



# OXYGATION



## OPTIMISING DELIVERY AND BENEFITS OF AERATED IRRIGATION WATER

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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 (oxygenation) 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 oxygenation on yield and water use efficiencies. Response to oxygenation is mediated through enhanced root growth and other root processes.*

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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 (SDI) 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, 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. 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.

Eight different crop industries (cotton, pineapple, lucernes, capsicum, strawberry, fig, table grapes, 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 crop 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 highlights 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 MII583 injector	PINEAPPLE subsurface drip with MII583 injector	LUCERNE subsurface drip with MI2088 injector	TABLEGRAPE drip above ground c.MII078 injector
			
FIG surface and subsurface drip c. MI584 injector, inundated crop	CAPSICUM surface drip with Oxcrop 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 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 2010 CQU Opal Award. The project lead to extending research with 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.



## Grower Case Studies “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 leads 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. We defined this as oxygation. 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.

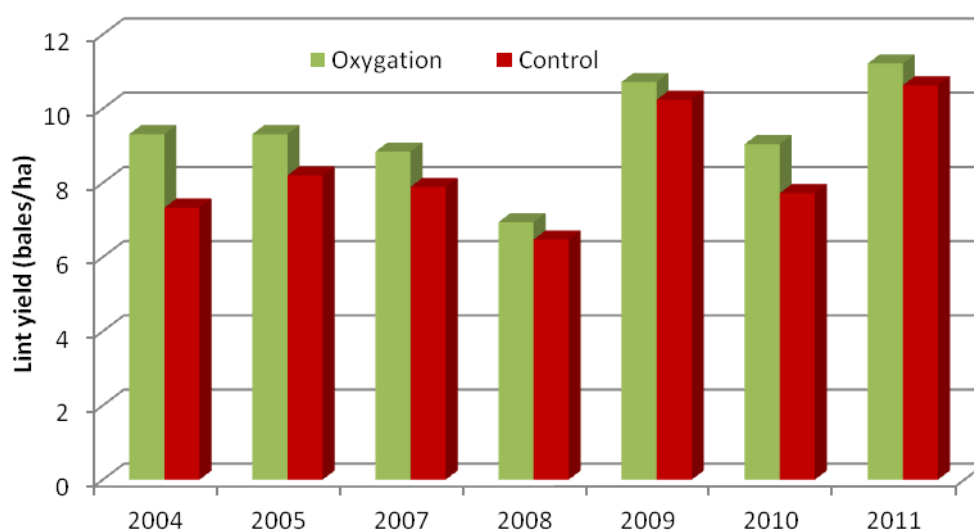


**Figure 1:** 12 bay SDI site (a on the left), air injector MI 1583 installed for individual bays (b on the middle), and the produce was harvested by machine for yield determination by the Grower, Tony Ronnfeldt, cooperating grower.

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. 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 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 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 other 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 its 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 also 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 in this project in association with research partners from a diverse range of organisations and industries within and outside the Australia to achieve the results.



# PROJECT MILESTONE REPORTING TEMPLATE

<b>Program:</b>	National Program for Sustainable Irrigation		
<b>Project Number:</b>	UCQ5070		
<b>Project Title:</b>	Optimising Delivery and Benefits of Aerated Irrigation Water		
<b>Research Organisation:</b>	Central Queensland University		
<b>Principal Investigator:</b>	David Midmore & Surya Bhattarai		
<b>Project Start Date:</b>	01/10/08	<b>Project Completion Date:</b>	15/05/12

**Milestone Report Title:** Final Report  
**Milestone Number:** 6  
**Milestone Due Date:** 15/05/12      **Date Submitted:** 07/05/2012

## General Project Information

### 1. Project Objectives

There are six key research objectives that will lead into the development of improved practices and industry outcomes revolving around 'judicious use of water.

1. To determine, through in-field trials, whether there are yield and water use efficiencies to be gained with the introduction of oxygation (using venturi, Oxysolver, Seair or fertilizer peroxides) into irrigated annual and perennial cropping.
2. If so, to optimise the delivery specifications for water/air [oxygen]/nutrient ratios for different soil types, and to develop a simple decision support system to allow for implementation by growers.
3. To extend the use of 'waste' water for irrigated cropping, while accounting for salinity and elevated Biological and Chemical Oxygen Demand, through oxygation, for we have shown oxygation to reduce negative effects of saline irrigation.
4. To ensure that there is no adverse effect of oxygation on quantity and quality of soil carbon, or on soil structure.
5. To quantify the effects of oxygation with the 'Oxysolver' and 'Seair' for furrow-irrigated cropping.
6. To add to the knowledge base on plant physiological response to oxygation, particularly in perennial species.

### 2. Location (s)

Field trials were conducted in Queensland Australia. Cotton and grape trials were conducted in Emerald, pineapple in Yeppoon, lucerne in Biloela, capsicum in Bundaberg, apricot in Stanthorpe, fig in Alton Downs; strawberry and Smart Lawn in Rockhampton. Work for bubble visualisation was carried out at the Australian Nuclear Science and Technology Organization (ANSTO) laboratory in Lucas Heights, NSW Australia, and in Brisbane and Rockhampton.

**Emerald** [three sites, Nyang - for Cotton, Australian Agricultural College Council (AACC) Emerald Campus - for Table Grape variety Flame and, Glency Grapes - for Table Grape variety Menindee, plus a new fourth site with macadamias]. The Nyang cotton crop was mostly sown in October [planting window variable due to wet weather during project period]. The site was well instrumented with installation of Enviroscan soil moisture sensors for continuous monitoring of soil moisture to the depth of 1.2 m and the installation allows for regular drip tape maintenance. This site allows for long-term study of the effects of oxygation on soil physical, chemical and biological properties and on soil carbon. Penetrometer data to assess the soil compaction in the wetting fronts due to oxygation has been collected from the soil at full moisture in the profile before the crop received its first irrigation. Change in soil organic carbon as the proxy of soil chemical characteristics and FDA test to assess the total microbial diversity have been carried out.

The AACC site for Grape has been returned to the Ag College by the lessee [it was uneconomic to manage, since the trellis system does not allow for tractor powered spraying of agrochemicals], and the college decided to pull all plants out; we captured all of the relevant data before the site was up-rooted at the end of 2010. We have undertaken some destructive sampling [since all were to be removed anyway] in October 2010, and completed dismantling the instrumentation from the site by January 2011. The third site, Glency grape is an excellent example of a well managed table grape farm, and the trial goes from strength to strength. The site has drip tube above the ground, hence it provided a site with an alternative to surface or sub-surface drip irrigation for testing of oxygation.

**Yeppoon** [one site, for pineapple] harvest comprised both the first and ratoon crops and compiled data for the total yield and marketable yield were presented to growers and in publications. Final total harvest, and industry harvested yield showed marked positive effects of oxygation. Assessment of *Phytophthora* infestation in different treatments was also carried out in the field crop. Assessed as number of plants infested by *Phytophthora* at the end of final harvest it was counted by the industry representative and research staff.



**Biloela** [one site for lucerne irrigation water sourced from ground water bore contained salinity up to 3200  $\mu\text{S}/\text{cm}$ ], with plant sampling continued to the end of 2011, a data set for three years, which included fresh and dry plant weight at regular intervals. Soil, water and crop samples were collected and analysed over the trial period.

**Bundaberg**, one full trial at one site, one for capsicum with collaboration with Crop-Management Australia, and two verification trials by crop consultants and industries for melon production. One site earlier planned for sugarcane has not materialised, but negotiations with N Qld continue [held back by CSIRO who wish to firstly trial SDI, then at a later stage oxygation]. The outcome of the project proposal submitted for funding is not announced yet. However, a commercial scale demonstration site with a melon grower at Ayr (Mr Tarin Bradford) has been installed with an air injection system, Mazzei 4090 for a plot of ~ 10 acres. The site utilizes one of the largest air injector (MI4090) among the NPSI funded project activities. The installation and test run has been successful, but due to wet weather only limited irrigation (2 irrigations) has been provided to the previous melon crop, and the unit has not been set up with a new melon crop which will receive most of crop water demand by irrigation.

Bundaberg based crop consultant, Eddy Dunn of Hortus Technical Services is trialling oxygation on a field crop of watermelon in a ferrosol with one of the biggest melon grower of the region, Mr Peter Greensil of Windermere Road, Bundaberg. The crop is being aerated with Mazzei model MII022, and some preliminary data are being collected by the Hortus Technical Support Team. Industry and consultants are both keen to continue the testing over seasons so that the performance of the system can be assessed over the dry and wet seasons.

Mini air injectors for individual rows were installed for preliminary observations. Pilot tests on mini air injectors for individual row aeration was carried out in Austchilli Bundaberg, in a heavy clay soil with drip irrigation. These growers managed trials, had minimum data collection, but provided a more subjective assessment of oxygation in low pressure lay flat type irrigation system common in many horticultural industries. Industry is keen to run another trial in a larger plot with larger size air injector using appropriate operating pressure. A new test in 2012 will be set up by a local crop consultant and agronomist in Austchilli.

**The Summit, Stanthorpe** [one site, for establishing crop of apricot], data collected on tree growth and fruiting and sample harvesting will be conducted as the crop comes to first harvest in January 2013. This site uses recycled waste water received from city council as treated effluent.

**Alton Downs, South Yamba**, nearby Rockhampton [one site, for figs], data collected over a year in a juvenile crop. Flood of 2010-2011 had severe effects on crop as numbers of rows were inundated. Some plants have started recovering and the grower has started managing this crop. Some data collection will commence on this crop to evaluate the effects of oxygation on flowering and fruiting of fig. This site is nearby CQUniversity, and the future follow up will be reasonably inexpensive.

In the **CQUniversity**, strawberry trials were conducted with a SeaAir and Mazzei injector oxygation system in year 1 and 2 respectively, and extensive data collected for yield and quality of berries. Strawberry is a new crop for the CQ region, as there is no reported commercial production of strawberry in the whole CQ region. The trial demonstrated opportunities for commercial production of strawberry in the Rockhampton region.

Use of fresh water for irrigation of urban landscapes, e.g. lawns, is becoming important issues as competing and increasing demands for fresh water in the cities and towns becomes more intense. We started a new trial for lawn oxygation, called smart lawn [see Newspaper coverage in Section 12, being tested in a residential block at Panorama Heights in Rockhampton]. This involves operation of air injectors for a subsurface drip irrigated lawn by the existing pressures on the water supply pipe line for homestead and garden oxygation. This is in addition to the installation of lawn oxygation systems at CQUniversity Centre for Plant and Water Science (CPWS) compound. A new application has been submitted to the university for developing a business scheme for the smart lawn concept and university funding to develop demonstration sites for lawn oxygation within the university compound of Central Queensland Innovation and Research Precinct (CQIRP) so that interested visitors, parties, business, and funding agencies can be shown a functioning model.

**In Echuca, Victoria** a new oxygation system for processing tomato is being discussed with Cedenco Australia, and a member of SK Foods Group in collaboration with Netafim Australia, and HAL. Data collection will be limited to largely observations. Industry is keen to run a full season experiment, commencing September 2012- Jan 2013, hence finetuning of the air injection system and trail design are being discussed with industry and Netafim Australia.

We have also been approached by various industries for extending the oxygation research in crops, and will prepare an ARC linkage grant proposal to support this work further. Jim Kelly of Arris Pty Ltd, South Australia for example has pledged some cash support (\$30,000) as industry cash contributions for the ARC funding application.

The research was undertaken at the following locations [a summary table 1 with full details is presented in the following section of the report]:

**Table 1:** Location and trial description of oxygation research activities in a number of annual and perennial crop species tested in different parts of Queensland, Australia

