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Dynamic changes in bubble profile due to surfactant and tape orientation of emitters in drip tape during aerated water irrigation

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ABSTRACT

Use of aerated water for drip irrigation using a pressure differential Venturi has been reported to produce positive response on crop yield and water use efficiency. We present two options for increasing the distance from the source of irrigation an air/water mixed phase travels. We discuss observed results for a row length of 500 m of drip tape.

The first option relates to the orientation of drip tape emitters to the ground plane. In the *up* orientation the emitters are on the top of the drip tape and in the *down* position the emitters are along the bottom of the drip tape. We found higher air void fraction with the emitters down, compared to the standard placement with the emitters up. We also discuss observations of field trials for this treatment.

The second option explored two concentrations (2 ppm and 4 ppm) of *BS*1000™ surfactant in irrigation water in the drip tape. Bubble size decreased, whereas air void fraction increased along the length of drip tape, with increased concentration of surfactant, in both up and down emitter positions in the drip irrigation tape. The best result was using non-ionic surfactant at 4 ppm with the emitter facing down where the bubble distribution and the availability of micro-bubbles over the 500 m irrigation was greatest. This knowledge will be of benefit in drip and sub-surface drip irrigated agriculture.

Introduction

Our aim is to be able to quantify the air void fraction and dissolved oxygen (DO) concentration along the length of tape in drip irrigation (DI) and subsurface drip irrigation (SDI). We will use this information to obtain better agricultural and environmental outcomes by studying the effects of the DO and air in the form of bubbles on plant and soil chemistry. We believe that DO and air bubbles in water play different roles in the root zone, their relative effects are unknown and of research interest. Being able to get water with significantly greater air void fraction and dissolved oxygen (DO) concentration further down the DI or SDI tape is an important outcome. We do this to increase the oxygen supply to the plant root zone. Poor oxygen supply in the root zone of crop plants can be a major bottleneck in irrigated farming. Evidence of hypoxia associated with drip and subsurface drip irrigation has been well documented (Silberbush et al., 1979; Goorahoo et al., 2002; Bhattarai et al., 2005). The purging of soil air and thus oxygen out of the root zone in response to irrigation has been termed the *irrigation paradox*. Water used for irrigation purposes can often experience a low DO value, particularly at higher temperature, saline irrigation water, and water with high critical oxygen demand (COD).

Soil aeration has been recognised as a major limitation of irrigated crop production for more than 60 years (Wiersma and Mortland, 1953). Early air injection methods used a compressor to deliver compressed air to the root zone via drip tape. In this method the distribution uniformity of air is rather poor, as the compressed air tends to escape from the drip emitters by the chimney effect (Goorahoo et al., 2002), i.e. as large volume of air exiting vertically from the DI and SDI emitters along the drip tape. By adapting Venturi air injectors Goorahoo et al. (2002) clearly demonstrated the benefits of using aerated water irrigation and proposed practical methods that are based on bubbles generated by the air injection system.

Aerating the crop root zone using hydrogen peroxide (H_2O_2) or injecting air using a Venturi principle in DI and SDI in hostile soil such as vertisols is discussed in Bhattarai et al. (2004, 2006). Hydrogen peroxide application, in spite of its positive benefits

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has not taken off in the industry as the long-term effects on soil and associated recurring costs of using H_2O_2 are not well understood or modelled. Su and Midmore (2005) modelled both point and line sources of air and water flow from SDI tape and demonstrated the asymmetrical distributions of water flowing from SDI tape. Air injectors and diffusers that generate small bubbles mixed into irrigation water streams as an air water slurry and then directly injected into the crop root zone have been found to be effective in ameliorating hypoxia providing positive response on crop growth and water use efficiency (Bhattarai et al., 2008, 2010; Bhattarai and Midmore, 2009; Dhungel et al., 2010; Pendergast et al., 2013). Recent analysis suggests the poor soil aeration can also be a permanent limitation in fairly drained soil when the irrigation rate with DI and SDI are near the potential daily crop evapotranspiration demand (Dhungel et al., 2012).

Uniform aeration across a field is important for consistent crop production. Mixing bubbles of heterogeneous sizes into irrigation water does deliver air into the root zone. However, a large proportion of the bubbles in the aerated water escape from the emitter proximal to the source of air injection. Further, due to the buoyant nature of bubbles in the water, the effectiveness of oxygen has been limited as most of the aerated water has exited the DI or SDI tape within 250 m or closer from the air injection point.

The air in all trials was injected into the irrigation water by a Mazzei model 384 air injection Venturi and which we classify as micro-bubbles (20–500 μm), macro-bubbles (1–10 mm) and unseparated air lumps in the irrigation water as well as in the form of dissolved oxygen.

