Optimising water and nutrient use on vegetable Farms

Peter O'Malley
Department of Agriculture & Food
Western Australia

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Media Summary

Efficient water and fertiliser use on sandy soils

The key to achieving efficient irrigation and fertiliser use is good irrigation design, and the correct scheduling of irrigation and fertiliser. Over the past 12 months Rohan Prince, a specialist development officer, has worked on more than 25 properties in WA to help growers improve their irrigation and nutrient use. He has conducted detailed monitoring of water and fertiliser use, soil moisture and nitrogen content and nutrient leaching on 15 vegetable crops grown on 9 of these properties.

Rohan was employed under the Horticulture Australia Project 'Optimising water and nutrient use on vegetable farms' to work on farm with growers to assess and upgrade irrigation systems to acceptable standards of efficiency, bench mark current practice and introduce growers to daily evaporation, crop factor based irrigation scheduling and growth phase fertilising. The major project objective was to achieve the adoption of evaporation based irrigation scheduling and plant demand fertilisation for the majority of vegetable crops grown on the Swan Coastal Plain.

The complex relationships between irrigation, soil moisture, soil nitrate levels, nitrate loss and compost and fertiliser application were demonstrated by the continuous monitoring of soil moisture and the weekly determination of soil nitrate content and leaching losses. The information gave growers the confidence to alter irrigation and fertiliser schedules to more closely match plant requirement and produce better crops with a minimum of inputs.

The low water-holding capacity and low nutritional status of sandy soils make it difficult to grow vegetables without leaching fertiliser into the underlying aquifers. The nitrogen being lost from vegetable production into the surrounding environment is of increasing concern and the industry is being asked to demonstrate they are using water and fertiliser efficiently.

The techniques employed were developed by a previous HAL funded project 'Increasing water and nutrient use efficiency in vegetable production on sandy soils', and results of this work were presented to groups seeking similar industry outcomes in New South Wales and Victoria.

Articles have been published in the WA Grower and papers presented at the national Vegetable Industry Conference 2007 and the Irrigation Australia Conference 2008.

Technical Summary

Achieving the correct balance between crop available water, fertiliser use, crop yield and leaching is essential to the sustainability of vegetable production on the sandy soils of the Swan Coastal Plain. The unconfined aquifers beneath the region are a major source of commercial and domestic water and efficient water use with minimum loss to the environment is the key to maintaining vegetable production in the region.

Nitrate leached from soils used to grow vegetables is of concern world wide and in most countries vegetable growers are being encouraged to adopt more efficient water and fertiliser practice. The key to achieving efficient irrigation and fertiliser use is good irrigation design, and the correct scheduling of irrigation and fertiliser.

From December 2008 to November 2009 funding from Horticulture Australia enabled a specialist development officer, initially employed on Horticulture Australia Project VG04009 'Increasing water and nutrient use efficiency in vegetable production on sandy soils', to continue to work on farm with growers to improve irrigation systems and implement evaporation based irrigation scheduling and growth phase fertilising.

Soil moisture, fertiliser and water use efficiency and soil nitrate was monitored for an additional 15 crops on 9 properties and the results used to encourage growers to adopt efficient water and fertiliser practice. Five workshops/field walks were held in conjunction with the vegetablesWA managed and Caring for our Country funded project, 'Good practice and better environmental outcomes in vegetable production'.

The equipment, software and techniques developed to monitor plant available water, soil nitrate levels and leaching were documented and packaged in a form suitable for it to be adopted nationally by groups interested in similar outcomes. An operation manual 'Soil Moisture Monitoring Unit Manual' has been written and is available from the authors of the report. The monitoring provides growers with a clear understanding of how irrigation, rainfall and fertiliser application interact within their soil. The information allows timely irrigation and fertiliser adjustments to be made throughout the crop. The impact of any changes made to existing practices can be demonstrated and quantified and this provides growers with the confidence to implement change.

The value of monitoring soil moisture was universally acknowledged by the participants and the majority of growers adopted evaporation based irrigation scheduling. Simple monitoring of soil nitrate demonstrated the effectiveness of existing fertiliser practice and promoted the adoption of '3Phase' fertiliser schedules which tailor fertiliser application to meet plant variable demand and increase fertiliser use efficiency.

The use of poultry manure was shown to increase soil nitrogen and carbon but result in high levels of nitrate leaching and increased ground water nitrate concentrations.