Industries	Collaborator	Address	Crop history	Soil type	Variety	Planting date	Treatment	Plot size	Aerator details	Oxygation	Crop stage	Preliminary crop Info	Irrigation details
<b>Pineapple</b> <i>Annanus comosus</i> (Completed)	Mr John Cranny	Tropical Pines, Yeppoon QLD	New	Loamy sand	GC-1	24/10/ 07	Oxygation, control at same watering rate, no irrigation plot	oxy 1.05 ha (7 blocks c 16 rows @ 1.5 m, pp 0.5 m), control 0.97 ha, & no irrig 0.125 ha	1 Mazzei model MI 1583	Commence 14/3/08	Harvest of main and ratoon crop. Diurnal data recording for leaf and soil gas exchange conducted.	Oxygation effects notable (6% increase in yield).	Plastro drip tube, 10 cm depth, emitter @ 0.3 m c 1.2L/h
<b>Cotton</b> <i>Gossypium spp.</i> (Completed)	Mr Tony Ronnfeldt	Nyang, Foley Rd, Emerald, QLD 4720	New, Long term effect of oxygation	Vertisol	Sicot 70BRF	21/10/08	Oxygation and control, 85% and 105% ETc	12 plots each 0.4 ha (16m x 270 m).	6 Mazzei model MI 1583	Wet season, oxygation to commence from first irrigation	2009 crop harvested in Feb 2010	Higher yields in oxygation (14%) in whole plot and sample harvest.	Netafim drip, 40 cm deep, emitter c. 25 cm c. 0.7L/h.
<b>Lucerne</b> <i>Medicago sativa</i> (Completed) Saline irrigation water (2250 uS/cm)	Mr Kim Mobbs Mrs Cheryl Mobbs	Mobbs' Farm , Thangool, QLD 4702	Lucerne-Wheat-Lucerne	Vertisol	Wheat for uniformity. Lucerne var Aurora	Wheat planting 17/06/07 and Lucerne 25/10/07	Oxygation and control at same watering rate	3 blocks each with 27 rows of 182 m long	2 Mazzei model MI 2081	Commence 11/12/2007	Harvesting completed, 10 harvests in two years.	Establishment phase dry soil conditions followed by wet period. No significant yield difference but saving in water.	Netafim drip, 40 cm deep, emitter c. 25 cm c. 0.7L /h
<b>Fig</b> <i>Ficus caria</i> (Revived)	Mr Clarie Higham	South Yamba Road, Altondown Road, QLD 4702	Earlier mango in this block, new crop of Fig now	Silty loam	Conadria a white fig	Layering placed on 22/01/2009, planting 09/04/2009	Oxygation and control , 2 depths at same watering rate	21 m x 8.4 m plot, 3 rows at 2.8 m x 1.4 m spacing, 4 trt with 3 reps	1 Mazzei model MI 584	Commence from first irrigation	Pruned back 13/10/2009, biomass weighted, plant nearing dormancy	Pruning improved uniformity. Juvenile plant biomass increased by oxygation. Suffered from flooding 2011, currently re-sprouting.	T tape , 15 cm and surface depth, emitter @ 0.2 cm, 1L/h)
<b>Grapes</b> <i>Vitis vinifera</i> (Terminated)	Mrs Klowa Pioch /Don Wills	AACC, Emerald Campus, QLD 4720	Established plantation	Sandy loam	Flame	5 years old plantation	Oxygation and control at 2 emitter depths (surface and subsurface)	50m x 9 m, 3 rows @ 3m x 2.5m in plot. 4 trt c. 5 reps	1 Mazzei model MI 1078	Trt commenced 14/02/2009	Destructive Harvested on October 2010. Lease returned to AACC	Dry biomass increased with oxygation. Harvest for final yield??	Netafim drip, 75 cm emitter, 2.7 L /hr.
<b>Grapes II</b> <i>Vitis vinifera</i> (Continuing)	Mr Glen Pearmine	Pearmine farm, Talafa Rd, QLD 4720	Established plantation	Vertisol	Menindee	2 yrs old planning	Oxygation & control , 4 reps of 2 trt 4,3,4,3 rows/ trt for each rep	1.13 ha G block 28 rows of 142 m length @ 3 m x 2.5 m spacing	1 Mazzei model MI1078	Commence 24/03/2009	Harvested Dec 09-11. Defoliation in May	2010 poor fruit quality due to wet weather. 5 % increase in yield.	Netafim drip tube, @ 0.5 m c 2L/h. Drip above the surface

Industries	Collaborator	Address	Crop history	Soil type	Variety	Planting date	Treatment	Plot size	Aerator details	Oxygation	Crop stage	Preliminary crop Info	Irrigation details
<b>Apricot</b> <i>Prunus armeniaca</i> Effluent irrigation (Continuing)	Mr Alfred Baronio	The Summit, Stanthorpe, QLD 4377	Existing plantation	Loamy sand	Early cot	2 yrs old plantation	Oxygation and control and 2 depths, 4 trt, 4 reps	1 row of 100 m long c 5 m x 2.5 m RR and PP per plot	1 Mazzei MI784	Commence 17/03/2009	Growth data collected over 3 seasons	Sporadic fruiting. Fruit count in Dec 2011. First harvest data expected on Dec 2012.	Plastro, drip tube, 0.75 m emitter, @ 2.35L/hr discharge
<b>Winter vegetables</b> (Bell pepper) <i>Capsicum annum</i> L (Completed)	Mr John Hall and Liu Curino	Crop-Management Australia, Bundaberg QLD 4670	New crop	Sandy soil	Variety: Pepe® Sweet Capsicums	Planted in 2 April 2009	Oxygation Oycrop Control	RR1.65m, pp 0.1m, row 51.5m & 132.5m long, 1 row/plot, 6 replications	1 Mazzei MI1078, Oycrop	Commence 16/05/09	Fruit yield increased by 4% due to oxygation in yr 1	Year 2 crop Exposed to wet weather.	T-tape, 10 cm depth c. 20 cm @ 1 LH. Covered by mulching plastic
<b>Sugarcane</b>	Continuous communication with Sugarcane industry in Bundaberg and Burdekin. A separate funding proposal submitted to Australian Government DAFF carbon farming future, and awaiting for outcome.												
<b>Watermelon</b> (Grower managed trial)	Mr Peter Greensil/Hortus	Windermere Road Bundaberg QLD 4670	Existing crop of melon	Ferrosol		Feb 2012	Oxygation and control	1 block, multiple rows with oxy and control	1 Mazzei MI 1078	April 2012	New crop planted	Installed, wet season effect, trialing in current crop	Netafim drip tape
<b>Watermelon</b> (Grower managed trial)	Mr Tarin Bradford	Tally QLD 4220	Existing crop of melon	Ferrosol		July 2011	Oxygation and control	1 block, multiple rows with oxy and control	1 Mazzei MI 4090	April 2012	New crop planted	Installed, wet season effect, trialing in current crop	John Deere drip
<b>Chilli pepper</b> (Growers managed trial)	AUSTCHILLI Craig Hall	4496 Goodwood Rd Bundaberg QLD 4670	Existing crop of chilli	Vertisol		March 2011	Oxygation and control	1 row each of oxy and control	1 Mazzei MI A9	April 2011	Harvested	Installed later in crop season. Interested big plot oxygation	Netafim drip tape
<b>Strawberry</b> (Completed)	CPWS, CQU	CPWS compound, Rockhampton, QLD 4702	New crop planted in different seasons	Loamy soil	Lowanna	May 2010 May 2011	Oxygation and control. Continuous fertigation	12 double rows at 1.5 m spacing, 20m long	Seaair in yr1 Mazzei MI384 Control	Commenced 2010, repeated 2011	Full crop harvested by hand in both crops	Crop grown for full season until Jan of following year. Yield potential realized.	Netafim drip tape 1 row per bed, 30 cm emitter spacing, 1.5 L/hr flow
<b>Smart lawn</b> (Continuing)	Tully Barnes	Panorama Ht Rockhampton, QLD 4702	New lawn	Refilled soil	Tropika Blue	8 March 2010	Oxygation, control and pop-up sprinkler	3 blocks. Drip at 30 cm row spacing	1 Mazzei MI 384, rainbird pop-up sprinkler	Commenced 8 March. Existing pipe pressure use	Established, regular clippings	Wet year, low supplementary irrigation.	Netafim drip tube, 30cm row & emitter space, 1.0 L/hr flow
<b>Tomato</b> (Planned for HAL funding )	Jason Fritsch/ Sam Birrell	Cedenco Australia, Echuca VIC	Processing tomato farm with SDI	Clay loam	Heinz	8/10/2012 expected	Oxygation and control	RR1.52 m, pp0.5 m, row length ~ 500 m and 1 row/plot, 15 rows 15 reps	1 Mazzei/bay MI 1583 to be confirmed	Commence immediately after planting	New block still to be set up with irrigation	New trail planned for 2012 in collaboration with Netafim	Netafim Dripper flow rate = 0.8 lph @ 0.3m spacing

### 3. Outcomes

We have completed data collection and analysis from cotton, pineapple, lucerne and capsicum trials. We will continue collecting data from grapes, apricot, fig and smart lawn for one more season, to be completed by the end of 2012, and present full set of data at relevant venues [e.g., at the International Horticulture Congress in Brisbane (two papers), at the Australian Irrigation Conference and Exhibition June 2012, Adelaide. Flooding (in 2011) and wet seasons in 2010 and 2011 affected flowering and fruiting of juvenile crops, hence delayed the onset of first fruiting season. We are keen to collect data with respect to the effect of oxygation on reproductive performance of tablegrapes, fig and apricot. An internal fund through CPWS CQUniversity will be used for continuing part of these activities. However, we will present the yield data (biomass) and other surrogate of growth for apricot and fig from juvenile crop, and recent data for lawn in this final report. The data collected post project period will be utilized for the publication of journal articles and full papers in industry magazines.

- In addition to the final report, we are also in the process of gradually publishing the research results in journals, industry magazines and as fact sheet/flyers for field days. FA full set of data from the pineapple trials has been recently published in the journal *Advances in Horticultural Science*, 2012 26(1): 3-16, and a fact sheet was circulated among growers and industry in a field day conducted in June 2011 on the Sunshine Coast. The effects of oxygation on pineapple over the entire crop duration was manifested as increase in both industry harvest (6%) and whole plot harvest yield as well as disease (*Phytophthora*) suppression. The data on lucerne (alfalfa), cotton, and capsicum are being compiled for preparation of manuscripts to be published in journals of their relevant fields.
- The cotton field trial on oxygation planted in the 2011 season at Nyang, Emerald was harvested in February 2012. This site provides long term data with the yield data collected over 7 different seasons. The data continue to show a positive effect for oxygation on yield and water use efficiency in each of those tested years, but in some seasons there was not a significant [statistically, that is] effect – but still a 5% increase in yield. The longer term average data showed that yield increase was 14.7% due to oxygation compared to control for cotton production in the heavy clay soil. The effect of sampling along the length of a row showed that the seed cotton yield did not decline significantly along the row length (220 m from the sub main/point of air injection). Field data from the same trial in 2005/6 suggest that there is no major difference in terms of benefit of oxygation allowing a drip line until beyond 165 m from the start of the drip line. Likewise in 2008/9 and 2011/2 there was no differential effect of oxygation according to distance from the venturi, although in both the latter years there was an indication [non-significant] of a greater positive effect further from the venturi. Therefore, the effect of oxygation on the surrogate measure crop growth suggests that yield was not non-uniform along the dripper line.
- Lucerne and capsicum and strawberry trials are completed; data compiled and are being processed for publication. In lucerne altogether ten harvests were carried out over the period of 2 years for both oxygation and control treatments. Gross lucerne dry biomass yield increased due to oxygation by only 1.1% (19.21 vs 18.99 t/ha) compared to the control treatment in a heavy clay soil. However, there was a 10% saving in irrigation water inputs. Industry finds these results particularly interesting in the areas where irrigation water is highly saline in nature; therefore oxygation reduces the salt input into the soil through irrigation as reduction in irrigation have parallel reduction in salt introduction in the soil. A fact sheet/flyer will be prepared and disseminated through the dairy and pasture industry to expedite the industry wide communication. For capsicum grown in a sandy loam soil at Bundaberg, oxygation treatments were imposed prior to flower initiation, and increased fruit yield by 4% with the Mazzei air injector compared to the control; the difference between the oxycrop (new air injection method) and control was very small. There was also a positive effect on oxygation of fruit quality as measured by the total soluble solid content in the ripe fruits. Data on yield, and yield attributes, fruit quality and plant physiology have been collected and are being analysed for a new manuscript. These data have been shared with other growers through Bundaberg Fruit and Vegetable Growers Association (<http://www.bfvg.com.au/>). In strawberry, yield benefits with oxygation employing the Seair and Mazzei air injectors did not differ on the loamy sandy loam soil. The effect of oxygation in terms of strawberry fruit yield was a 4.5% increase for the same amount of water and fertilizers. The results of strawberry trials have been shared with the Sweet Strawberry Runners, and Strawberry Australia Inc (<http://www.strawberriesaustralia.com.au>) Queensland branch for disseminating of information to growers and strawberry nursery industries.
- A display unit of the prototype oxygation system has been prefabricated and presented to the participants and organisers of the Australian Irrigation Conference and Exhibition since 2009. We noted in the recent IAA conference in Launceston, TAS (June 2011) the display unit presentation gave a very interactive demonstration of the oxygation system, and allowed us to communicate with



a number of growers, industry and researchers (Figure 3), which further fomented interest and enquires by a number of industries representing both annuals and perennials, and from growers, consultants and researchers. The oxygation display unit is also regularly presented to the community during CQUniversity open days and CQ innovation week display, where a larger number of people representing growers, students from schools, irrigation businesses and industries, and other interested individuals participated in the interactive oxygation system operation. We also presented a paper together with our DAFF collaborator and participating grower at the Australian Irrigation Association Conference on June 2011 in Launceston, TAS, updating outcomes of oxygation research and opportunities for expansion of use and diversification of application.



**Figure 3:** Mr Joe Linton (left), a cane grower from Burdekin, discussing potential application of air injection for sugarcane with NPSI manager Guy Roth (middle), and CQU researcher Surya Bhattarai with display unit (right) during the IAA conference in Launceston, TAS, 2011.

- The third year Research Review and Planning meeting (RRPM) for oxygation was combined with the Burdekin irrigation future meeting conducted on 11-13 December 2011 in Ayr and Townsville where both cane and horticultural growers were present. In this meeting a range of stakeholders, including 25 participants representing growers, industry representatives, researchers, consultants and extension officers of the area, participated in the meeting. In the meeting the status of on-going trials, results of completed trials, progress on data collection and analysis, and opportunities and scope for strengthening collaboration with industries and growers were presented and discussed.
- A new fully fledged oxygation trial to be funded by HAL in Echuca, Victoria with Cedenco Australia for processing tomato oxygation has been planned. This builds on a preliminary trial that incorporated Neatfim venturi that was set up earlier in 2010 in this site. Research collaborator from Cedenco (Jason Fritsch) and Netafim Australia (Sam Birrell), Australian Processing Tomato (<http://www.hin.com.au/>) Industry Development Officer (Liz Mann), and processing tomato growers from Echuca were involved in the discussion group meeting held in Feb 2012. The research will evaluate the effect of oxygation on processing tomato yield, quality and water use efficiency. As the site is yet to be installed with a new irrigation system, the first year crop will be planted in September 2012 and will be conducted as a replicated field trial in collaboration with Netafim Australia (Sam Birrell).
- Enhanced partnership with business and industries arose through active collaboration in this project. We are working to develop long-term R&D collaboration with Netafim Australia to enhance and optimise the use of drip irrigation. Likewise, the oxygation calculator is being developed with some changes in the website for oxygation which will bring a new portal comprising a step by step procedure for installation of oxygation systems for general agriculture, lawns and garden oxygation. A final version will be uploaded incorporating data from the aeration of treated effluents and saline irrigation water, and above-ground drip irrigation from the trials in Stanthorpe, Emerald, and Smart Lawn system respectively.
- A number of new projects on irrigation have been developed and submitted based on our outcomes from the current NPSI funded project. We have six new funding applications (Netafim R&D, HAL, DAFF carbon farming future, PSLP solar drip, VC engaged research, Mannheim) awaiting approval for funding in collaboration with industries and other research providers.
- Progress on bubble visualization, collaborating with CQU computational science (Dr Ron Balsys) and ANSTO physicist (David Wassink). A manuscript has been submitted for publication, and a new version of visualization unit upgrading the visualization technique is underway with these collaborators. A new student from Brazil Mr Paulo Eichler is involved in testing the system and pilot run of the bubble dynamics in 500 m long row length in May-June.

