OXYGATION

OPTIMISING DELIVERY AND BENEFITS OF AERATED IRRIGATION WATER

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Executive Summary

Increasing competition on supply of fresh water for irrigation by agricultural, domestic, sports and industrial users demands water use efficient irrigation methods and compliance with environmental regulations. Drip irrigation (DI) and subsurface drip irrigation (SDI) are advocated for improvements in water use efficiency (WUE) and are increasingly being adopted by horticultural industries in Australia and overseas. Greater flexibility for automation and versatility of application of drip irrigation technology encourage wider-scale adoption by these industries. However, the higher initial investment for installation and lack of significant yield gains due to drip irrigation compared to conventional irrigation methods are somehow deterrents for broad-scale adoption.

Ways to optimise the use of DI and SDI will have multiplier effects on water savings for irrigation in agricultural and other industries and minimize environmental impacts associated with traditional irrigation methods. One of the significant areas where greater optimization of DI and SDI is realized is through the use of aerated water for irrigation (oxygation). Sustained wetting fronts around emitters associated with DI/SSDI impose hypoxia in the rhizosphere. This impedes root respiration leading to sub-optimal plant performance. As irrigation water exits an emitter, it purges soil pores of soil air (containing up to 20% by volume of oxygen) with water that contains less than 10 ppm oxygen, a quantity we have shown is used up quickly by roots and soil microbes. Rising soil temperatures, salinity, and soil compaction will exacerbate this effect, as may disease such as *Phytophthora* of pineapple. Plant roots and soil microbes require oxygen for respiration.

In soils with inadequate aeration the lack of oxygen results in reduced plant growth and diminished productivity for many reasons, including: reduced root growth and root size; reduced root ability to absorb minerals and water; reduced photosynthesis and plant growth due to stomatal closure; loss of soil N due to the in-activity of microbes; adverse changes in soil chemistry; increased susceptibility to disease, and an alteration of the balance and supply of plant growth regulators.

Aeration of the irrigation stream, a process termed 'oxygation', overcomes this constraint. Oxygation is a new innovation in irrigation technologies. Aerated DI and SDI by different methods, such as venturi for air injection, allows for the simultaneous application of water, air and other agro-chemicals directly to the crop root zone. Therefore, it can potentially improve crop yield and water use efficiency. Conventional irrigation methods such as flood irrigation have large inefficiencies due to run-off, drainage and evaporative loss. SDI can significantly improve the WUE over that of flood irrigation, and oxygation can significantly improve WUE of SDI.

Oxygation involves mixing atmospheric air with irrigation water using a venturi and delivering it via a surface or subsurface drip irrigation system. An oxygation system can be installed as part of a new SDI system or may be retrospectively fitted to any existing SDI system. A venturi air injector is installed within the pipeline and draws air directly into the water stream. A single venturi can be installed immediately after the pump outlet and the air distributed through the main line to sub mains and lateral drip lines, or a single injector may be fitted to the beginning of each drip line. The amount of air ingress depends on the pressure differential across the venturi and the motive flow through the venturi.

Mazzei or Netafim Air Injectors improve soil aeration by entraining air (in the form of micro-bubbles) into

irrigation water. The added air improves growing conditions, increasing root respiration and microbial activity. These improved soil conditions have resulted in significant increase in yields. All NPSI funded project activities in this report utilized Mazzei air injectors.

System requirements include drip/subsurface drip irrigation, water flow must be 3.8 LPM - 30.3 LPM per drip line (for M1384, 584 and 1583 injectors), and the terrain must be level to moderately sloped. We are also evaluating alternative approaches for super saturating irrigation water with air using twin vortex, oxysolver and Seair diffusing systems and plan researching benefits on furrow and sprinkler irrigation. We also present our research progress on diversifying the use of oxygation in landscape (lawn) and sports industries (sport grounds) to improve the WUE of these industries and to minimize the offsite movement of pesticides and nutrient from such hidden landscapes.