Optimising water and nutrient use on vegetable farms

The infertile coarse sandy soils of the Swan Coastal Plain (SCP), which extends 100 km north and south of Perth, are used to produce the majority of Western Australia's vegetables. The year round production of good quality vegetables on these naturally infertile sands with poor water holding capacity and low nutrient retention requires relatively large and frequent irrigation and fertiliser applications.

The region is irrigated by licensed self-supply groundwater bores from the underlying confined and unconfined aquifers. This water resource is also used to supply about half of Perth's integrated water supply scheme. Declining groundwater levels caused by reduced rainfall, increased consumption and land use changes has led to the licensing of bores, meters being installed on most commercial bores, stricter controls and emphasis being placed on using water efficiently.

Irrigation of around 1500 mm plus rainfall of 7300 mm each year exceeds the annual 1800 mm Class A pan evaporation and applied fertilisers surplus to crop uptake are leached into the underlying aquifer (O'Malley P. and Prince R 2009., Lantzke N., 1997, Sharma M.L. et al., 1991). Nitrogen leaching is a significant source of water pollution (OECD, 1982: Carpenter et al., 1998, Changsheng et al., 2009) and it can degrade surface and ground water resulting in eutrophication and non-potable water supplies (Smith et al., 2003 : Weier 1999). The vegetable industry's potential to leach substantial quantities of nitrogen raises environmental concerns, questions the long term sustainability of the industry and without demonstrated efficient use it will increasingly restrict options for the industry's expansion and relocation.

The objectives of the project were;
(1) To employ and develop an industry resource person to work on farm with growers to improve irrigation systems and increase water and fertiliser use efficiency by adopting evaporation based irrigation scheduling and '3Phase' fertiliser practice.
(2) Demonstrate to vegetable growers the value of evaporation based irrigation scheduling and the use of soil moisture probes to fine tune scheduling.
(3) Introduce growers to the concept of scheduling fertiliser application to meet crop demand and the use of soil analysis to validate crop nutrition.
(4) Develop the tools to monitor water and fertiliser use efficiency and demonstrate the importance of good irrigation and fertiliser practice in achieving good quality crops with minimum leaching of nutrients.
(5) Promote results of the work nationally and extend details of the techniques used to interested groups in other Australian states.
(6) Prepare a Cost Benefit Analysis for extension of the Project beyond 12 months.

Background

Vegetable production is a major enterprise on the SCP (Table 1.). The industry can be classified by size and complexity of farm operation into four groups i.e.:
• Large farms growing highly mechanised field crops such as carrots, onions and potatoes.
• Medium sized farms that are semi-mechanised; typical crops include lettuce, celery, heading brassicas, melons and tomatoes.
• Small highly labour intensive farms with low to moderate levels of mechanisation; typical crops are bunching vegetables, leafy salads and strawberries.
• Small farms growing in soil or substrate in greenhouses or shelter

The project focused on improving the practices of unprotected cropping of vegetables on the SCP.

Table 1 – Estimated Quantity of Vegetables produced on the Swan Coastal Plain (tonnes) 2007

Beans	1,593
Broccoli	3,345
Carrots - winter	26,849
Carrots - summer	29,833
Celery	9,402
Lettuce	11,235
Sweetcorn	152

Source; Australian Bureau of Statistics

The majority of vegetable farms are located on soils within the Spearwood and Bassendean dunes system geomorphic classification (Bettenay E. et al., 1960). These soils are referred to as Yellow and Grey Phase Karrakatta and Bassendean sands. They are soils of almost pure coarse sand with low levels of clay and organic matter (Table 2.).

Table 2. Average soil properties of vegetable farms monitored by the Project

Analyte		Unit	Average	Range
EC	(1:5)	mS/m	10	7 - 19
pH	(CaCl2)		7	6.0 -7.2
OrgC	(W/B)	%	0.66	0.33 - 1.28
Nitrogen	(total)	%	0.054	0.028 - 0.116
Phosphorus	(total)	mg/kg	320	100 - 500
Phosphorus	(HCO3)	mg/kg	78	35 - 130
Potassium	(total)	%	0.286	0.08 - 0.34
Potassium	(HCO3)	mg/kg	37	24 - 69
Sand	2.0 - 0.02mm	%	95.9	94.5 - 96.5
Silt	0.02 - 0.002mm	%	1.1	0.5 - 1.5
Clay	<0.002mm	%	3.1	2.0 - 4.0
Coarse sand	2.0 - 0.18mm	%	90	84.5 - 96.0
Fine sand	0.18 - 0.02mm	%	6	1.5 - 11.0

Organic carbon levels on most properties were within the range of 0.33 to 0.55 per cent but properties with a long history of heavy and repeated application of poultry manure exceeded 1 per cent.