- Smart Lawn activities are being streamlined. The garden aerator, an oxygation system independent of pump pressure that can be operated by tap pressure only is aimed at application and adoption for subsurface drip irrigation of lawn and small scale garden operations [the system under pilot testing on CQUniversity Campus showed promising results], has been extended with a user in Panorama Height, Rockhampton. Landscape and irrigation specialists agreed to invest in the materials for the trial; we provided the expertise and will continue data recording for the monitoring of the progress. A good media cover of this trial appeared in The Morning Bulletin front page on 16 September 2010 (<http://www.themorningbulletin.com.au/story/2010/09/16/new-smart-lawn-watering-system-saves-money-too/>). We have initiated consultations with relevant stakeholders and preliminary ideas on developing a number of display areas of smart lawn within CQUniversity CQIRP are being discussed and proposed to CQUniversity for initial funding before an ARC application and robust business models are finalised. Savings in water use, better turf quality, and containing nitrate in the lawn are a few of the reported benefits of smart lawn as reported by the collaborating grower.

We continue to receive and respond to enquiries, e-mails and phone calls from industries, businesses and researchers both in Australia and overseas about the application of oxygation in different crops and agro-ecological domains. Prof Midmore is working with Netafim and potato crop consultants in the UK. Crop consultants are in active communication with growers, hence sharing information and technologies with QLD crop consults has been found effective in disseminating the details and information about oxygation.

#### 4. Target Audience(s) for the research

The main target audiences of the project are growers, crop consultants, irrigation business and industries. A list of collaborating growers, agro-ecological domains and their respective industries details is presented in Section 2, locations of the trials. The target of consultants is gradually increasing over the reporting/project period (two of the later group are already engaged on the project – Eddy Dunn from Hortus Technical Services [Bundaberg], and Stephen Tancred of Orchard Services [Stanthorpe]), but as we have been installing oxygation at the field sites more and more consultants have come in contacts (e.g. Allcorbes, Austchilli, etc). A number of community-based natural resource management organization such as BBIFMAC, water boards, and other allied organization with t links to growers such as Jim Kelly of Arris Pty Ltd, South Australia are also making positive impacts on disseminating the information and contacts for oxygation research and on-farm adoption. We have gradually increased and extended our focus and incorporated the Agribusiness sector, particularly irrigation suppliers. Introducing the contact persons in different irrigation suppliers to the information and approach on oxygation has helped increased their understanding and enhanced communication between the irrigation businesses and agricultural and horticultural users of oxygation. We now have an established collaborator from Netafim Australia - Mr Sam Birrell, John Deere Australia - Geddes Ethal, Agri-Fibre Industries - John Hall, Toro-Ag- Kerry Scanlon, Seair - Guy Scott, and Brisbane Water - Keith Barr. In Queensland we are increasingly involving McCracken for business aspects of this project and in Stanthorpe we have engaged Steve Wieland, IrriMaster Australia. Our Total Eden's contact at Rockhampton is Mr Ashley Bahnisch, Emerald - Mr Paul McGavin, Bundaberg - Aaron Salesman, and Biloela- Nigel Cusack whom we have nominated as oxygation contact persons in their businesses. Very recently Dowdens Pumping Mackay - Mr Adam Trask is increasingly involved in promoting business on adoption of oxygation. The cooperating growers and local irrigation businesses have started engagement into oxygation trials and started sharing their experience. Therefore, our target audience at this phase comprises growers, consultants, local and national irrigation businesses/suppliers, manufacturer of irrigation products such as Netafim, Plastiro, T-tape, government departments such as DAFF, DERM, crop specific R&D associations (such as BFVA), teaching and research associations (such as AACC), industries development officers` (IDO) from different commodity industries, research higher degree students and academic and research institutions.

Increasing communication has been taking place with local and regional NRM groups (CHRRUP, Yeppoon and Cawarral Study Group on Pineapple, The Burnett Mary Regional Group for Natural Resource Management Ltd (BMRG)) and industry bodies such as BFVA at this stage. Our communication with the regional water planners and policy makers is active. For example, in some of our current trials such as in Emerald (during the cotton season) we are working very closely together with the Water Use Efficiency research groups in DAFF. Business and industries are becoming gradually more interested as they have been approached by a number of growers for air injectors and have mentioned the work of CQU on oxygation that is being supported by NPSI. We are gradual targeting policy makers at different levels from grassroots, to regional bodies, increasing their interest in water use efficient methods such as oxygation.

Recent interest on the alternative uses of oxygation particularly in the lawn irrigation, with soil-less culture and potential for the oxygation of sports ground is taking a new dimension and we hope to engage them more in the future. Growing interests by different industries, irrigation businesses and consultant may be appropriately catered

for in the new project proposals (as we actively submit new funding applications to other potential funding agencies in case the NPSI does not continue in a new phase) to enhance the adoption through greater engagement of consultants and businesses focussing on capacity building and skills transfer.

## Milestone Report Information

### 5. Milestone Requirements and Deliverables

Deliverables:

1. Final Report
2. Decision Support System (DSS) finalised and in operation.
3. Two page project report on conduct of research including discussing learnings of researchers and learnings of project participants.
4. Text and graphics suitable for a NPSI Sustainable Irrigation Management Update.

a) Annual advisory meetings held

This was reported upon in earlier milestone reports, one meeting was held at the end of March 2010 and attendees are indicated in an earlier report. A further telephone meeting with those able to phone in was held on 1<sup>st</sup> November 2010, with the following discussed:

- i. All co-operating growers and research collaborators are impressed with the progress of work made over this period
- ii. Up scaling of the research results, from trial plot to paddock levels
- iii. Consistency of the positive effect
- iv. Long term effect of oxygation on soil and crop
- v. Other benefits of oxygation not fully understood
- vi. Many co-operators provided letters to support the nomination of Surya P. Bhattarai, for CQUniversity Vice-Chancellor Engagement Award. NPSI funded project to CQU is an exemplar case for effective engagement of industry and businesses in research and development.
- vii. What is next after the project period - not clear to the growers and industry

We also held a final research review meeting incorporating many growers, participating consultants, irrigation businesses and manufacturers, community based organizations, and participants from other universities (JCU), BSES, CSIRO on 11-13 December 2011 in Ayr and Townsville with a detailed review of the progress and discussion of new projects, and setting the dimensions for oxygation research as well as drip irrigation for the longer term, especially with a focus on Burdekin irrigation future.

b) Development of Decision Support System (DSS). The decision support system for oxygation includes an updated version of the on-line oxygation calculator, manual/handbook of oxygation, flyers/fact sheet and decision support flow diagram. These are based on calculations from Mazzei air injector performance tables which provide information on the potential motive flow and air injection rate for different inlet and outlet air pressure differential across the venturi for each size and category. Once the irrigation requirement for the block is known, selection of size and type of venturi can be worked out from the performance table ([http://www.mazzei.net/files/injector\\_perf\\_table\\_US.pdf](http://www.mazzei.net/files/injector_perf_table_US.pdf)). On-line macro excel sheet with built in formula for the calculations to determine air injection rate will be uploaded as link in the website.

c) Trials set up in NSW and SA. Rather than extending southwards, we have expanded our activity where more irrigation water is likely to be available for future food and fibre production. Hence we have expanded in Emerald (macadamia) and into the Burdekin (water melon at Ayr- the biggest air injection system in this project successfully installed and tested), with trials on Macadamia and water melons respectively. In part the shift away from the south has also been conditions by our potential co-operator in South Australia, Foster, changing hands and the new owners were not completely in the spirit of engaging immediately into research. We have also realised the potential of oxygation to address some of the excess water problems with strawberries, and root borne disease in pineapple, and have some exciting results from that intensive trial. In strawberry we evaluated the use of aerated water source for general drip irrigation. This system does not include in-line an air injection system, but rather aerates the water source using a Seair Diffuser (Seair Diffusion System, Canada). If this approach is successful then the majority of the horticultural industry in Australia with lay flat and low pressure operating systems can make use of this technique. The early result of this trial is promising as evidenced by the response in paralleled to the mazzei air injector with the yield benefit at a range of 4.5%. Our collaboration with southern states for oxygation work has been linked through Jim Kelly of Arris Pty Ltd, South Australia. Surya Bhattarai and Jim Kelly supported a master student (Nahla

Abbas) in University of Adelaide on her research on oxygation (evaluating the effect of hydrogen peroxide, different quality of irrigation water and compost in tomato production). Our recent engagement with APTRC and Cedenco in Echuca will open up opportunities to extend oxygation work in Victoria with processing tomato growers.

## 6. Project Progress & Milestone Achievements (up to 5 pages)

*Oxygation in furrow irrigation can be a future opportunity*

The opportunities and options for oxygation of furrow irrigation are being discussed with a number of growers particularly those with cotton, grain and pasture industries at Emerald, Bundaberg and Biloela. We have been aerating water for above-ground drippers in the Glency Grapes at Emerald, and drippers at two different depths (surface and 150 mm) at AACC Emerald campus for table grapes. The results from these two trials provide us an insight into the potential benefit of aerated water with surface irrigation systems as the water delivery by above ground dripper into the soil produces to some extent similar effects to furrow in terms of delivering air and oxygen carried in the irrigation water.

A short-term trial on cotton carried out by one of our undergraduate students using differently aerated water (from Seair, HP mixed, tap water and deoxygenated water), evaluated the effects of water use and leaf gas exchange properties of cotton seedlings in soil less culture. This trial showed that Seair diffusion system can mix as much as 2-4% of the bubbles in the form of micro-bubbles and the bubbles in the suspension supported greater plant water use and leaf transpiration with Sea air water compared to other ways of aerating water.

We have also set up a trial with strawberries where one treatment is aerating with micro bubbles the irrigation source before pumping along the drip lines. The other treatment is a control with no aeration. Mike Lewis, director of Environmental & Energy Technologies (EET) Australia has agreed to provide a test unit of mixaerator (<http://www.mixaerator.com/ModCoreFrontEnd/indexH.asp?pageid=97>) for trials. We aim to use this equipment for aeration of water bodies that are used as the source of water for furrow irrigation. We will trial this system if the test unit is available within this year in a small trial plot with furrow irrigation in Rockhampton/Emerald. Preliminary consultations with the growers have been conducted for the testing of the system in the field.

Glasshouse/screen-house trials conducted on pineapple quantified the effect of oxygation, compost tea and different depths of drainage for suppression of phytophthora infestation in a heavy clay soil. Root, plant and soil sampling have been performed; and the scoring for disease symptoms were carried out on the pot plants. Plant height (46 vs 42 cm), light interception (47 vs 39%) and leaf chlorophyll (SPAD) concentration (43 vs 40), increased where as phytophthora disease infestation slightly decreased in oxygation compared to control (0.45 vs 0.55 in 0-5 scale) and no significant effect of compost tea and drainage levels on growth parameters were noted in the standing crop.

Work on upgrading of the visualization unit to improve image quality and the processing system is underway, as is the design of an apparatus that can be taken into the field. In our effort towards complete oxygen budgeting of irrigation water, we have designed a portable field monitoring system comprising a liquid and gas flow system (<http://www.endress.com>) coupling with a visualization unit and flexible air injection setup that can accommodate different types of air injectors for the trials. This field potable Gas and Fluid Flow measurement system for simultaneous measurement of water and air in different oxygation system uses Endress + Hauser (Switzerland) Proline T-mass 65 Thermal Dispersion Flow Meters. We are actively working in bubble visualization system for the new research in processing tomato. The system will be finetuned in Rockhampton in a number of optimization trials involving Paulo Eichler (Occupational trainee), and will be utilized in the field research at Echuca for trials in processing tomato with Cedenco.

*Resources base for training package*

The project has generated sufficient data, contacts and interest across the industries that training on optimization of drip irrigation can be organised to transfer the skill and knowledge for installation, operation and maintenance of oxygation system.

A two-day training (30 November to 1 December) on irrigation and water management was offered at CQUniversity with the support of AACC for 10 participants comprising growers, irrigation businesses, school teachers and crop consultants. Hands-on and skill-oriented sessions were conducted on the operation of oxygation systems for different crops. Refinement of the training package that includes a Business flyer,



Website update, and development of Training Manuals and client specific training for stakeholders may be a suitable option for the future.

On-the-spot sessions on oxygation for growers, consultants, and business/irrigation suppliers were also organised during the pineapple field days conducted in the field. A pineapple Field Day was run on 29 July 2010, where the training of pineapple growers and consultants was conducted at Yeppoon, and another field days on 21 July 2011 on the Sunshine Coast.

