated portion of the localized anoxia treatment. Nutrient solutions of the nonaerated controls became more alkaline during stress than did the nonaerated portions of the localized anoxia treatments, indicating a possible direct or indirect effect of the aerated portions of the localized anoxia treatments on the corresponding nonaerated half. Compensation in ion uptake by dry bean roots subjected to localized anoxia appeared to be the result of increased root growth, greater respiration rates, greater transpiration rates and, for Pinto III, an increase in the ion uptake rate per unit root weight. This compensatory uptake of water and nutrients by the root system may be one mechanism by which roots overcome localized stress within a soil profile.

Introduction

Anoxia reduces the uptake of ions by the root system presumably through the inactivation of active transport systems and a depolarization of cell membranes. Localization of anaerobic zones adjacent to portions of the root system frequently occurs in heterogeneous soil media and could also result in a reduction of the effective root surface area available for ion uptake.

Under conditions where a portion of the root system is subjected to continuous or intermittent anaerobiosis it is conceivable that the aerated portion of the root system could compensate for the reduced ion uptake in the anaerobic zone. Compensatory increases in ion uptake and stimulation of root growth have been shown to occur when localized portions of root systems from nutrient depleted plants are exposed to

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high nutrient concentrations\textsuperscript{6,7,8}. Trought and Drew\textsuperscript{24} found a similar response in wheat seedlings when one seminal root was exposed to an aerated complete nutrient solution while the remainder of the roots were anoxic. This study examines the ion uptake of five genotypes of \textit{Phaseolus vulgaris} L. exposed to conditions of localized anoxia.

Materials and methods

Two experiments were conducted using five and two dry bean genotypes, respectively. Cultivars Seafarer, Swan Valley, Domino, Pinto III and MSU experimental line 31908 were represented in the first experiment. Results for Swan Valley and Domino were qualitatively similar to Seafarer and are not reported here. The second experiment examined in more detail the effects of localized anoxia on Seafarer and line 31908. Both experiments utilized the procedures and aeration treatments reported earlier\textsuperscript{18,19}.

Seeds were surface sterilized with 1\% sodium hypochlorite solution for 10 minutes and germinated in the dark on trays containing moist paper toweling and cheesecloth. An incubator maintained temperatures at 23°C ± 0.5 for germination and initial seedling growth. Radical root tips were removed 24 to 48 hours after germination. This produced a split root system composed of basal roots forming laterally to the main axis of the plant. Seedlings were given a 24 h exposure to light when the hypocotyls were > 2 cm in length. Seedlings were transferred to split root chambers each containing one liter of aerated Hoagland's nutrient solutions adjusted to a pH of 6.0. Compensation of the nutrient solution in the first experiment consisted of quarter strength Hoagland's nutrient solution with 1.50 mM K\textsuperscript{+}, 0.25 mM H\textsubscript{2}PO\textsubscript{4}\textsuperscript{−}, 3.75 mM NO\textsubscript{3}\textsuperscript{−}, 0.5 mM Mg\textsuperscript{2+}, 0.5 mM SO\textsubscript{4}\textsuperscript{2−}, 1.25 mM Ca\textsuperscript{2+} and 2.25 × 10\textsuperscript{-2} mM Fe as Fe EDDHA solution. Trace elements were provided accordingly to Hoagland and Arnon\textsuperscript{19}, with a 20\% reduction of manganese to reduce the possibility of Mn toxicity. Plants in the second experiment were initially grown in quarter strength Hoagland's nutrient solution for four days and then replaced with half strength Hoagland's solution. Chambers in the first experiment were constructed from plastic containers lined with saran coated polyethylene bags. The second experiment utilized acrylic chambers sealed to collect rhizosphere gases and inhibit the loss of water through evaporation\textsuperscript{20}.

Oxygen partial pressures in the nutrient solution were maintained above 19 kPa pO\textsubscript{2} (YSI MKodel 53 Biological Oxygen Monitor) by flowing compressed air through fritted glass gas dispersion tubes at a rate of 160 ± 10 cm\textsuperscript{3} min\textsuperscript{-1}. Chambers were randomly assigned positions on the greenhouse bench. Supplemental cool white fluorescent light was used to provide a photoperiod of 16 h light and 8 h dark. Photosynthetically active radiation at midday ranged from 200 (cloudy) to 1,900 (clear) μmole m\textsuperscript{-2} sec\textsuperscript{-1} at the primary leaf surface.

Three aeration treatments were randomly allocated to the split root systems of each genotype after a period of eight days of growth. Aeration treatments consisted of two controls, both halves of the root system aerated (AC); both halves nonaerated (NC) and a localized anoxia treatment (LA), in which the gaseous treatments were split, with half of the system aerated (ALA) and the other half nonaerated (NLA). Oxygen partial pressures in the nonaerated treatments were maintained below 0.5 kPa pO\textsubscript{2} by continually equilibrating the nutrient solution with nitrogen gas. The neutral red staining technique\textsuperscript{21} was used to differentiate between root growth occurring before and during the treatment period.

The first experiment included measurements of oxygen uptake, ion uptake and xylem exudation rates. Root growth measurements were also measured and are reported elsewhere\textsuperscript{19}. Oxygen uptake was measured for each treatment combination before the imposition of the aeration treatments and after a 72 hour treatment period. Measurements were made by flowing nutrient solution surrounding the root system past a clark electrode (YSI Model 53 Biological Oxygen Monitor) maintained at a constant temperature of 20°C. Oxygen uptake rates were calculated from the decrease in oxygen content of the solution with time. Xylem exudation rates were determined by measuring the volume of exudate collected in latex tubing placed over the ends of the cut stem for a specified time period. Nitrate ion content was measured in solution samples, taken immediately before and after the