While average field capacity of these sands is around 9 per cent it can be as low as 6 per cent. Soil moisture retention is poor and a breakdown in hydraulic conductivity at low tensions restricts plant available water to between 2 and 4 per cent of soil volume depending on the soils relative proportions of fine sand, silt clay and organic matter (Figure 1). To achieve maximum yields with a minimum of fertiliser leaching the soil must be maintained at or near field capacity using frequent irrigations of less than 5 – 8 mm to avoid leaching. On most days, even during winter, daily scheduling of uniformly applied irrigation is essential to maintain plant available water.

Maintaining soil moisture close to field capacity increases the risk of winter rain leaching plant available nutrients beyond the crops roots and without careful fertiliser scheduling losses can be high.

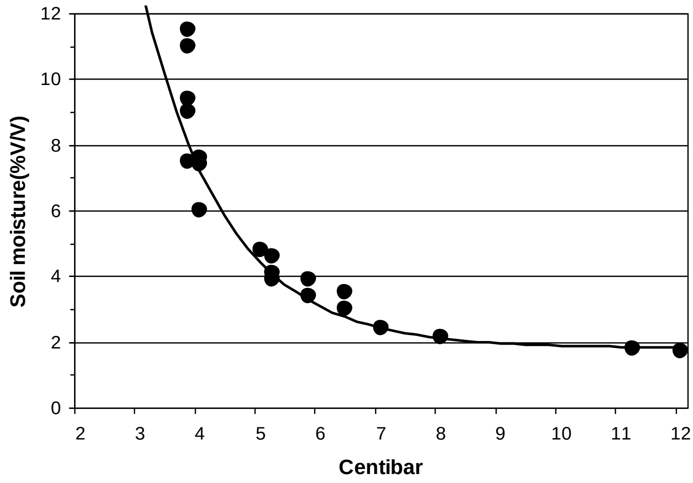

Figure 1. Soil moisture retention of typical grey phase Karrakatta sand

The Department of Agriculture and Food Western Australia (DAFWA) previously carried out a series of projects to establish evaporation replacement crop factors which achieve maximum yields for a range of vegetable crops grown on sand but at the time of commencing project VG04009 very few growers used daily evaporation and crop factors to schedule irrigation (McKay and Davison 2000; Teasdale L. et al., 2000; McPharlin, unpublished). In cooperation with project VG04009 and funding from the WA Premiers Water Foundation crop factors for growing the major vegetable crops were reviewed and published on the vegetablesWA best practice web site (http://www.vegetableswa.com.au/irrigation /crop.asp) and incorporated in a web based Vegetable Irrigation Scheduling System (VISS) (http://www.vegetableswa.com.au/demo_home.asp).

Traditionally, the application rates of organic and inorganic fertiliser used to grow good commercial vegetable crops on these sands has been high, rates of 50 cubic metres of poultry litter plus 500 kg/ha of nitrogen fertiliser being commonly used. Research shows that much of the nitrogen supplied by manure is leached and could potentially be replaced by the strategic use of inorganic fertilisers (Sharma M.L. et al., 1991, Lantzke N. 1997; Phillips et al., 2003). Horticulture has been identified as a major source of excess nutrients in the Swan River Catchment and underlying aquifers (Swan River Trust 2002) and continuing effort is needed to further reduce the amount of nitrate nitrogen being leached into groundwater from vegetable farms.

Nitrogen nutrition is one of the most important factors controlling vegetable yield and quality but it is also the most difficult element to manage. Plants usually absorb nitrogen as nitrate from a mixture of inorganic and organic sources. Soil organic nitrogen is a resource of variable availability and that, combined with variable plant demand means the pool of nitrogen is extremely labile. The fine balance required to optimise yield at the same time as minimising the risk of leaching surplus nitrogen is difficult to achieve and requires careful crop and soil monitoring.