A practical action online training manual on oxygation will be a useful tool for the industry, that assists step by step f installation of oxygation for different types of industries and irrigation systems, including different quality irrigation water. The manual will be more complete once research data collection is finalised from perennial crop trials; including from different quality irrigation water (treated waste water such as one in Stanthorpe, and lawn oxygation systems).

## Industry I: Pineapple Contact: Mr John Cranny, Tropical Pines, Yeppoon QLD 4703

### Experiment: Aeration of irrigation water for improvements in pineapple crop health and yield

In a field trial on pineapple at Yeppoon the effect of oxygation on fruit yield, quality, water use efficiency, and crop health was evaluated. Part of this activity is also co-funded by Horticulture Australia Limited (HAL). The first season crop was harvested in Jan-Mar 2009 and an additional harvest from ratoon crop commenced in July 2010, and continued until Feb 2011 due to staggered crop. The crop was also trialled in a glasshouse, where the effects of oxygation, compost tea and drainage depth for suppression of root rot and heart rot diseases (*Phytophthora cinnamomi*) were evaluated. Destructive harvesting of the ratoon crop was also conducted in January 2010 for an assessment of crop dry matter partitioning. Activity details and interim outputs of the trial were presented in the first, second and third ARPM. The updated outcome of the research activities and lesson learnt was also presented at the Yeppoon and Cawarral Study Group Meeting held on 29 July 2010 where pineapple growers from this region, HAL representatives, DEEDI and CQUniversity team participated in the meeting, and also in the Pineapple field day on 21 July 2011 on the Sunshine Coast. Data on yield, quality and WUE from year 1 trial and year 2 trials were compiled, and presented as flyers, handouts, and as journal publications (copies attached with final report).

### Objectives achieved:

The field and controlled-environment trials were successfully completed. Positive effects of oxygation were noted in fruit yield and quality even when the irrigation contribution was very small due to an unusually wet season. More data on crop, soil, and water, and soil respiration, gas exchange during and after oxygation, and the incidence of *phytophthora* in different treatments are presented in the published journal article. Communication with growers, irrigation industries and other research providers and business have been effective and industry is aware of this research outcome through the sharing during industry forums, field days and training and by our published materials (research note handouts to participants during the Pineapple field day in 21-22 July 2011 on the Sunshine Coast).

### Outputs:

Mostly reported in Milestone Reports 4 and 5. As in the first crop, the ratoon crop in the second year also received substantial rain from December through to April 2011, and soil moisture remained saturated or within the Readily Available Water (RAW), hence as in year 1, the crop in year 2 was also largely dependent on the rain contribution, which did not allow a full test potential of oxygation for pineapple production. Only a small proportion (~20%) of total water input to the crop over the two seasons was contributed by irrigation, the rest supplied as rainfall.

**Table 2:** Pineapple fruit yield from the sample area (Harvested yield) and industry marketable harvest (Industry yield) for the main crop and ratoon crop.

Treatments	<sup>1</sup> Harvested yield (t/ha)			<sup>2</sup> Industry yield (t/ha)			Phytophthora (% plants)
	Main crop	Ratoon	Total	Main crop	Ratoon	Total	
Control	68.20	38.17	106.37	50.92	18.25	69.17	4.9
Oxygation	79.60	54.11	133.71	53.08	20.18	73.26	3.0
No-irrigation	71.30	19.07	90.37	49.50	16.42	65.92	10.5
P value	0.005	0.001	0.032	0.295	0.051	0.076	<0.001
LSD(p≤0.05)	6.43	10.76	12.36	n.s.	3.17	7.39	1.379

(Mean separated by LSD, n.s. – not significant). <sup>1</sup> Harvested yield is all fruits harvested from the sample area, <sup>2</sup>Industry yield refers to only marketable yield harvested on whole plot basis by the industry picking process

Detailed evaluation of effects of oxygation on fruit quality parameters indicated that fruit flavour, colour and translucency were all improved by oxygation. The effect of long-term oxygation on soil biological, chemical and physical properties, and change in soil physico-chemical characteristics were also measured. The environmental assessment as subsurface drainage and water quality as influenced by oxygation in light textured soils was also monitored up until the end of the second harvest. Some of the data not included in the pineapple manuscript in Adv Hort. Sci will be incorporated in a postgraduate thesis of Jay Dhungel.

#### Specific research or knowledge assets generated:

Pineapple responded positively to oxygation as demonstrated by the field trials in the sandy loam. Larger rather than more furits was the response to oxygation. Fruit quality is one of the major determinants of profitability and *Phytophthora* infestation is a serious concern for field crop. Growers have shown interest if oxygation could have positive effects on suppression of *Pytophthora* under field situations. Crop water use has prominent effects on fruit yield and quality. Oxygation effects on fruit quality at different irrigation regimes may potentially improve such relationships. Oxygation under the field conditions reduced the incidence of *Phytophthora* significantly from 11 to 3% compared to no irrigation control (Table 2).

#### Detailed scientific technical reports:

A manuscript on "Oxygation effects on yield, quality, water use efficiency and physiological performance of pineapple" has been published in Acta Horticulturae, and a final report including the fruit yield, quality, WUE and economic analysis is presented in a manuscript published in Advances in Horticultural Science, technical report submitted to HAL and NPSI. Summary of two years data was also presented at the ARR meeting in Bundaberg in March 2010, year 2 in CQU and year 3 in NQLD.

### Industry 2: Cotton Contact: Mr Tony Ronnfeldt, Nyang, Foley Rd, Emerald, QLD 4720

**Experiment:** Optimising delivery and benefits of aerated irrigation water for subsurface drip irrigated cotton industry

This is a long-term study site (2004-2012) for evaluation of oxygation on cotton at the paddock scale. Effects of oxygation on cotton lint yield, quality and WUE, and long-term changes in soil chemical, physical and biological properties were assessed. In the first two seasons (2004/05 and 2005/06) the effect of oxygation was quantified at two irrigation rates (85% and 105% ETc), whereas in two latter seasons (2007/08 and 2008/09) the effect of oxygation was evaluated at only one irrigation rate (85% ETc). In the other seasons, the irrigation rate was increased to 100% as the variety Sicot 71BRF showed poor performance and was water stressed at low ETc, particularly when the earlier part of the season was drier. The root system of this variety was shallower than that of Deltapine 556 and possibly could not extract water stored at depth in profile, as shown by the onsite soil moisture records by Enviroscans. The outcome of these research activities were presented in the yearly annual research review meetings (26 March 2010 and 2011), and also presented in the 15th Australian Cotton Conference held from August 10–12, 2011 on the Gold Coast.

#### Objectives achieved:

The objectives for cotton trials in the field site on a vertisol was to ascertain the longer-term effect of oxygation and to evaluate the effect of oxygation along the lateral row length on uniformity of aeration, and crop performance.

#### Outputs:

Multi-year field trials were successfully conducted since 2004/05, except in 2006/2007 due to drought-restricted irrigation allocation. Positive effects of oxygation were noted consistently on lint yield over a number of seasons on field cotton trials. Industry cotton lint yield (i.e., grower harvested) increased with oxygation in all trial years at Emerald in the vertisol when irrigation rate was maintained at 85% of ETc or above. Similarly an increase in WUE was also noted, associated with greater lint yield for the same amount of irrigation water in both oxygation and control plots. Yields in all years benefitted from oxygation, although the difference was not statistically different in each year, and the overall benefit was 14.7% (Table 3).

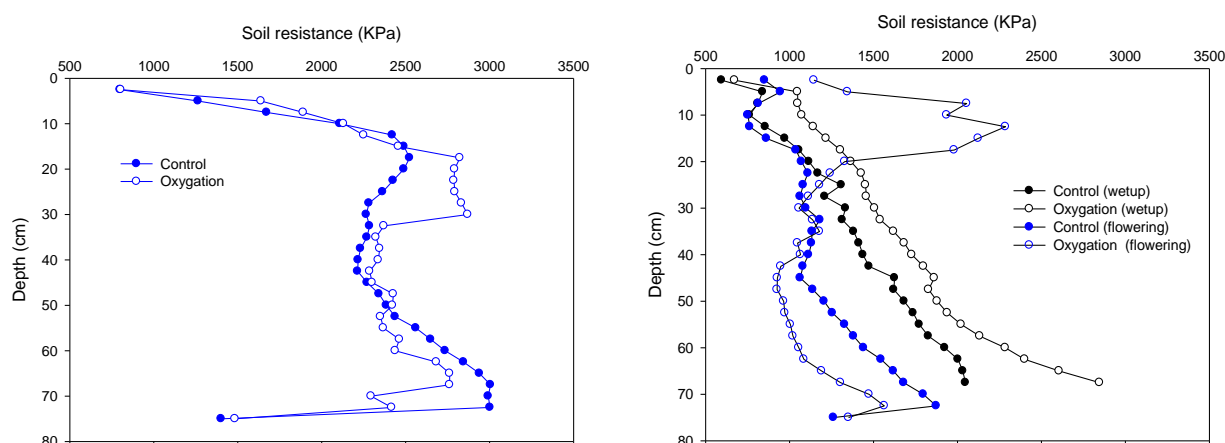
**Table 3:** Lint yield of cotton (bales/ha) in response to oxygation in vertisol over seven seasons, Nyang, Emerald.

Treatment	2004/05	2005/06	2007/08	2008/09	2009/10	2010/11	2011/12	Combined
Oxygation	9.32	9.33	8.84	6.90	9.11	9.04	11.215	9.108
Control	7.35	8.02	7.89	6.47	8.33	7.71	10.626	8.057
P value	0.078	0.005	0.031	0.532	0.242	0.112	0.314	0.061
SED	0.941	0.30	0.249	ns	ns	1.191	ns	0.514

### Specific research or knowledge assets generated:

Lint yield of cotton harvested by industry due to oxygation increased consistently compared to the control on a vertisol. However, a number of controlled environment trials suggested that the aeration uniformity along the lateral can be heterogeneous and affected by a number of parameters that affect the distribution of bubbles in the aerated water streams. Intensive plant sampling and data collection along the length of drip line was made in a number of years.

Field data from the trial in 2005/6 suggest that there is no major difference in terms of benefit of oxygation along a drip line until beyond 165 m from the start of the drip line. Likewise in 2008/9 and 2011/2 there was no differential effect of oxygation according to distance from the venturi, although in both the latter years there was an indication [non-significant] of a greater positive effect further from the venturi.



**Figure 4:** Changes in soil compaction in a vertisol profile due to oxygation at the end of crop season in 2009 (left) and during wet up and flowering stage in 2010 (right) .

We did find effects of oxygation on soil penetrometer resistance, which was greater with oxygation due most likely to the more effective water uptake and drying of soil with oxygation (Figure 4). Soil biological activities (FDA) were enhanced (Table 4) in the oxygation treatment compared to the control.

**Table 4:** Effect of long term oxygation on soil biological properties, Nyang, Emerald.

Treatments	Fluorescein ( $\mu\text{g/g dwsoil/h}$ )	CFU bacteria (Log)	CFU fungus (Log)	Soil respiration ( $\text{g com m}^{-2}\text{h}^{-1}$ )
Oxygation	46.49 $\pm$ 0.87	5.81 $\pm$ 0.061	3.50 $\pm$ 0.106	0.890 $\pm$ 0.079
Control	42.68 $\pm$ 0.79	5.93 $\pm$ 0.055	3.51 $\pm$ 0.051	0.698 $\pm$ 0.041
Furrow	36.32 $\pm$ 1.38	5.96 $\pm$ 0.062	3.22 $\pm$ 0.100	

NB: Amount of fluorescein produced by the hydrolysis of fluorescein diacetate (FDA) is directly proportional to the microbial activity in the soil (Swisher and Carroll, 1980)

### Detailed scientific technical reports:

A manuscript on “Oxygation effects on yield, quality, water use efficiency, physiological response and long term effects of oxygation on soil physical, chemical and biological properties” is prepared for submission to the Agronomy Journal, controlled environment cotton trial data will be submitted to the Journal of Cotton Research. This report includes a brief economic analysis, showing payback on investment after two years of cotton production (Table 5 and 6).

**Table 5:** Details of cost to retro-fit air injection to 0.4 ha plots at current site

Item	Unit	Price (\$)	Cost (\$)*
Venturi injector	1	265	265
PVC elbows	4	10	40
PVC t-pieces	2	10	20
Valves	2	45	90
Pressure gauges	2	30	60
<b>TOTAL</b>			<b>475</b>
Cost of oxygation 1 ha (475 x 2.5)			1187

\* Costs would be less if installed with new system

**Table 6:** Details of returns per ha at current site

Yield (control)	Yield (Oxygation)	Yield difference (bale/ha)	Cotton price (\$/bale)	Return to investment
8.756	7.628	1.128	500	562.5
Return to investment , yrs (1187/562.5)				2.1yrs

Much data on cotton oxygation have been submitted as part of a PhD thesis by Lance Pendergast on 31<sup>st</sup> March, 2010.

### Industry 3: Lucerne **Contact: Mrs Cheryl Mobbs, Mobbs Farm, Thangool, QLD 4702**

**Experiment:** Aerating saline irrigation water to improve WUE and performance of subsurface drip irrigated lucerne

This site utilizes highly saline deep bore irrigation water (2000-3200  $\mu\text{S cm}^{-1}$ ) solely or in conjugation from other bore which contains less saline water (900  $\mu\text{S cm}^{-1}$ ). In this trial effectiveness of oxygation was compared with control with saline water source in a vertisol. The comparative oxygation trials have been running for almost three years. Data in terms of fresh and dry yield of lucerne, quality of hay, water use efficiency and a number of other growth and development related parameters were collected.