As given in Bhattarai et al. (2013) near the injection point the flow is turbulent. Within 100 m the flow transitions to a laminar flow. With the air injection Venturi a large proportion of the bubbles are in the micro–macro size, gradually turning to bulk (lumps) as the bubbles coalesce in the irrigation line at greater distances away from the source of air injection. Depending on the pressure internal to the drip tape at a given point the air/water phase will escape from the emitters at a variable rate.

In the current trial emitters are spaced 20 cm apart. Depending on the water pump pressure and other factors at some point the pressure in the pipe drops to atmospheric pressure and the flow of air and water from the emitters stops, particularly if the pump capacity is smaller than the volume of the flow that is required for irrigation and the operating pressure of the tape is low.

Experiments with cotton (Pendergast et al., 2013) reveal that from a biological perspective useful volumes of air can reach the plant root zone in 250 m long rows and that there is a resultant 10% yield increase in field trials (taken over eight years of data). However, this is about the limit from the biological perspective that Venturi pressure air injection is useful. Crops utilising DI and SDI tape have rows of up to 800 m long. To increase the distance that a mixed air/water phase can travel down the DI or SDI tape is a challenge.

As the dissolved oxygen (DO) can be low (4–8 ppm) in irrigation water, to meet crop demand for O_2 we aim to maximise the diffusion of O_2 from micro and macro bubbles to irrigation water. Smaller sized bubbles have a greater surface area for diffusion to occur. Also smaller bubbles are less buoyant and travel further down the DI or SDI tape.

Bhattarai et al. (2013) report on continuous image capturing to estimate the void fraction of air along a Venturi aerated water stream in SDI tape. In that work bubble sizes were estimated from captured images using the *ImageJ* software along six stations of drip irrigation (DI) or subsurface drip irrigation (SDI) tape. The bubble profile was collected over 169 m.

For the purpose of this research we used a modified visualisation unit for bubble photography of an irrigation water stream containing bubbles. We photographed at 12 positions along 500 m of SDI drip tape to profile the air/water fractions along the length of the drip tape.

We discuss two options for increasing the distance the air/water phase achieves along commercial irrigation drip tape. We use two positions of the emitters relative to the ground plane. In the *up* orientation the emitters are 90° to the ground plane and in the *down* position the emitters are −90° to the ground plane. The second option explored concentrations of 2 ppm and 4 ppm of *BS*1000™ surfactant in irrigation water in the SDI tape.

We report on our findings from the current trials. We discuss these in relation to previously reported trials and propose a future course of action for monitoring air void fractions in DI and SDI systems.

Materials and methods

Experimental site

The experiment was conducted at CQU Rockhampton campus, Australia (23°19′7.45″S, 150°31′21.01″E), on a 500 m long, flat, level terrain in order to achieve accurate results for bubble distribution in drip and sub-surface drip irrigation tape.

Irrigation system

For each treatment a 1500 l tank was filled with town drinking water and pumped through the SDI tape. The pump used was a DAVEY XF 92 (Davey Australia Limited. http://www.davey.com.au/) with 98 lpm flow with a 0 m head (manufacturers data sheet). A 17 mm diameter drip tape (t-tape) with 20 cm space between emitters was used. The emitter flow rate for this tape is rated at 1.1 l/h at an operating pressure between 35 and 110 kPa. Air was injected into the irrigation tape using a Venturi air injector model 878-2 (25 mm male threaded) from Mazzei Corporation, USA. The pressure difference was controlled using manometers maintaining 386–393 kPa at the inlet and 110–130 kPa at the outlet of the Venturi. This pressure differential was chosen to draw 12–15% air by volume into the water stream based on Bernoulli's principle and manufacturers specifications. Twelve stations were selected at varying distances along the drip tape and connectors were installed to allow for fitting the camera system in order to photograph the bubble flow at that point of the drip tape. As for normal agricultural practise we closed the end of the drip tape.

Camera assembly (bubble visualisation unit)

For previous bubble visualisation in irrigation, a prototype unit was created as described by Bhattarai et al. (2013) allowing, at desired locations, imaging of the bubble flow during aeration of irrigation water. In the current research optimisation of the prototype was undertaken to obtain clearer images. A clear transparent 1 m length of Pyrex glass pipe was used instead of the square plastic tube used in the earlier work given in Bhattarai et al. (2013), as the former is optically clearer. Otherwise our new prototype follows the same design as given in Bhattarai et al. (2013).

Since irregular flow is generated when water passes through the connections attached to the glass tube, the camera and the flash unit was mounted 0.66 m along the Pyrex tube in the direction of flow. As the pipe diameter is 17 mm this gives approximately 39 times the diameter of the pipe for this effect to settle. As the diameter of the Pyrex tube closely matched the diameter of the irrigation pipe and as the connections had a smooth internal surface between the irrigation pipe and the Pyrex tube, any irregular flow introduced was much less than in the previous system.