The potential for leached nitrogen to degrade surface and ground waters and lead to eutrophication and non-potable water supplies and the importance of reducing the use of a surplus of nitrogen has led to a proliferation of work to minimise nitrogen losses. Most are based on measuring soil mineral nitrogen at planting (Nmin) and applying models which account for all sources of nitrogen that become available to a plant during its growing period (Sullivan D.M. et al.; Trembley N et al. ; EU-ROTATE_N www.warwick.ac.uk/go/eurotaten; FertorgaNic DSS V 4.0 www.fertorganic.org); Overseer Nutrient Budgets, www.agresearch.co.nz/overseerweb/. This work also promotes the concept of 'growth curve' based nitrogen fertilisation scheduling where only sufficient nitrogen to meet the plant's immediate requirement for growth is supplied.

Fertiliser programs for growing leafy crops in sand and suitable for extending to growers had been previously developed by Phillips et al 2007. These were based on meeting the crops' fertiliser need at each growth stage and were rebadged as the '3Phase' method of fertilising. Details of the programs for broccoli and lettuce were made available as farmnotes.
http://www.agric.wa.gov.au/objtwr/imported_assets/content/hort/veg/cp/broccoli.pdf
http://www.agric.wa.gov.au/objtwr/imported_assets/content/hort/fertiliserstrategiesforlettuce.pdf
Programs for cabbage and celery production will be published in the final report for the HAL funded project VG07036 'Enhancing fertiliser use and efficiency for transplanted vegetables'.

Method

The Project officer, Rohan Prince, was initially appointed for project VG04009 in October 2005. Rohan worked closely with 4 – 8 growers at a time to introduce the use of efficient irrigation design evaporation based irrigation scheduling and "crop demand" fertiliser strategies which optimised water and fertiliser use efficiency without compromising yields. Initial emphasis was placed on encouraging producers to upgrade existing irrigation systems to achieve good standards of irrigation uniformity and the adoption of evaporation based irrigation scheduling.

The majority of growers attended 'Water Wise on the Farm' training provided by DAFWA and the Swan Catchment Council and there was a collaborative attempt by a number of projects to improve water use efficiency.

Crops were intensively monitored for irrigation, soil nitrate and moisture content, and leaching. Results were discussed with the individual grower and the adequacy of the irrigation and fertiliser scheduling demonstrated. Growers were then introduced to the concept of tailoring their fertiliser applications to meet plant demand and encouraged to modify existing schedules or adopt the recommendations developed by Phillips et al 2007.

The information collected allowed past and good practice to be benchmarked and documented.

Project VG08020 'Optimising water and nutrient use on vegetable farms' enabled this work to be extended for 12 months and a further 15 vegetable crops on 9 properties were monitored.

Promotion and results of the work was presented to industry at a series of workshops organised in conjunction with vegetablesWA as part of a collaborative approach, across organisations, aimed at improving grower irrigation and fertiliser practice.

Articles were published in the local ‘WA Grower’ magazine and presentations made at National Conferences and meetings organised in New South Wales and Victoria.

Extension of the project beyond 12 months into years 2 and 3 was subject to preparation of a Benefit/Cost analysis and a stop/go milestone and a decision not to continue the Project was made at a Vegetable IAC meeting in August 2009.

On Farm Monitoring

Before monitoring commenced the participating farm’s irrigation system was assessed and sprinkler uniformity tested to establish that it was operating at an acceptable standard. The accepted standards of DU 75% and CU of 85% were considered a minimum requirement. This allows irrigation to be scheduled by applying recommended crop factors to daily evaporation without the risk of some areas of the crop being severely under watered. Minor operating changes were made to ensure that sprinklers were operating at recommended pressures, that sprinkler risers were straight, that all sprinklers had the same nozzles and that all sprinklers in the monitored area were of the same type. Where possible the grower was involved in the sprinkler testing process so they gained a greater understanding of their irrigation uniformity and the ‘applied’ versus ‘calculated’ application rate.

A representative area of the farm was chosen. The depth and timing of irrigation was measured with a continuously recording tipping bucket and weekly irrigation totals confirmed using simple rain gauges. Volumetric soil moisture and drainage was continuously monitored at three depths using TDR soil moisture probes placed in the top 60 cm of the soil profile. Sensors at 0-15 cm and 15-30 cm monitored the effective root zone soil moisture while a lower probe at 30-60 cm monitored water that moved beyond the effective root zone of the crop.