The outcome of these research activities were presented in the yearly annual research review and planning meetings, NPSI research partners meetings, and IAA conferences since 2009, and at the VI international Conference on Irrigation of Horticultural Crops in Chile (1-7 November 2009). The results of the lucerne trials is also being discussed with other growers in Biloela region and with the Netafim agronomists in Shepparton, Victoria as there are a number of subsurface drip installation for lucerne where this technology can potentially be adopted.

#### Objectives:

To evaluate the benefit of aerating saline irrigation water for lucerne production and water use efficiency in a heavy clay soil. The ability and extent of salt exclusion by the aerated lucerne roots and salt partitioning and budgeting were also carried out. The long-term effect of oxygation on soil biological (soil respiration and FDA), physical (soil resistance) and chemical properties (soil nutrients and salt) were also evaluated in the lucerne field.

#### Outputs:

Sample plots and whole plot harvests have been collected since February 2009 and there are already ten harvests to date. Dry weight (hay is sold with 18% moisture) of the harvest increased only by 1% in oxygation compared to the control but the amount of irrigation input to the oxygation plot was 12% less compared to the control (Fig 6 left). The crop was resown with the wheat in 2007-2008, hence the reduced number of cuts. Detailed crop harvest, quality and water use data were also collected over the trial period and will be included in the manuscripts. Table 7 and Figures 5 and 6 summarise the data collected. The  $\text{Na}^+$  content in the leaf collected one year after the experiment was more than double of that of the oxygation treatment, 0.438 vs 0.201%. This suggests greater exclusion by aerated roots.

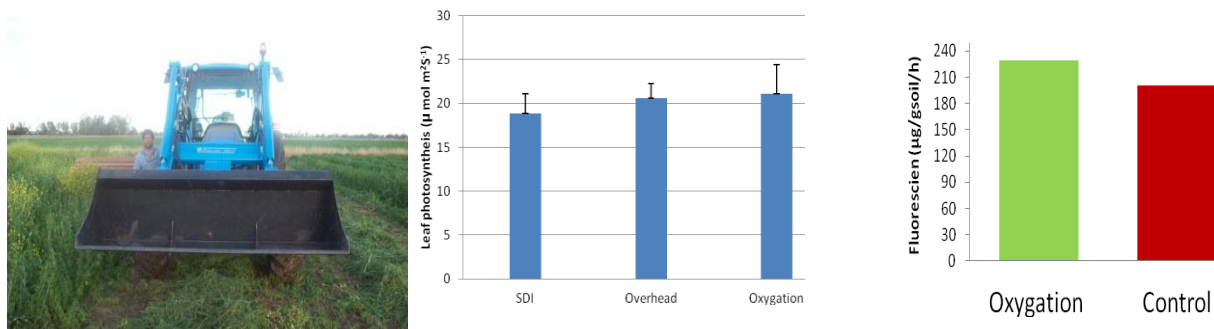
**Table 7.** Cumulative dry weight of lucerne (kg/ha) with and without oxygation at Biloela in a heavy clay soil irrigated with saline water.

Treatments	Soil pH	Conductivity ( $\mu\text{mol m}^{-2} \text{s}^{-1}$ )	Dry weight (kg/ha)
Control	7.36	561	7599
Oxygation	7.47	756	7693
SE	0.21	53.7	234

#### Specific research or knowledge assets:

We are monitoring salt movement around the emitter (Figure 6 right), deep drainage and leaching associated with treatments estimated using the solusamplers and array of micro-gophers, and long term effects of saline irrigation water on crop and soil and salt partitioning in the plants. Under the acute water shortage when the other methods such as flood and furrow and even sprinkler were not effective for irrigation, SDI system was able to delivery small amounts of water to keep the crop alive. The grower was impressed with such features and benefits of SDI when the amount of water for irrigation became so limiting.

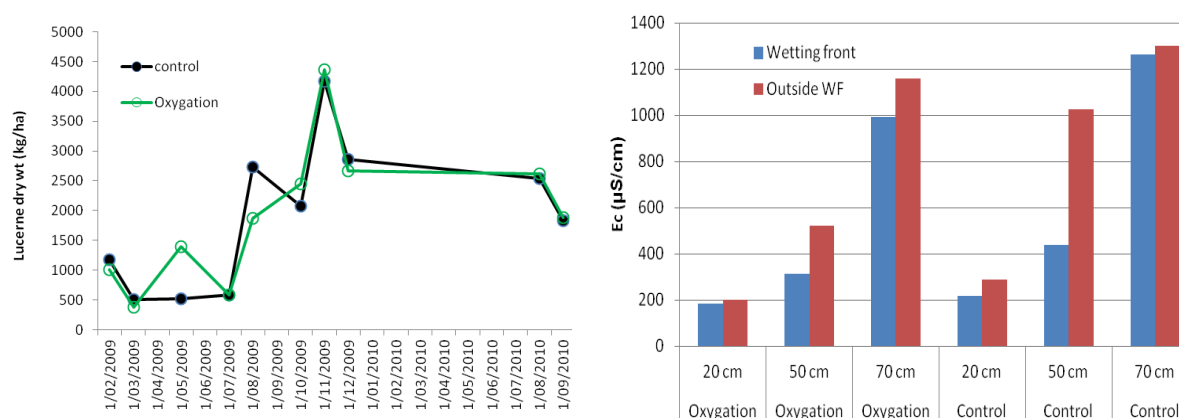




**Figure 5:** Harvesting is intensive in lucerne (10 harvests in 18 months by machine), leaf photosynthetic activities (middle) and soil biological activities (right) increased with oxygation in a vertisol due to aerated irrigation.

#### Detailed scientific technical reports:

A detailed report with all statistical analysis for yield, quality, water use efficiency, plant physiological performance, long-term effect of oxygation on soil biology, chemistry and physical properties and economic analysis is under preparation to be presented in a separate manuscript and submitted to an appropriate journal for publication.



**Figure 6:** Harvests of lucerne over time as affected by oxygation treatment (left), and distribution of the salts in the soil (right).

#### Industry 4: Figs Contact: Mr Clarie Higham, South Yamba Road, Altondown, QLD 4702

**Experiment:** Evaluating the effect of oxygation and emitter depth on crop establishment, vegetative growth, earliness, yield and fig quality on a silty loam soil

Vegetatively propagated planting materials (marcots) were planted for the trial on 9 April 2009, with and without oxygation at two emitter depths. There was variation in planting material that showed a visible effect on growth after the winter season; hence the grower decided to prune plants to standard heights. As the positive effects of oxygation before pruning was visually apparent, the decision was made to weigh the pruned materials and determine partitioning of dry matter between leaf and stem. The outcomes of this research activity were presented in the Annual Research Review meetings, and will be further presented at the Australian Irrigation Association Conference and Exhibitions in 2013. These results of the current fig trial are also regularly shared and discussed with growers and industries, post-harvest research group in CQUniversity, water use efficiency officers of DAFF and with local irrigation business.

#### Objectives:

The objective of this research is to evaluate the effect of oxygation on fig establishment, vegetative growth, earliness, dry matter apportioning, fruit yield and quality. Also to determine the effects on WUE and associated physiological basis for any enhanced effects with oxygation.

#### Outputs:

The crop while still in a juvenile phase, regular data collection continued for water application rate, crop and soil monitoring. Periodically data were collected on soil chemical, physical and biological properties. As a fruit crop of short vegetative duration, data on yield, quality and WUE would have been ready by the end of current project period. However, the flooding of 2010-2011 inundated the crop for few weeks killing some rows. Hence, the effects of oxygation

on early vegetative growth as measured on the biomass yield of the pruning material are presented in this report as is the cumulative water use over the same period in Figure 7.

**Table 8.** Above-ground total dry matter yield (g/plant) of second season pruning materials harvested on 12 February 2010, 309 days after planting and cumulative applied water to the plot

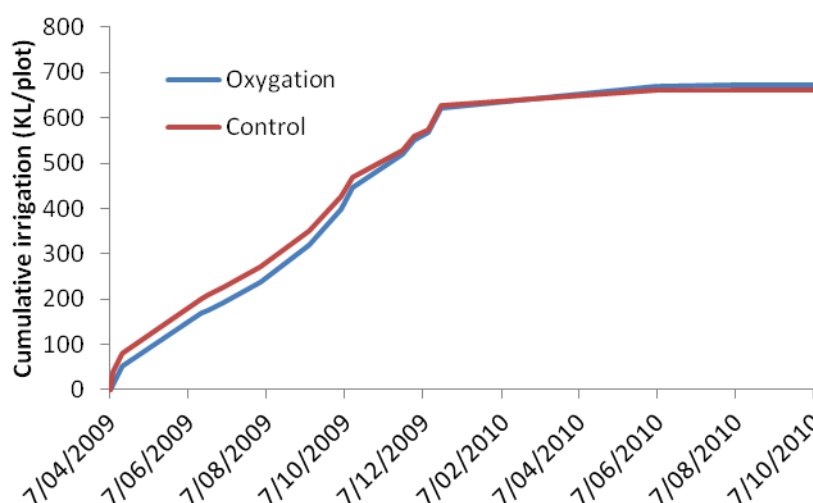
Treatment	Dry matter yield (g/plant)		Mean	Applied water (ML ha <sup>-1</sup> )
	Deep emitter (150 mm)	Shallow (surface)		
Control	1442	2167	1804	4.44
Oxygation	2017	2378	2197	4.22
SED	Aeration= 383.4 <sup>ns</sup>	Depth=383.4 <sup>ns</sup>	A x D= 542 <sup>ns</sup>	NA

#### Specific research or knowledge assets:

Uniformity of planting materials is extremely important for early establishment of a uniform crop for research purposes. Rooting of marcottage before planting could provide uniform planting materials that establish a uniform crop in the field upon planting. Control of vegetative growth is crucial for the fig industry; therefore, a dynamic irrigation scheduling is required. Evaluating the effect of oxygation with such dynamic irrigation scheduling that influences vegetative growth, dormancy period, fruit yield, earliness and quality are important aspects of the research in this trial.

#### Detailed scientific technical reports:

A detailed report consisting yield, quality, water use efficiency, plant physiological performance, long-term effect of oxygation on soil biology, chemistry and physical properties and economic analysis will be prepared after two years of crop data, and submitted as a manuscript will also be developed for publication in the Rare Fruit Council of Australia magazine and the 'Fruit Journal'. The current data from the harvest of vegetative stage suggest that biomass yield increased by 64% in this trial (Table 8). If this trend holds true for the fruit yield, response to oxygation in fig will be very high. This is also one of the reasons for continuing data collection from the flood-recovered plants in this site.



**Figure 7:** Cumulative irrigation input over the period of 8 months in oxygation and control plot of fig at Altondown, CQ, Australia.

Many plants at this site has recovered from flooding, and some yield data will be collected by the end of 2012. Continuing data collection to assess the effects of oxygation on yield, quality and WUE will be required at this site using the research funding beyond the current project funding period, and organised through the internal sources from CPWS.

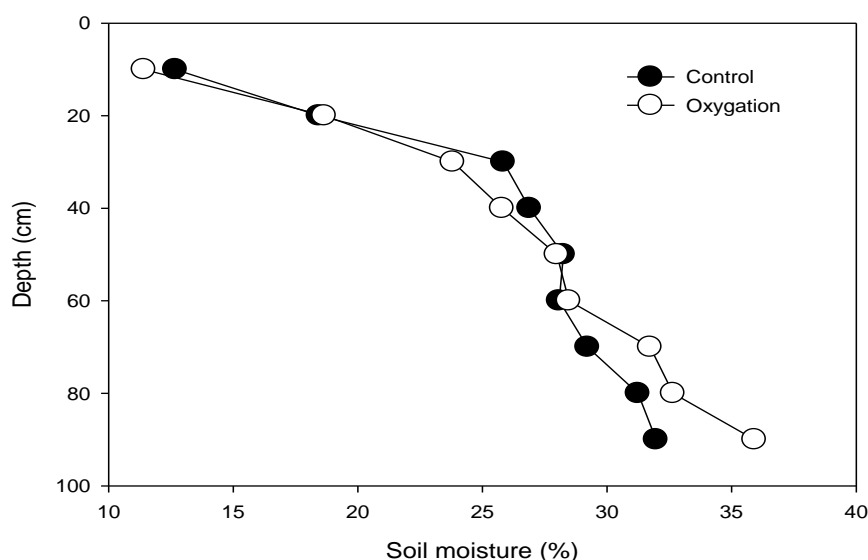
#### Industry 5: Grapes Contacts: Don Wills/Klowa Pioch, AACC, Emerald Campus, QLD 4720

**Experiment:** Oxygation for root aeration of table grape var. Flame in a sandy soil at different emitter depths

The field trial on Flame table grapes was installed on a sandy loam with two different drip irrigation emitter depths (surface and 15 cm), with and without oxygation. The comparative oxygation trial was superimposed on a standing crop of 5 years of age and oxygation commenced from 14 February 2009 after harvest of the crop. In this site the decision was made to install one air injector unit for the entire trial of four replications close to the trial plot. In this

site “Mazzei” venturi air-injector-Model 1078 (Mazzei Injector Corporation, USA) was installed to deliver 12% air by volume of water into the irrigation stream supplying the randomly assigned *Oxygation* treatment plots. The farm was under lease to a private operator. Due to the issues of the trellis (health and safety and ease of spraying), the lease did not continue and AACC decided to uproot the plants. We collected destructive plant samples for estimation of biomass yield (Table 9) and also carried out a number of measurements on plant physiological response before plants were uprooted.