A number of earlier studies conducted under controlled environments in pots and the glasshouse showed positive response to oxygation in medium and heavy textured soils. With this recent innovation of aerating the irrigation stream (oxygation), returns, yields and water use efficiencies (WUE) of SDI crops all increase (see Advances in Agronomy 88: 313-377 (2005)). This preliminary research clearly highlighted the opportunities of harnessing the potential benefits of oxygation for yield, quality and crop water use efficiency in Australian horticultural industries across diverse crops, soil types and irrigation water qualities. On large-scale field trials with SDI and surface drip, yield increases in cotton of 19% and in cucurbits of 12-60% were achieved, with significant improvements in product quality as measured by increase in °brix percentage of the fruit (i.e. sweetness). We have undertaken trials on heavy clays and lighter soils and for surface trickle under mulch, and trickle above the ground, showing positive and beneficial effects of aerated water irrigation. In this report we summarize the outcomes of oxygation research carried out by CQUniversity Australia in collaboration with Australian primary industries in a range of annual and perennial crops, and suggest the approach for large-scale adoption by irrigation industries in Australia.

Ten different crop industries (cotton, pineapple, lucernes, capsicum, strawberry, fig, table grapes, melon, vegetables and apricot), plus crops consultants and irrigation businesses in QLD were involved in testing the benefits of oxygation in field scale research. Data collected over 2- 4 seasons on yield and water use efficiency suggested that yield benefits of 4 – 19% were achievable with oxygation. Oxygation involves installation of an air injector (pressure differential venturi) in-line for mixing air with irrigation water. The installation cost of air injector can be AU$ 600-1000 per hectare depending on size of air injectors and requirements of accessories and fittings. Air injectors can be installed into new irrigation installations or retrofitted into existing drip irrigation systems.

The response to oxygation varies with crop and soil types, quality of irrigation water and type of drip irrigation. Horticulture industries in Australia span the range of these variables, therefore there is need for collaborative research, industry engagement and involvement of multidisciplinary research teams in the field of oxygation research to harness the full potential benefits of this technology to the industry.

The project has resulted in significant benefits to cotton, with an average lint yield increase of 14%. Large cotton areas in Australia are furrow irrigated, hence, adoption of oxygation within the realms of existing cotton irrigation practices is currently limited. Future research is therefore suggested on use of aerated water with furrow irrigation, the primary method for irrigation of cotton. Increase in yield (6% in industry yield and 26% in total yield) and suppression of *Phytophthora* has been recorded on pineapple. In other crops (capsicum, strawberry, grapes) yield increases by 4-10% have been recorded. In apricot and fig the crop is still in the juvenile stage, and will be ready for harvest in 2012/2013 season only. Data will be collected from these crops beyond the funded project duration.

Oxygation as a tool delivers air into the crop root zone. Oxygen limitations can be significant in compacted, saline, and water logged soil, and with high BOD effluent irrigation water. Therefore, potential applications of oxygation can go beyond the improvement of water use efficiency and increased yields with ordinary drip and subsurface drip irrigated crops, into amelioration of other conditions that impede the diffusion of oxygen in the rhizosphere.

Air within the irrigation water is a two phase flow fluid, hence, it imposes challenges for uniformity of air distribution along the irrigation line. This situation may be severe particularly when the drip irrigation is run over long row distances. Development of monitoring tools for measurement of air fraction and ways to minimize the heterogeneity of air bubbles distribution are currently underway. A number (7) of refereed journal articles have been published, postgraduate and undergraduate students have been involved (8), active collaboration with irrigation business, crop and irrigation consultants has been developed, and more field testing by independent crop consultants is underway, suggesting a gradual dissemination of the technology beyond the project timelines and resources. The following pictures highlight industries under collaboration for oxygation research in Queensland, Australia, showing diversity in terms of crops and focus in terms of soil aeration.

COTTON subsurface drip with MI1583 injector

PINEAPPLE subsurface drip with MI1583 injector

LUCERNE subsurface drip with MI2088 injector

TABLEGRAPE drip above ground c.MI1078 injector

FIG surface and subsurface drip c. MI584 injector, inundated crop

CAPSICUM surface drip with Oxycrop and MI1078 injector

STRAWBERRY drip irrigation with MI384

APRICOT Subsurface surface drip c. MI784

Sufficient data have been collected from cotton, pineapple, lucerne, and capsicum trials to make valid conclusions from the trials. One more season's data will be collected from fig, apricot, table grapes, and the smart lawn (potential opportunity for urban water security) with support from our Research Centre's funding, to bring the on-going activities towards the a logical conclusion.