On most sites soil tension at 15 cm and 30 cm depth was continuously monitored using a tensiometer fitted with a pressure transducer. This allowed the specific relationship between soil moisture and tension for the site to be estimated and minimum water recharge levels established. Figure 2. shows that the amount of suction (- centibars) a plant must apply to extract water increases sharply when the soil is allowed to dry below 9 per cent moisture. To achieve maximum yields in these poor quality sands soil tension should be maintained above -4.5 to -5.0 centibar.

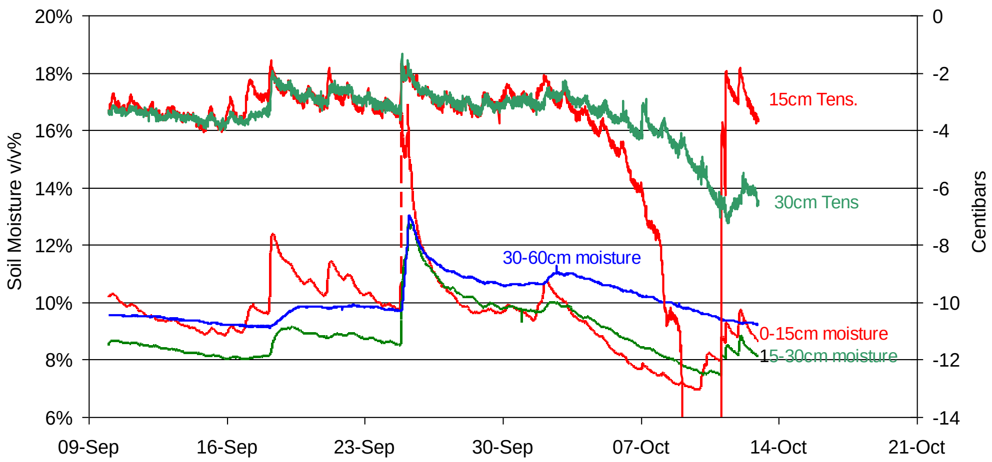

Figure 2. Soil moisture plotted with soil tension.

Data was logged to a Campbell Scientific CR 200 data logger and down loaded daily via telephone modem. Computer software ‘R-Logger’, developed using the freely available ‘R’ program, allowed irrigation timing, depth and soil moisture to be summarized via a graphical interface and emailed as a PDF to participating growers (Figure 3).

Nitrogen fertiliser practice was monitored each week by estimating the quantity of plant available nitrogen (kg/ha) in the top 30 cm of soil and the quantity collected in the lysimeters buried beneath the crop. For soil analysis, twelve samples, taken at two depths, 0-15 cm and 15-30 cm using a sand auger, were bulked and analysed for nitrate concentration using a R.Q. Flex® meter after 50: 50 v/v aqueous extraction (USDA, 1999). Samples were regularly checked for the presence of nitrogen as ammonium but conversion of ammonium to nitrate in these sands appears to be rapid and significant levels were seldom found. Organic nitrogen was not determined.

Each monitoring unit contained;

- A Campbell’s CR200 data logger,
- three Campbell Scientific CS-625 volumetric water content (vwc) probes (logged every 15 minutes),
- *Irrometer®* tensiometer fitted with a low tension tip and a pressure transducer,
- *Ecowatch®* 7852 tipping bucket rain gauge recording in 0.2 mm increments, (time stamping of the data enabled the timing and quantity of each irrigation event to be recorded),
- and a Maxon MM-5100 modem.

The unit was powered by a 7.5 Ah, 12 Volt sealed lead acid battery recharged by a 10 watt solar panel.
All components were housed in a safe case and each complete unit had an approximate cost of $4000.

Complete monitoring unit

There is a range of different probe types available for measuring soil moisture and a number of reviews listing their strengths and weaknesses have been published (Charlesworth, 2005). The CS-625, TDR type, probe manufactured by Campbell Scientific was selected from the range available because of its relatively large sphere of influence, robust build and high resolution and precision.

Each probe averages soil volumetric moisture (0 – 50%) within a 3 cm radius around the length of each probe (0.8L of soil volume), to an accuracy of +-2.5% with a resolution of 0.1% and a repeatability (precision) of 0.1%.