#### Progress against the milestone requirements:



**Figure 8:** Pattern of soil moisture distribution at different depths in oxygation and control plot of table grape at AACC, Emerald, CQ, Australia

#### Objectives achieved:

The objective of the research is to evaluate the effect of aerated irrigation water on crop water use (Fig 8) fruit yield, quality and earliness and determine the physiological basis for such enhanced effects associated with oxygation. The effect of oxygation on the movement of soil water, air and ions in the crop root zone in a sandy loam soil was evaluated for commercial application of oxygation by the table grape variety flame industry was to be carried out.

#### Outputs:

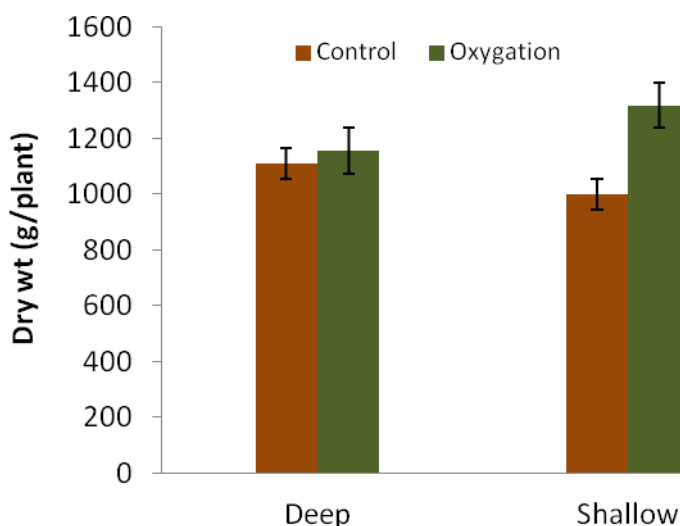
The initial data on water application rate, crop growth, vegetative/reproductive growth and partitioning are being analysed. Long term data collection for analysis of growth, development, yield, and quality and water use efficiency could not be made in this site due to forced termination of the field trial. By the end of two-years of trials, we have only few data on growth, development, and biomass yield. These data will be presented in the form of a manuscript for a journal publication in combination with the another set of table grape trials in Glency Grape at Emerald with variety Menindee.

**Table 9.** Leaf gas exchange, chlorophyll content, soil fluorescien (surrogate of microbial load), and soil respiration with and without oxygation in grapevine plot at the AACC site, Emerald, CQ, Australia.

Treatments	Leaf photosynthesis ( $\mu\text{ mol/m}^2/\text{S}$ )	Stomatal conductance ( $\text{mol/m}^2/\text{S}$ )	Transpiration rate ( $\text{mmol/m}^2/\text{S}$ )	Leaf chlorophyll (SPAD)	Fluorescien ( $\mu\text{g/g dwsoil/h}$ )	Soil respiration ( $\text{g CO}_2/\text{m}^2/\text{h}$ )
Control	4.8	0.09	6.46	46.7	242	1.697
Oxygation	5.8	0.11	7.45	50.3	157	1.753
SED	1.6	0.04	1.42	2.05	39.8*	0.061**

**Specific research or knowledge assets generated by the project-development of new insight, technique or understanding:**

A destructive sampling for the harvest of leaf, canes and fruits were carried out in October 2010 for evaluation of the effect of oxygation in this crop (Figure 9). Oxygation increased the dry biomass of the crop by 17% (1052.8 in control vs 1235.8 g/plant) in oxygation. There was no statistically significant difference on effect of dripper depth by oxygation interaction on the dry biomass of the crop in the trial (Figure 9).



**Figure 9:** Effects of oxygation and depth of drip placement on dry weight of grape variety Flame at pattern of soil AACC, Emerald, CQ, Australia.

**Detailed scientific technical reports can be provided as an attachment:**

A detailed report with all statistical analysis for yield, water use efficiency, plant physiological performance, long-term effects of oxygation on soil biology, chemistry and physical properties and economic analysis will be combined with those of the other grape trials and developed as manuscript for publication in the Grape Research Journal after the third year of crop data from the Menindee variety.

**Industry 6: Grapes    Contacts: Mr Glen Pearmine, Talafa Rd, Emerald QLD 4720**

**Experiment:** Oxygation for root aeration of table grape var. Menindee in heavy clay soil in central Queensland

This trial used aerated water for above-ground drip irrigation on table grape var. Menindee superimposed on a 5 year old crop and commenced on February 2009. The first crop after oxygation commenced was harvested from 14- 18 November 2009. Irrigation continued even after harvest but the frequency was reduced to keep the vine active. High irrigation was maintained until April, and slowed until August during dormancy and then recommenced in early September 2010 and 2011.

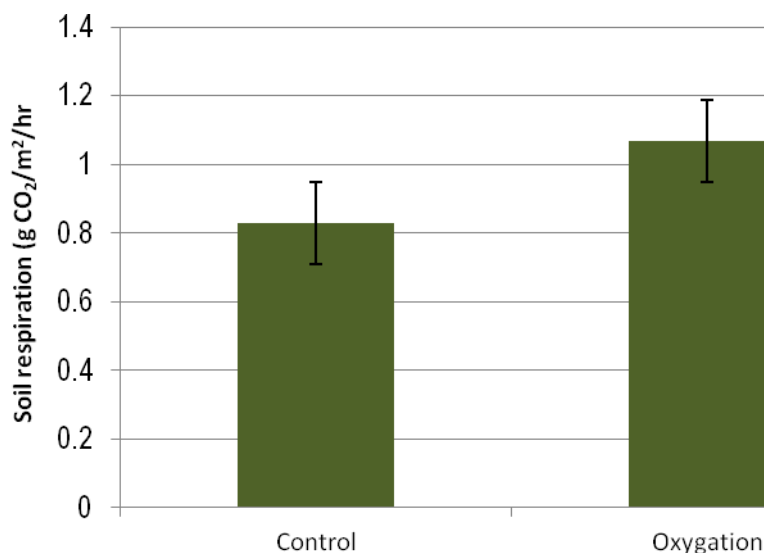
**Objectives:**

The objective of the research is to evaluate the effect of aerated irrigation water on fruit yield, quality and earliness of table grape var. Menindee, and determine the physiological basis for such enhanced effects associated with oxygation.

**Outputs:**

Data on water application rate, soil moisture distribution, crop growth, vegetative/reproductive growth and partitioning, chlorophyll content, leaf and soil gas exchange have been monitored. Long term data collection for analysis of growth, development, yield, and quality and water use efficiency will be made. By the end of the fourth year of harvest, we will have sufficient data on growth, development, reproductive performance, yield and quality data to thoroughly evaluate the benefit or otherwise of oxygation. Quality of berry is a very important parameter in table grapes; therefore effects of treatment on berry quality (sweetness as measure by °Brix), berry size and total acidity are being monitored. Indications are that benefits on yield, quality and water use efficiency due to oxygation are present at this site for table grape variety Menindee.





**Figure 10:** Soil respiration rate (means with standard error) immediately after irrigation in oxygenation and control plot of table grape variety Menindee at Emerald, CQ, Australia.

#### Specific research or knowledge assets:

In the trial site of Glen Pearmine we have been comparing the effect of oxygenation with above ground drippers. The observations and results from this trial, if positive, will make a very strong argument for the trials planned for oxygenation of a furrow crop in this project. Data collected in year 1 suggest that enhanced soil respiration (Figure 10) and marketable yield of berry (Table 10) are characteristic of oxygenation, although the differences did not reach statistical significance. Data on crop, soil and water have been collected and crop harvest for year two and three commenced in December 2010 and 2011, respectively. Detailed harvest record and quality assessment will be carried out for the 2012/3 crop, and four years data will be pooled for publication in an industry magazine. The three years average suggested that the berry yield in Menindee increased by 10.2% due to oxygenation compared to the control (Table 10).

**Table 10.** Marketable berry yield and load per plant for table grapes variety Menindee with and without oxygenation in grapevine plot at Emerald, CQ, Australia.

Treatment	2009/10		2010/11		2011/12		Average	
	Marketable yield (t/ha)	Berry load (kg/vine)	Marketable yield (t/ha)	Berry load (kg/vine)	Marketable yield (t/ha)	Berry load (kg/vine)	Marketable yield (t/ha)	Berry load (kg/vine)
Control	5.72	4.57	10.83	8.65	6.71	5.36	7.60	6.19
Oxygenation	6.04	4.83	11.28	9.01	8.27	6.61	8.53	6.82
SED	1.29	1.03	2.15	1.72	1.26	1.01	1.57	1.25

#### Detailed scientific technical reports:

A detailed report consisting of yield, quality, water use efficiency and plant physiological performance, and long-term effects of oxygenation on soil biology, chemistry and physical properties and economic analysis will be prepared after four years of crop data, and submitted as a manuscript to the Journal of Grape and Wine Research. Also the evaluation of benefits of oxygenation on nitrogen use efficiency and leaching of nitrate from table grape vineyard will be incorporated into the manuscript.

#### Industry 7: Apricot Contact: Mr Alfred Baronio, The Summit, Stanthorpe, QLD 4377

**Experiment:** Aeration of secondarily treated effluent for SDI of apricot on a sandy loam soil of the Granite Belt in Queensland

In this trial site, effect of oxygenation at two different emitter depths (surface and 15 cm below the ground) using treated effluent on apricot in granite soil (loamy sand) is being tested. The oxygenation trial in this site is unique in terms of quality of irrigation water used for the trial. The comparative oxygenation treatments were superimposed on a three year old standing crop (var Earlycot), and commenced on 17 March 2009.

The outcome of this research activity was presented in the Annual Research Review and Planning meeting in 2010 and was also presented in the 2011 Irrigation Australia Conference and Exhibitions. These results of the current apricot trial

are also regularly shared and discussed with growers and industries, the post-harvest research group in CQUniversity, DAFF staff at Stanthorpe and with local irrigation business.

### Objectives:

To evaluate the effect of oxygated effluent irrigation on crop growth and physiological performance, water use efficiency and long term soil quality.

### Outputs:

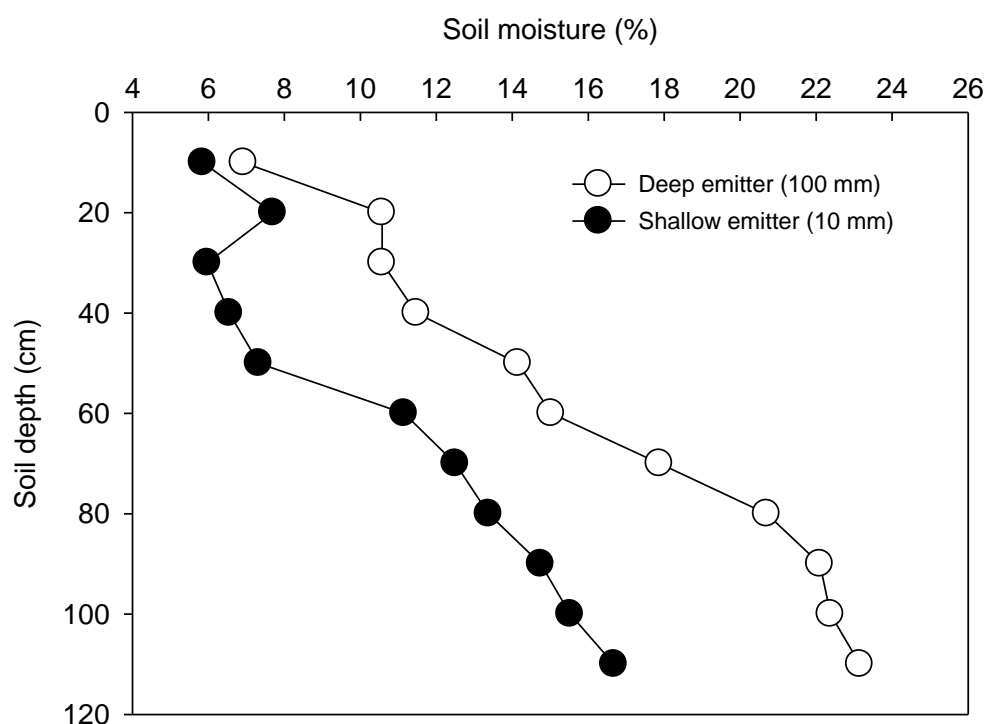
Data on water application rate, soil moisture, crop growth, vegetative/reproductive growth, and chlorophyll and leaf gas exchange are being monitored. Data for growth analysis, development, yield, and quality and water use efficiency will be collected as the trees progress to bearing this year. The early observations in the juvenile tress showed a positive effect of oxygation on tree growth evidenced by plant height (Table 11), and positive effects on leaf photosynthesis, transpiration, and leaf gas exchange parameters.

