Oxygation: Enhanced root function, yields and water use efficiencies through aerated subsurface drip irrigation, with a focus on cotton.

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Abstract

Soil aeration is one of the critical determinants of plant production. This research investigated the potential of oxygation, the aeration of subsurface drip irrigation (SDI), to alleviate the consequences of episodic flooding associated with SDI in vertisols (the predominant soil type in cotton production) with a view to achieve improved yields and water use efficiencies. Cotton performance, as affected by aeration and irrigation application rate, was evaluated over two consecutive seasons, with a particular focus on root characteristics and physiological processes. Aerated cotton (2005 results) significantly outperformed non-aerated cotton in terms of both yield (27% more lint) and crop water use efficiency (26% more lint per megalitre water used). The more extensive root development of aerated plants suggests that the temporal hypoxic/anoxic events associated with SDI in clay soils is indeed mitigated by aeration of the irrigation water. Data from the 2006 experiment (recently harvested) are not included in this paper.

Key Words

Oxygation, aeration, subsurface drip irrigation, crop water use efficiencies.

Introduction

Fresh water is a finite resource and water use in Australia is expected to rise by more than 50% by 2050. The Australian irrigation industry uses up to 70% of developed water resources. Competition for water is already a constraint on irrigated agriculture thus water use efficiency is regarded as a key component in increased sustainability (White and Raine, 2004). While subsurface drip irrigation (SDI) can be nearly 100% efficient (furrow normally at 60-70%) historically SDI irrigated cotton provided disappointing results. It has been suggested that the temporal waterlogging, and associated hypoxic/anoxic rhizosphere conditions attendant with SDI in heavy clay soils, impinge upon optimum plant development (Bhattarai *et al*., 2006). Roots require an adequate supply of oxygen to enable normal respiration (Everard, 1985; Grable, 1966). Insufficient available oxygen triggers a range of adaptive responses, often at the expense of yields and water use efficiencies (Drew, 1992; Barrett-Lennard, 2003; Visser *et al*., 2000). A range of experiments (glasshouse/shadehouse), using oxygated SDI and focusing on its potential benefits in ameliorating the negative effects of oxygen limited rhizospheres, has consistently produced enhanced growth, yield and water use efficiency benefits (Bhattarai *et al*., 2004a, 2004b)**,** although most studies were conducted under glasshouse conditions.

The present research examines the potential of oxygation to alleviate the consequences of episodic flooding associated with SDI in a vertisol (the predominant soil type in cotton production) in the field in order to achieve improved yields and water use efficiencies. A principle aim was to elaborate on the specific mechanisms by which plant growth, yield and water use efficiencies are affected by increased root-zone aeration.

Methods

On a 5.2 ha programmable automated subsurface drip irrigation (SDI) site a two-way factorial experiment (*Aeration* or *No aeration* x *85%* ET_c or *105* ET_c) was set up. Within each plot a further (non-randomized) treatment, distance **(***Distance* **-** 35, 105, 165 or 230 m from the main lateral) was monitored. The cotton

Deltapine variety, Bollguard 11[R]/Roundup Readyready[R] cotton (Deltapine Australia Pty Ltd DP 556 BG11/RR AM) was sown in 1m rows on 30 October 2004 with a final plant population of 13 plants m^{-2}. “Mazzei” venturi air-injectors (MIC Bakersfield USA) installed in-line enabled controlled aeration (12% air in water). Irrigation rate was determined using the crop evapotranspiration rate (ET_c) as calculated using the modified Penman-Monteith equation (Meyer *et al.*, 1999) and data supplied by the on-site weather station, multiplied by the appropriate crop factor (Kc - based on accumulated heat units after planting, see Table 1).

Table 1: Calculated crop coefficients (Kc) at the various stages of plant development used to determine

irrigation rates

		Squares		Flowering			Open bolls				
	Emergence	1st	Mid	1st	50%	Max	1st	25%	50%	95%	Harvest
Crop coefficient (Kc)	0.22	0.35	0.50	0.65	0.83	1.20	1.20	0.83	0.64	0.44	0.10

Spatial and temporal moisture dynamics in the soil profile were monitored by a comprehensive network of both Enviroscan™ (Sentek, Australia) and Gopher™ (Soil Moisture Technology, Australia) soil moisture probes. No field run-off was recorded for any treatment. Deep-drainage was calculated by subtracting ET_c from the sum of water applied and effective rainfall. The use of two Fibox-3 oxygen meters (PreSens GmbH, Germany, 2003) coupled with PSt3 oxygen sensitive fiber optic mini sensors, called Optodes, enabled the direct measurement of soil oxygen concentration in both the gaseous and liquid phase in the rhizosphere. An infrared gas analyzer (IRGA) from LCA-4 (ADC, UK) enabled measurement of the leaf gas exchange parameters photosynthesis, transpiration and sub-stomatal conductivity at 37, 59, 72, 92 and 109 days after planting (dap). Harvest was undertaken 159 dap. Data were subjected to Analysis of Variance using the statistical package GenStat version 6.1 (VSN International Ltd) and were considered at 95% significance level. Aeration and irrigation treatments were considered as whole plots. Distance was considered as subplots, but without randomization. Sums of squares for non-significant interactions were included in the error term.