The probe consists of two stainless steel rods 300 mm in length and 3.2 mm in diameter, spaced at 32 mm, connected to a printed circuit board encased in an epoxy resin. The cables for each probe can be up to 300 m long (5-15 m used) and allows the logger unit to be positioned outside the crop to reduce the risk of damage by machinery or workers.

Soil moisture over each 0 -15 cm profile was measured by inserting the probes at the appropriate depth at a 30 degree angle into the undisturbed soil under a plant. Minimal disturbance of the soil profile being measured gave a good representative value with no preferential pathways formed around the probe.

Field capacity of the sandy soils measured ranged from 6-13%.

Typical installation of a soil moisture (TDR) probe and 15cm tensiometer.

Drainage and nutrients leaching below the root zone was estimated weekly using three simple drainage lysimeters installed to collect water at a depth of one metre. Lysimeters were specially manufactured 700 mm deep plastic drums 500 mm in diameter. The collection area, 250 mm from the bottom, was separated from the soil by 100 micron geo fabric supported on a grate. Two hoses, air inlet and collection, were run to the soil surface and leachate collected using a vacuum pump. The lysimeters were installed by hand, such that the geo fabric was 1m below the soil surface. A template, slightly larger than the lysimeters, was used during installation to minimise soil disturbance. Care was taken not to mix the soil profile. Water and N leached between harvest and the planting of the next crop was attributed to the production of the harvested crop.

Installation of a lysimeter.

Weather Information

As part of project VG04009 the weather coverage by DAFWA for the Swan coastal plain was expanded to provide growers with a better estimate of the evaporation occurring on their property and allow more accurate scheduling of irrigation. The network was increased from 5 to 8 stations by installing additional stations at Lancelin and Wanneroo, north of Perth, and Myalup in the south. These stations measure wind speed and direction, solar radiation at 3m above ground, air temperature and relative humidity measured at 1.5m height, soil temperatures at 40 mm below ground surface and rainfall at standard rain gauge height of 350mm to a resolution of 0.2 mm. A modified Penman Monteith equation is used to calculate the Class A pan evaporation applied to the 'crop factor' irrigation scheduling recommendations i.e. evaporation X Crop Factor = crop requirement. The live weather stations are accessible from the Department's Website (www.agric.wa.gov.au) and from a link on the vegetablesWA website (www.vegetableswa.com.au). The weather station network is also used by the Vegetable Industry Scheduling System (VISS).

In September 2006 a service to send live evaporation data from DAFWA weather stations direct to vegetable growers by mobile phone text message was introduced. This was a cooperative project between DAFWA and vegetablesWA funded by the Western Australian Premier's Water Foundation. The daily text message is sent at a time set by the grower and includes daily evaporation from midnight to midnight, rainfall for the 24hrs prior to the message being sent and the weather forecast from the nearest Bureau of Meteorology forecasting site.

Monitoring Service

Growers were kept informed of their irrigation practice using charts (Figure 3.) showing irrigation/rainfall and soil moisture. The charts show visually how irrigation timing and depth alter soil moisture in each profile.