**Table 11:** Effect of treatments on plant height, crown size and stem girth at 30 cm above the ground measured 26 months after implementation of oxygation treatments

Irrigation treatments	Plant height (m)		Crown size (m <sup>2</sup> )		Stem girth (mm)	
	Deep	Shallow	Deep	Shallow	Deep	Shallow
Control	3.20	3.78	3.88	4.20	91.50	91.50
Oxygation	3.73	3.73	4.40	4.40	92.75	91.50
SED	0.26	0.32	1.09	0.64	21.16	20.34

### Specific research or knowledge assets:

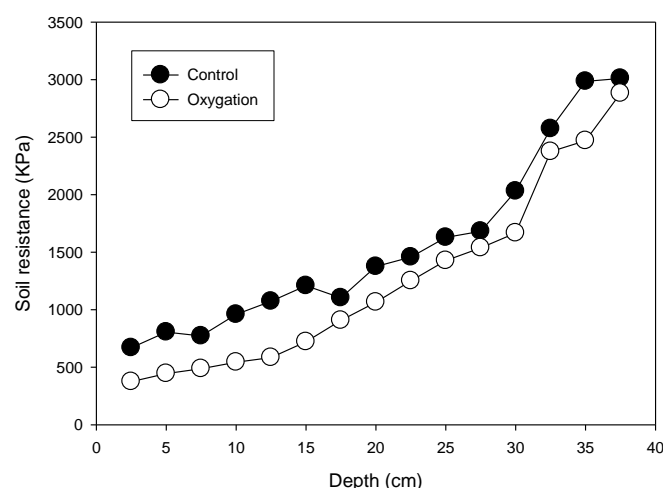
The effect of long term application of oxygated effluent on the movement of soil water (Figure 11), air and ions in the crop root zone, and soil physical and biological properties will be of major concern at this site. We have recorded very low dissolved oxygen in the source irrigation water and oxygation may prove beneficial for aerating effluent irrigation. It may reduce the BOD in the soil water, but may not enhance the oxygen status *per se* in the soil solution. Dissolved oxygen concentration in the irrigation water as low as 0.89 ppm in the summer and up to 7.58 ppm during winter months. High nitrate and phosphate concentration, and growth of algal bloom and high biological oxygen demand in the effluent holding ponds can make the water source hypoxic and anoxic.



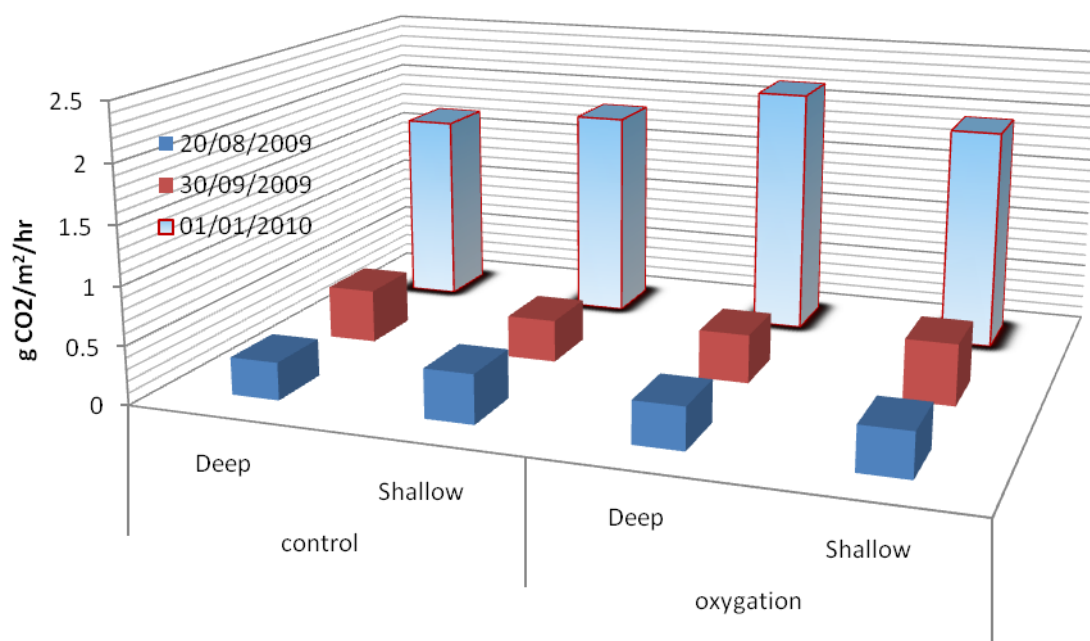
**Figure 11:** Pattern of soil moisture distribution at different depths in oxygation and control plot of Apricot at Stanthorpe, QLD, Australia.

**Detailed scientific technical reports:**

Effects on crop growth, development, yield, quality, WUE and long term changes in soil biological, chemical and physical properties due to continuous application of effluents will be assessed. Soil respiration and FDA test for soil biological activities, ions movement in the soil, and soil carbon analysis as chemical and soil resistance, infiltration and hydraulic conductivity as surrogate of soil physical properties will be continued until the end of the trial. Cost benefit analysis for oxygation with treated effluent will be undertaken when the first season of fruit harvest takes place in December 2012. These data will be presented in the form of a manuscript for a journal publication. Deeper placement of drip tube increased the soil moisture in the profile (Figure 11), and oxygation reduced the soil compaction effect (Figure 12), and increased soil respiration during summer (Figure 13) compared to the control.



**Figure 12:** Pattern of soil resistance (a measure of compaction) at different depths in oxygation and control plot of Apricot at Stanthorpe, QLD, Australia.



**Figure 13:** Pattern of soil respiration with respect to different emitter depths with and without oxygation of Apricot at Stanthorpe, QLD, Australia.

Over the next season benefits of oxygation on yield, quality, earliness and yield components of apricot in the light textured soil will be evaluated. Benefits of oxygation on nitrogen use efficiency and minimization of nitrate leaching from apricot orchard is continuously being evaluated.  $\text{NO}_3$  movement in the soil profile suggests that the soil in the plot (in the granite belt) is a freely draining soil. Plumes of  $\text{NO}_3$  were recorded post irrigation events (Table 12). Larger volumes of deep drainage were noted at deeper depths compared to the surface laid drip system and the concentration in the deep drainage was also higher at deeper depth compared to the shallow control.

**Table 12.** Nitrate concentration and volume of drainage collected at shallow (20 cm) and deep (50 cm) solusamplers installed in the edge of wetting fronts in granite belt soil under apricot at Stanthorpe between irrigation events.

Treatments	$\text{NO}_3$ concentration (mg/L)		Drainage volume (ml) <sup>1</sup>	
	Shallow (20 cm)	Deep (50 cm)	Shallow (20 cm)	Deep (50 cm)
Control	3.50	6.00	2.37	14.19
Oxygation	4.062	7.25	2.69	12.69
SED	0.723	0.686	0.53	1.12

<sup>1</sup>Drainage collected in Solusampler of 5 cm width and 10 cm length buried in the soil

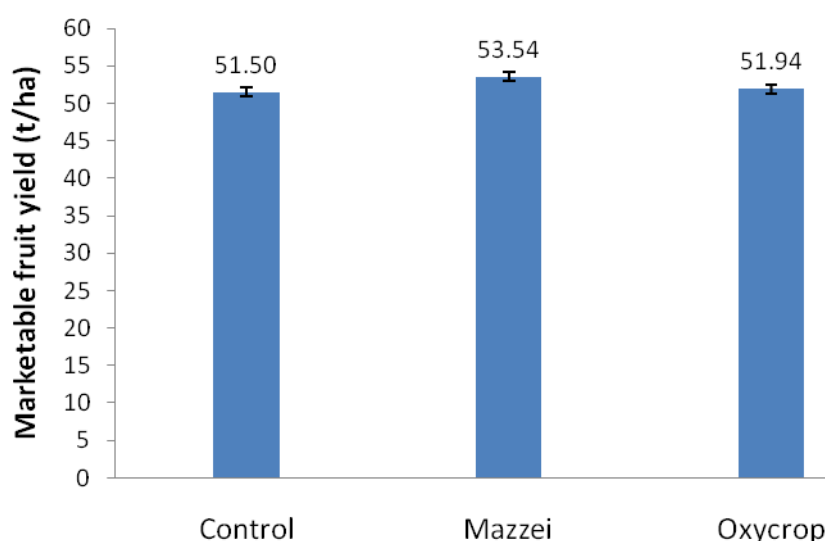
#### Industry 8: Vegetables Contact: Mr John Hall/Liu Curino, Crop-Mgt Aust, Bundaberg, QLD 4670

**Experiment:** Comparison of different oxygation methods for capsicum production in different soil types (11 Darlington St, Bundaberg)

Performance evaluation of different air injection systems (Mazzei air injector, Oxycrop and control treatments) for capsicum yield, quality, and WUE in a loamy sand soil was conducted in Bundaberg. The comparative oxygation trial was superimposed on the standing crop (three weeks after transplanting) on 18 May 2009. The outcome of this research activity was presented in the Annual Research Review meeting (26 March 2010) in Bundaberg, and was presented in the Australian Irrigation Conference and Exhibition, 8 - 10 June 2010, Sydney, NSW Australia. These results of capsicum trial were shared and discussed with growers and industries, post-harvest research group in CQUniversity, DEEDI staff, Bundaberg Fruits and Vegetable Growers Association (BF&VGA) representatives, local irrigation business, industries and consultants.

#### Objectives achieved:

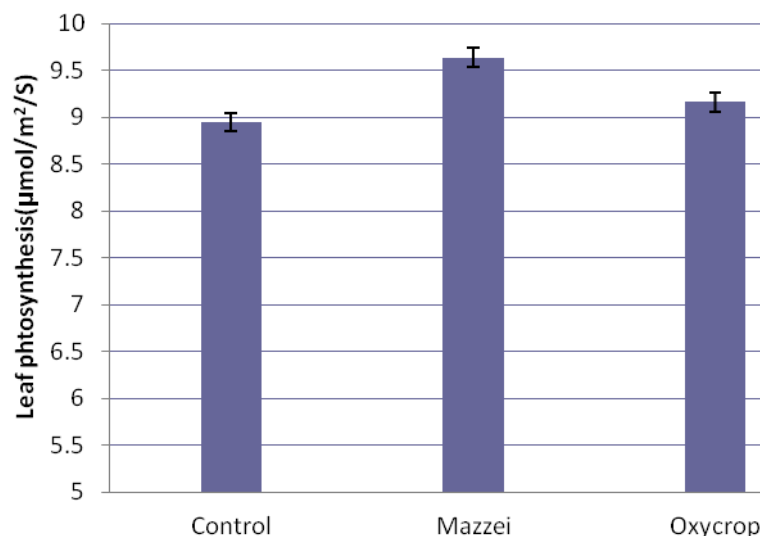
The effects of different oxygation methods on yield, quality and WUE of capsicum on a loamy sandy soil were quantified.



**Figure 14.** Marketable fruit yield (mean  $\pm$  SE) of capsicum for two different methods of oxygation in a loamy sandy soil at Bundaberg, 2009.

#### Outputs:

Oxygation treatments were imposed to the crop just prior to the flower initiation stage of the crop. The results suggest that oxygation increased fruit yield by 4% (Figure 14) and there was a positive effect of oxygation of fruit quality as measured by the total soluble solid content in the ripe fruits (Table 13). Increase in fruit yield was also accompanied by greater leaf photosynthetic rate measured during the fruit enlargement stage (Figure 15)



**Figure 15:** Leaf photosynthetic rate (mean ± SE ) with oxygation (Mazzei and Oxydrop) and without (control) in Capsicum during fruit ripening stage at Bundaberg, QLD, Australia.

Research collaboration with the manufacturer of oxydrop has allowed us to test the alternative method of air injection system suitable for horticultural industries. Improvement in the design and engineering of oxydrop to harness the potential of oxygation for air injection in the field irrigated with low pressure lay flat type irrigation is promising. Future evaluation of oxygation products will assess nitrogen use efficiency in order to minimize opportunity for nitrate leaching with irrigation of vegetable crops.

**Table 13.** Soil and fruit parameters for Capsicum at Bundaberg as affected by oxygation.

Treatment	Soil moisture (%)@20 cm	Soil moisture (%) @12 cm	Soil Temp (°C)	Plant ht (cm)	SPAD	Fruits/plant	Fruit quality parameters		
							TSS (%)	Thickness (mm)	Volume (ml)
Control	16.7	28.3	21.2	44.8	64.7	23.9	5.8	9.3	122.40
Mazzei	14.5	24.6	21.7	41.2	65.1	24.3	5.8	9.3	116.54
Oxydrop	16.3	26.7	21.7	43.0	65.5	23.8	6.0	9.9	123.48
SE	3.0	4.7	0.6	3.6	2.9	3.2	0.4	1.4	12.51

#### Specific research or knowledge assets:

In this trial we tested a new system for oxygation, oxydrop, developed by John Hall of John Deere and made a comparative evaluation in a capsicum crop. The oxydrop was installed at a much later stage of the crop (44 days after transplanting), whereas the Mazzei was installed earlier (21 days after transplanting) hence the system only operated for a short period of time and all after crop flowering. It is possible that the oxydrop will produce better results if installed at an earlier stage of the crop. We are discussing details of new trials using oxydrop with the manufacturer, with a view to repeating the experiment in a number of winter and summer vegetable crop species in Bundaberg and Stanthorpe in the future when the manufacturer fine tunes the equipment (oxydrop).

#### Detailed scientific technical reports:

A detailed report consisting yield, quality, water use efficiency, plant physiological performance, long-term effect of oxygation on soil biology, chemistry and physical properties for different oxygation methods for capsicum production in Bundaberg was presented in number of ARRPM and IAA conferences. A short article has been contributed for Bundaberg fruit and vegetable growers' newsletter. A manuscript is also being developed for publication in Good Fruits and Vegetable and the International Journal of Vegetable Science.



**Industry 9:** Sugarcane (discussing with industry (Netafim), researchers (Steve Attard of CSIRO), and growers in Bundaberg and Burdekin, and increasing awareness and sharing information on results from other crops).