The project established active linkage with 10 different industries, and developed successful collaborative research activities producing practical outcomes for industries. In recognition of the excellence in engaged research and innovation, project team member Dr Surya Bhattarai was awarded the 2010 CQU Opal Award for regional engagement. The project led to extending research with the sugarcane industry in the Burdekin, evaluating the drip and furrow for control of deep drainage and runoff, with potential opportunity of evaluating oxygation for minimization of nitrous oxide emission from irrigated sugarcane.

OPAL AWARD

SMART LAWN

SUGARCANE

Grower Case Study "Oxygation of cotton"

Australian cotton in Queensland's Central Highlands is predominantly grown on a heavy clay soil (a vertisol). Cotton crops grown in vertisols often experience episodes of low oxygen concentration in the root zone, particularly after irrigation events. Drip and subsurface drip irrigated cotton crops receive frequent irrigation and develop sustained wetting fronts in the rhizosphere. This condition lead to poor diffusion of oxygen, causing temporal and spatial hypoxia. Use of aerated water for irrigation can ameliorate the hypoxia in the wetting fronts and, therefore, overcome the negative effects of poor soil aeration. The cotton crop is extremely sensitive to even short term water logging and yield penalty can be high for short-term exposure to hypoxia.

A replicated field trial has been conducted since 2004, on a cotton property at Nyang, Emerald in collaboration with grower Tony Ronnfeldt and DAFF Emerald water use efficiency program. The trial was carried out over seven seasons. The field trials consisted of sub-surface drip irrigation with and without aerated water (control) throughout the growing season. Of the total of 12 bays, each with ~0.4 ha, six of them were allocated for oxygation and the remainder as controls, in six blocks (Fig 1a). Oxygation of the plots was achieved by employing Mazzei air injector model MAI-1583, set to inject 10-12% of the air by volume of water (Fig 1b), and the yield was recorded from machine harvest for each bay by the grower (Fig 1C). Mazzei were operated in each of the irrigation events. Long-term average of 7 seasons showed yield increased by 14.7% with aeration using Mazzei air injectors (Fig 2). Tony has been continuing this trial, earlier with different irrigation rates (85% and 105% ETc) but currently the irrigation input has been kept as standard and uniform at 100% ETc and the only variable for the trial site is oxygation.

Figure 1: 12 bay SDI site (a on the left), air injector MI 1583 installed for individual bays (b on the middle, and the produce was harvested by machine for yield determination by the Grower, Tony Ronnfeldt, cooperating grower.

Tony is passionate about SDI and air injection irrigation. He has been active in communicating about this research and potential benefits of oxygation to a number of growers both locally and beyond. A few cotton growers with SDI from Moore have enquired about the performance of the system and have received harvest data.

Large areas of cotton area in Australia are under flood/furrow. Flood irrigated cotton crops are also reported to experience hypoxia in heavy clay soil. Hence, aerated water irrigation for furrow/flood can be of potential significance for the cotton industry in Australia. A Cotton-CRC funded undergraduate student Lisa Lowie used aerated water from Seair diffusion system and used it to grow cotton in hydroponics. The data suggest that greater transpiration and leaf gas exchange with the Seair diffusion system with aerated irrigation water underpins opportunities for using aerated water in furrow irrigation. The more smaller bubbles the more that stayed in suspension for irrigation of cotton in the soilless culture system; smaller bubbles (<20mm) can be as much as 2-4% of the total water volume.