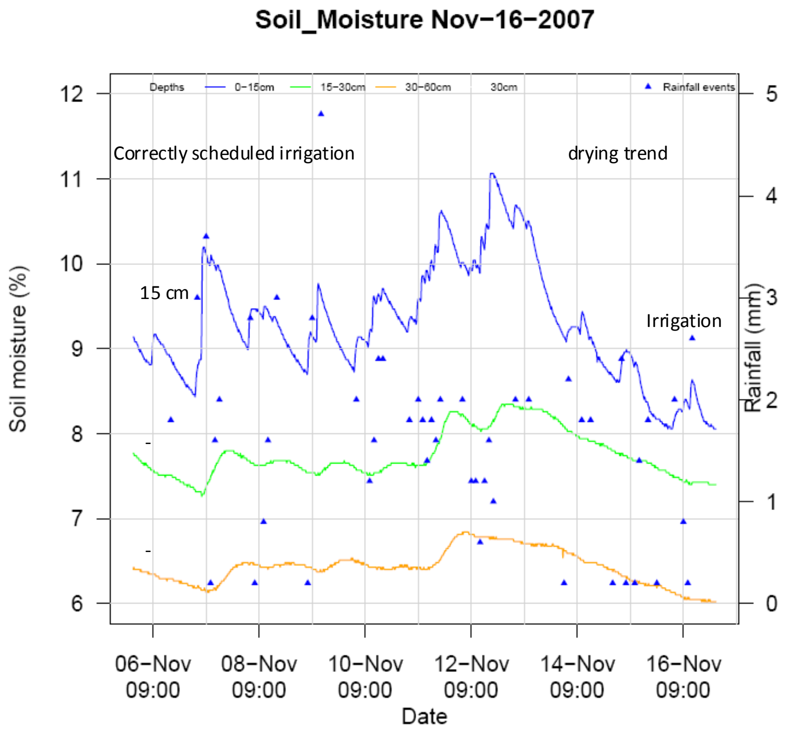

Figure 3. Decreased irrigation/rainfall (▲) causing soil moisture recorded in the lower profiles to fall

The time taken for the wetting front to move through a profile and the depth to which soil moisture is increased can be seen. Soil moisture in the 0-15 cm profile rises sharply after irrigation and then decreases as water is lost by evaporation, crop use and drainage to lower profiles. If irrigation is heavy and exceeds field capacity the 0-15 cm soil profile drains quickly showing a steep decrease in moisture with a corresponding steep increase in moisture in the 15-30 cm soil profile. A subsequent increase in soil moisture in the 30-60 cm profile indicates deep drainage. The steepness or slope of the rise and fall in soil moisture indicates the severity of the drainage event.

When irrigation scheduling is good soil moisture content of the 30-60 cm soil profile remains steady. When irrigations are too heavy or too light soil moisture in this deeper profile will rise or fall (Figures 3 & 4.).

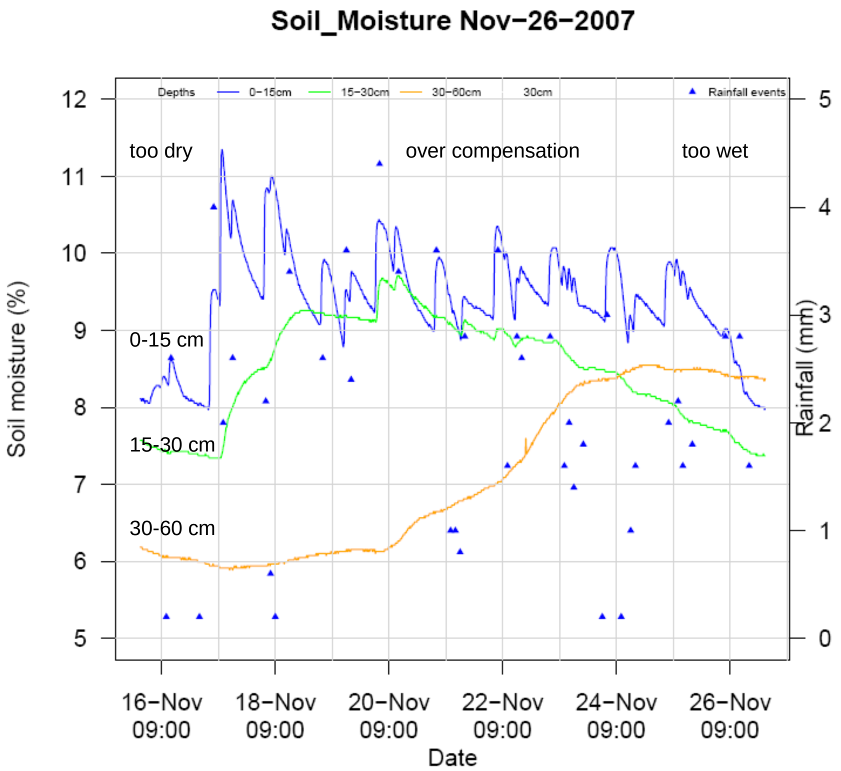

Figure 4. Drainage from increased depth and frequency of irrigation/rainfall (▲) causing soil moisture of the deeper profiles to rise.

The accuracy of the grower's Irrigation scheduling and the quantity of water and nitrate nitrogen collected in the lysimeters was discussed with growers each week. A comprehensive report was prepared at the completion of each crop. The report contained tables and charts which gave weekly summaries of the amount of irrigation/rainfall applied to the crop compared to the crop requirement calculated by applying recommended crop factors to daily evaporation and a chart showing soil nitrate N content, fertiliser N applied and nitrate N collected in the lysimeters. This allowed growers to view the relationships between recorded irrigation, soil moisture and leaching and fertiliser application, soil nitrate content, plant uptake and nitrate loss. Examples of these reports are given in appendix 4 & 5.