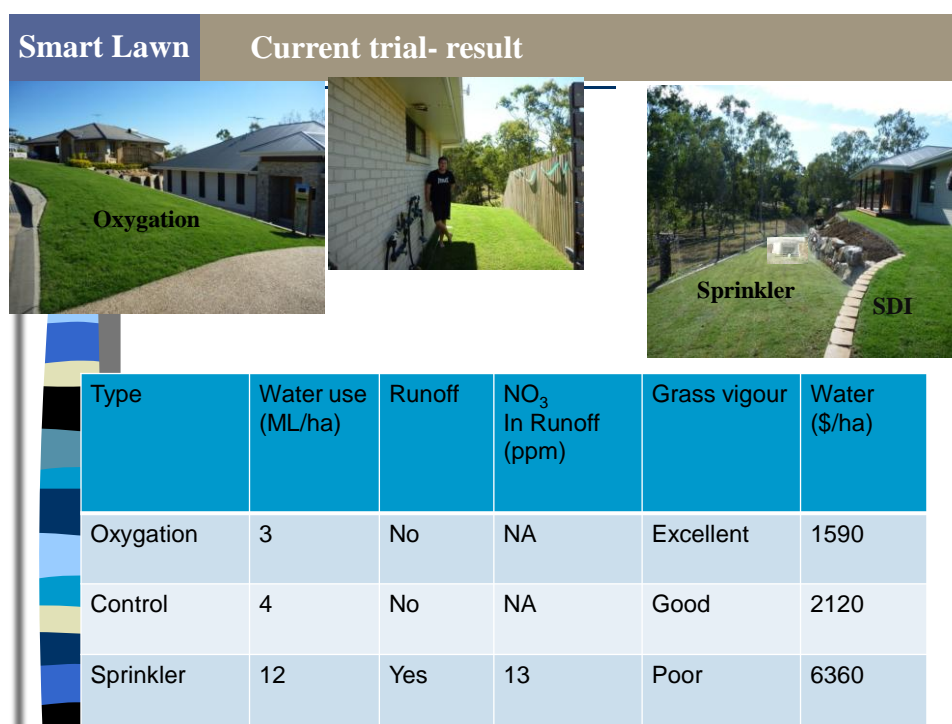
**Contact:**

Mr Jay Hubert, 32 Bourbong St, Bundaberg QLD 4670 or new growers in Bundaberg/ Burdekin.

**Experiment:** Evaluating the effect of oxygation in sugarcane crop health, yield and quality. This experiment is not progressing from the viewpoint of field trials but progressing significantly in terms of developing awareness among sugarcane growers about the oxygation method that can be adopted to improve WUE by industry. There is a potential opportunity for linking oxygation of sugarcane in Burdekin with the proposed DAFF carbon farming future project jointly submitted with DERM for funding.

**Industry 10:** Smart Lawn, some pilot testing within the CQUniversity campus in Rockhampton and a lawn user in Rockhampton Panorama height.

Some of the early observations and response from the user are encouraging. A separate funding proposal has been prepared for CQUni towards establishing three different types of lawn system in the CQIRP, for the purpose of demonstration and the long term plan is to develop it as business model. Some salient features of smart lawn are savings in water, minimization of nutrient loss, and appealing lawn that can be used while it is still irrigating. The details are presented in the pictorial below (Figure 16):



**Figure 16:** Smart lawn involving air injection system, utilization of pipe pressure for operation of venturi, use of solar power, and rainwater for appealing lawn, pilot test at Rockhampton, Australia.

## 7. Next Steps (up to ½ page)

*Please briefly describe what the project will be doing during the next Milestone reporting period and how these activities will deliver against the next milestone requirements.*

The research activities on cotton, pineapple, lucerne and capsicum are completed, some reported and published in journals (pineapple) and others in progress for publications.

For other crops such as fig and apricot, the effective fruiting period did not commenced within the current project period, hence we cannot draw conclusions from the data collected by June 2012. The research continues with the internal funding support from CPWS, allowing collection of harvest data for fig and apricot and will provide opportunity to collect one more season's data from the grape field trials where we have noted encouraging results in year 2009, 2010 and 2011. Project extension beyond June 2010 is therefore requested.

Oxygation of irrigation water sources for furrow could potentially bring a completely new dimension on irrigation research. We have been hampered by lack of access to the relevant equipment (despite promises). Starting a pilot test, detailed discussions with NPSI and the development of a new project proposal for research in this area will be important.

We will continue to publish research data in refereed international journals for wider communication with researchers and development, and in industry magazines to increase awareness for the local industries.

We expect to expand research work on oxygation of lawns, and monitoring of aeration uniformity using field portable visualization units developed in collaboration with ANSTO, and continue discussions to engage the sugarcane industry with oxygation research.

## **8. Linkages with other research (up to ½ page)**

*Describe any collaboration that has occurred with other research projects and/or activities.*

Macadamia research project funded by Woolworth Land Care Program

At a recent research meeting and consultation with Australian Macadamia Society and growers we created interest for research on irrigation and crop water use. A new proposal for the Australian Macadamia Society and HAL is being prepared and will be submitted in November 2012.

Current discussion with Netafim for long term research partnership is progressing well. Long term R&D along a similar line has been discussed with Measurement Engineering Australia (MEA) for evaluation of soil moisture sensing equipment aimed at optimising operation of drip irrigation systems.

Meeting with Industry Development Officer (Lourens Grobler) of Queensland Strawberry Industry where we discussed in detail the opportunities for incorporating oxygation research for improving the fruit quality, yield and root disease management. The data from the current strawberry trials at CQU will be published in the Industry Magazine by early 2011.

Linking with the Federal Government funded Reef Rescue research activity where we are comparing SDI with current alternative irrigation practices in the cane and banana industries, with a view to reducing runoff and deep drainage and the off-farm transport of agrochemicals.

## **9. Issues of Concern / Risks (up to ½ page)**

*Describe any issues of concern arising in the project or difficulties encountered in meeting this current or future milestone(s). Please provide an explanation of any delays that have occurred and the action taken to address the delay. Identify any factors that you think may impact on the extent and/or quality of outputs/outcomes and discuss what is being done to minimise these risks.*

Trials site closure at the AACC Emerald Campus in 2011 precluded data collection thereafter.

Flooding in 2010/11 and excess water set back crops, obviated much need for irrigation and severely damaged the fig trial.

The fig and apricot crops are still in the juvenile phase, and are not fully bearing. Data collection for another 2 years is important for these crops to evaluate the effects of oxygation. Further support beyond the project period to carry on these research activities is sought.

## **10. Opportunities (up to ½ page)**

*Provide details of any new opportunities arising or unintended outcomes of the project that were not foreseen or planned.*

- Sugarcane industry for DAFF carbon farming future – evaluating the effect of drip irrigation and oxygation in minimising nitrous oxide emissions from sugarcane farming
- Increasing links with new industries such as strawberry and macadamia is very encouraging for the expansion of oxygation work in the future
- Smart lawn and opportunities for developing ARC linkage project for 2013 submission
- Some opportunities to work with Kiwifruit industries are being sought

## 11. Impact data for knowledge, adoption and promotional activities undertaken (up to 2 pages)

The purpose of this section is to gather information on the project's communication and adoption activities and findings. It is important to collect the data specified when conducting activities such as workshops to effectively measure the project's impacts.

Please provide the following information:

- Journal articles, papers etc that have been produced as part of this project must be submitted.
- Events held by your project (eg stakeholder workshops, seminars, demonstration of field activities etc) **with summaries of participant feedback from events** (including recorded reactions and indicated gains in Knowledge, attitudes, skills or intentions to change). Please provide participant contact information if they have given permission to use their details.
- **Summaries of findings from surveys, narratives, observation, focus groups or other sources of evaluation data collection**
- **Summaries of any case studies undertaken which show impact of changes made in terms of productivity, economic return, environmental benefits and/or social change.**
- **Summary of any spatial data collected and/or generated (eg maps).**
- List of events attended to represent/promote your project, (e.g. conference, policy meeting, presentations given)
- Media reports generated (please attach copies of any newspaper articles, national radio interviews etc)
- Communications products (please attach copies of any brochures, fact sheets, publications or other products)
- Web content developed for the project website or delivered for the Program website.

### Journal Articles

- Bhattarai, S.P. Balsys, R., Wassink, D., Midmore, D. J. and Torabi, M. (2012). The total air budget in oxygenated water flowing in drip tape. Manuscript submitted to *International Journal of Multiphase flow*, 2012.
- Torabi, M., Midmore, D. J., Walsh, K.B., Bhattarai, S.P. and Tait, L. (2012). Analysis of factors affecting the availability of air bubbles to subsurface drip irrigation emitters during oxygation. *Irrigation Science*, Accepted for Publication 2012
- Dhungel, J., Bhattarai, S.P., and Midmore, D.J. (2012). Aerated water irrigation (Oxygation) benefits to pineapple yield, water use efficiency and crop health. *Advances in Horticultural Sci*, 2012 26(1): 3-16.
- Dhungel, J.K., Midmore, D.J. , Walsh, K.B. , Bhattarai, S.P., Subedi, P.P. and Xinming, C. (2012). Oxygation enhanced pineapple yield and quality. *Acta Horticulturae (ISHS)* 889:551-555  
[http://www.actahort.org/books/889/889\\_70.htm](http://www.actahort.org/books/889/889_70.htm)
- Chen, Xi., Dhungel, J., Bhattarai, S. P., Torabi, M., Pendergast, L., and Midmore D. J. (2010). Impact of oxygation on soil respiration, yield and water use efficiency of three crop species. *Journal of Plant Ecology* (Accepted in October 2010), DOI:10.1093/jpe/RTQ030
- Bhattarai, S. P., Palada M. C., Midmore, D. J., Wu D. and Salas R. (2010). On-farm evaluation of fertilizer briquettes and low-cost drip irrigation for smallholder vegetable production in Cambodia. *Irrigation and Drainage*. DOI: 10.1002/ird.571
- Bhattarai, S.P., Dhungel, J. and Midmore, D. J (2010). Oxygation improves yield and quality and minimizes internal fruit crack of cucurbits on a heavy clay soil in the emi-arid tropics. *Journal of Agricultural Science* Vol. 2, No. 3: 18-25
- Bhattarai S. P. and Midmore, D. J. (2009). Oxygation effects on physiology and water use efficiency and salt tolerance of cotton and vegetable soybean in a vertisol. *Journal of Integrative Plant Biology*.51 (7):675-688.

### Books/ book chapters

- Bhattarai, S.P., Midmore, D. J. and Su, N. (2010). Sustainable irrigation to balance supply of soil water, oxygen, nutrients and agrochemicals. In Biodiversity, Biofuels, Agroforestry and Conservation Agriculture. *Sustainable Agriculture Review*, Vol 5: 237-259 .

### Poster presented

- Bhattarai, S. P. and Midmore, D. J. (2010). Effect of emitter depth and oxygation on growth and development of young fig tree. Poster presented in the 28<sup>th</sup> International Horticultural Congress, held on 22-27 August 2010 at Lisboa, Portugal.
- Bhattarai, S. P., Midmore, D. J. and Brown P. (2010). Unveiling why oxygation is promising for horticultural irrigation. Poster presented in the 28<sup>th</sup> International Horticultural Congress, held on 22-27 August 2010 at Lisboa, Portugal.

Torabi, M., Midmore, D. J., Walsh, K.B. and Bhattarai, S. P. (2010). Response of four vegetable species to oxygation in a pot experiment in screen house. Poster presented in the 28<sup>th</sup> International Horticultural Congress, held on 22-27 August 2010 at Lisboa, Portugal.

#### **Paper presented in international conference**

Bhattarai, S. P., Midmore, D.J., Pendergast, L. and Ronnfeldt, A. (2011). Oxygation: using aerated water for cotton irrigation with sub-surface drip: Opportunities for gains in yield and water use efficiency. Irrigation Australia Conference, 22 - 25 August 2011, Launceston, Tasmania, Australia.

Bhattarai, S. P., Midmore, D. J., de la Peña, R., Palchamy K., Symonds, R. (2010). Breeding for drought tolerance in tomato: capitalizing on multiple approaches. Paper presented in Plant Breeding for Drought Tolerance: A Symposium, 24-25 June 2010, Colorado State University, Fort Collins, Colorado, USA. <http://www.droughtadaptation.org/Symposium/Speakers.html>

Bhattarai, S. P., Midmore, D. J., and Dhungel, J. (2010). Diversifying the application of oxygation to lawn, landscape, and large scale agricultural irrigation. Paper presented in Australian Irrigation Conference and Exhibition, 8-10 June 2010, Sydney, Australia.  
<http://www.irrigationaustralia.com.au/visitor.cfm?id=3>

#### **Magazines**

Bhattarai, S.B. and Midmore, D.J. (2008). Potential benefits of oxygation-aeration to the Australian fruit industry. Australian Fruitgrower 2(1): 22-23.

Bhattarai, S.P., Midmore, D.J. (2009). Potential benefits of oxygation-aeration of irrigation water. Australian Nutgrower Dec. 38-40.

#### **Electronic Media**

The Morning Bulletin, 16 September 2010.

New Water saving invention will grow on you

Web link: <http://www.themorningbulletin.com.au/story/2010/09/16/new-smart-lawn-watering-system-saves-money-too/>

## **12. Planned Knowledge, adoption and promotional activities and associated Evaluation activities (up to ½ page)**

*Describe any planned knowledge, adoption and/or promotional activities and the proposed evaluation activities planned to occur during the next Milestone reporting period.*

Publication of individual crop research reports or findings in the respective industry magazines, and relevant refereed journals as indicated in the summary sheet of plan of action.

Final update of the Oxygation website to include all the current research results and outcomes of promotional activities.

Final presentation to Australian Irrigation Conference in June 2013, outcome and outputs of the research will be presented, display unit of oxygation demonstrated for operation.

Discussion with relevant industries and NPSI for continuation of some research activities, planning future research activities and opportunities for funding support to continue research, innovation, adoption and capacity building for oxygation research will be sought.

## **13. IP Register**

*If your project maintains an IP Register, then please provide an updated list of the register. If maintaining an IP Register is not part of the project agreement, please write N/A.*

Potential IP with Smart Lawn activities and prototype