Results

There were no significant differences in relation to position along the lateral (i.e. the treatment *Distance*) for any of the variables relating to plant performance.

Aerated plants produced significantly more cotton (27%) than non-aerated plants with an associated significant improvement (27%) in crop water use efficiency (Table 2). There were no interactions between treatments. The drier irrigation regime (i.e. 85% ET_c) significantly outperformed cotton irrigated at 105% ET_c in terms of both yield (24%) and crop water use efficiency (41%). Although shorter, aerated plants produced a significantly heavier total plant biomass at final harvest in comparison to their non-aerated counterparts (Table 2). No significant differences between treatments for either number of leaves or average individual leaf area were recorded. Aerated plants produced smaller but more numerous leaves, the combined effect resulting in a significantly greater total leaf area per plant (23%) in comparison to the non-aerated plants (Table 2).

Table 2: Lint yield, crop water use efficiency, total plant biomass, harvest index and total leaf area per plant as affected by aeration and irrigation regime. Standard error of the difference (SED) is provided where significant.

Treatment		Lint yield (bha^{-1})	CWUE (bML^{-1})	Total plant biomass (g)	Harvest index (lint per plant/above ground biomass)	Total leaf area per plant (m^y)
Aeration	No aeration	7.35	0.953	252.0	0.148	0.74
	Aeration	9.31	1.208	305.3	0.140	0.91
Irrigation	85	9.22	1.266	280.5	0 .160	0.85
(%ETc)	105	7.45	0.895	277.0	0 .128	0.80
	SED (df=21)	0.83	0.115	25.21	0 .011	0.08

There were no differences between any of the treatments for mean net rate of photosynthesis, leaf transpiration, leaf stomatal conductance or total leaf chlorophyll (data not presented).

More extensive fibrous root mass and significantly heavier taproots were noted for plants receiving aeration compared to those without (Table 3).

Table 3: Effects of soil moisture and aeration on tap-root length, tap-root weight, fibrous-root weight, and combined tap-root and fibrous root weight as affected by aeration and irrigation regime. Standard error of the difference (SED) is provided where significant.

Treatment	?	Tap-root length (cm)	Tap-root (g)	Fibrous root (g)	Tap-root & fibrous root (g)
Aeration	No aeration	20.86	12.86	12.87	25.73
	Aeration	21.70	15.41	14.75	30.11
Irrigation Treatment	85	21.18	12.56	13.84	26.4
(%ETc)	105	21.38	15.71	13.73	29.44
SED			1.05		

Conclusion

Significant gains in yield and water use efficiencies with oxygation of cotton on a vertisol were evident in this field trial. Improved performance of the plants exposed to oxygation compared to those not oxygated, particularly in the case of the heavier irrigation regime (i.e. the 105% ETc irrigated treatments), suggest a beneficial role in overcoming the temporal hypoxic root-zone events often associated with SDI. The magnitude of the gains were similar to those of earlier oxygation research in the glasshouse or in pot trials. That lint yield was greater at 85% ETc than 105% ETc suggests that the lighter irrigation rate was supra-optimal. This was supported by soil moisture data (not presented) showing that soil moisture of the 105% ETc irrigated treatments consistently exceeded field capacity, particularly at depth.

The more extensive fibrous root mass and heavier taproots of the aerated plants indicate a more functional root system capable of supporting more vigorous growth. Extensive soil coring was undertaken in arrays close to emitters, and indications are that root length density was increased by aeration close rather than more distant from emitters. Enhanced rhizosphere O_2 levels were noted (data not presented) and are not only conducive to the development of a more extensive root system but also influence root ability to take up water. Adequate O_2 availability in the root zone contributes to root membrane integrity thereby affecting water uptake and transport within the plant. The significant gains in crop water use efficiency recorded for the aerated treatment may be attributed to their more extensive and vigorous root systems.

Although no differences were detected for either unit rate of photosynthesis or transpiration, the enhanced leaf area of aerated plants may have enabled greater light interception and consequently higher yields (as leaf capture of solar energy is often related to fruit yield).

Results suggest that oxygation has the potential to make a major contribution to sustainable water use. The aeration of SDI can successfully alleviate O_2 deficiency in the rhizosphere enabling significant gains in both yield and water use efficiency thus greatly enhancing the economic feasibility of this mode of irrigation.

Further investigation into the dynamics of oxygation (e.g. plant physiological responses) are still required to optimise this method.

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