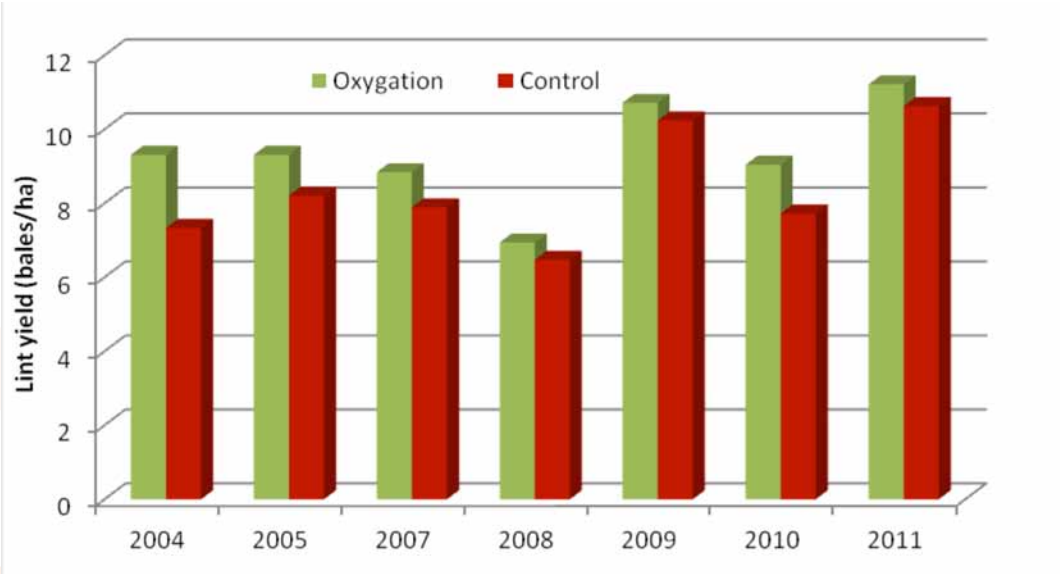

Figure 2: Lint yield harvest by industry over the seven seasons for oxygation and control treatment at Nyang, a long term research site at Emerald, CQ Australia.

Tony Ronnfeldt was keen to share his experiences with others in cotton and other industries. He presented in the 2011 Irrigation Australia Limited Conference in Launceston, Tasmania. Tony and his family have decided to continue oxygation in the current block with SDI installation, and expect to continue to increase lint yield.

Growers and consultants in QLD, other states and overseas have also started using oxygation. Tarin Bradford at Tully NQLD is a melon grower and is currently trialing on his own initiative an MI 4090 for a 10 acre block. Peter Greensill and Eddie Donn of Hortus Limited have also been trialing Mazzei air injectors in melon crops.

Irrigation business enquiries for the source of Mazzei air injector and have prompted stocking for the local demands. Toro Ag Australia in Brisbane, Total Eden Water in Rockhampton and Emerald and Dowden's Pumping Rockhampton have now started stocking air injectors for irrigators. According to Tony the extra yield and potential income outweighs the cost of air injection installation in an already existing irrigation design for drip and sub surface drip irrigation. Tony's continuous commitment to aerated irrigation water has also aroused the interest of growers in the vicinity. Adoption of oxygation by table grape growers in Emerald is believed to be due to the positive influence of air injection irrigation on cotton.

The Centre for Plant and Water Science (CPWS) at CQUniversity, Australia is a pioneer in oxygation research. The centre engaged industries, businesses and collaborators in a range of activities relating to oxygation. Research is being conducted to improve the efficiency, especially the uniformity of supply of air along drip lines, of existing oxygation systems, to perfect novel oxygation delivery systems and to expand application of oxygation to a range of crops and environmental conditions. CQUniversity researchers, academic staff and postgraduates worked on this project in association with research partners from a diverse range of organisations and industries within and outside the Australia to achieve the results.

The National Program for Sustainable irrigation (NPSI) is a partnership of cotton research & Development corporation, Water Population and communities, Gascoyne Water co-operative, Goulburn-Murray rural Water corporation, Grains research & Development corporation, Harvey Water, horticulture Australia limited, lower Murray Water, Ord irrigation co-operative, South Australian research and Development institute, Sugar research & Development corporation, Sun Water, and Western Australia Department of Water and the Australian Government Department of Sustainability, Environment.

For further information visit the website **www.npsi.gov.au**

As part of its charter to improve technologies for water use, whether these are physical or biological technologies, the National Program for Sustainable irrigation has supported the development of David Midmore's research and his extension of improved irrigation management to irrigators by optimizing drip and subsurface drip irrigation employing aerated irrigation water.

Improving water use efficiencies in crop production is an absolute requirement for agricultural world which must double world food production without putting pressure on limited water supplies, according to crop physiologist and co-author of this report, Prof David J Midmore (pictured).

The work undertaken at CQUniversity Australia over the past decade suggests that drip and subsurface drip irrigation succumb to temporal hypoxia in the wetting fronts upon irrigation, and this irrigation paradox can be overcome by using aerated water for irrigation. A series of research studies both strategic and applied under the leadership of Prof Midmore and his team, suggests that crop response to aerated irrigation water (oxygation) is very promising in a number of crops both under controlled environment trials and in field tests. The longer term studies conducted in cotton, pineapple, lucerne, and grapes shows positive benefits of oxygation on yield and water use efficiencies. Response to oxygation is mediated through enhanced root growth and other root processes.

NATIONAL PROGRAM FOR
Sustainable Irrigation