Figure 5 compares recorded irrigation and rainfall with crop irrigation requirement calculated using daily evaporation and recommended crop factors and shows the amount of water leached for a winter lettuce crop. Leaching cannot be avoided in winter and rain in excess of evapotransporation quickly moves nitrate through the soil.

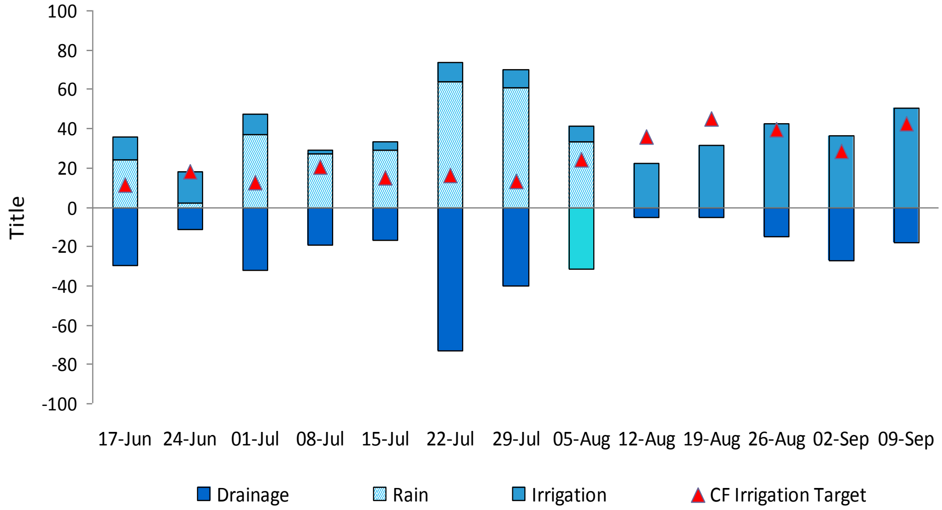

Figure 5. Winter lettuce - Rain, irrigation, CF Irrigation Target (calculated crop requirement) and drainage.

Although leaching cannot be avoided careful fertiliser scheduling to supply only the immediate needs of the crop will minimise nitrate loss.

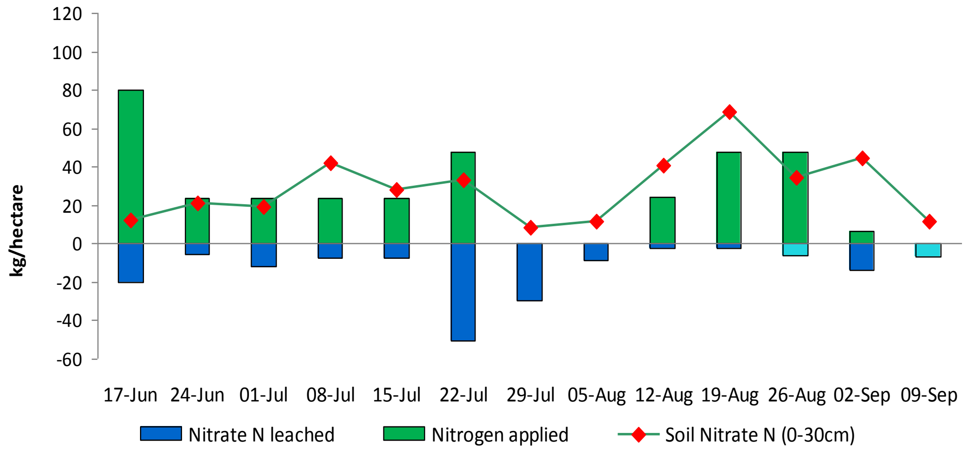

Figure 6. Winter lettuce - Good fertiliser scheduling of crop shown in Figure 5 minimised loss of nitrate.

Some drainage cannot be avoided and crops watered to achieve maximum yield, without surplus rain, will still lose 20 – 30 per cent of water to drainage (Figure 7). Drainage of less than 20 per cent will normally reduce yields.

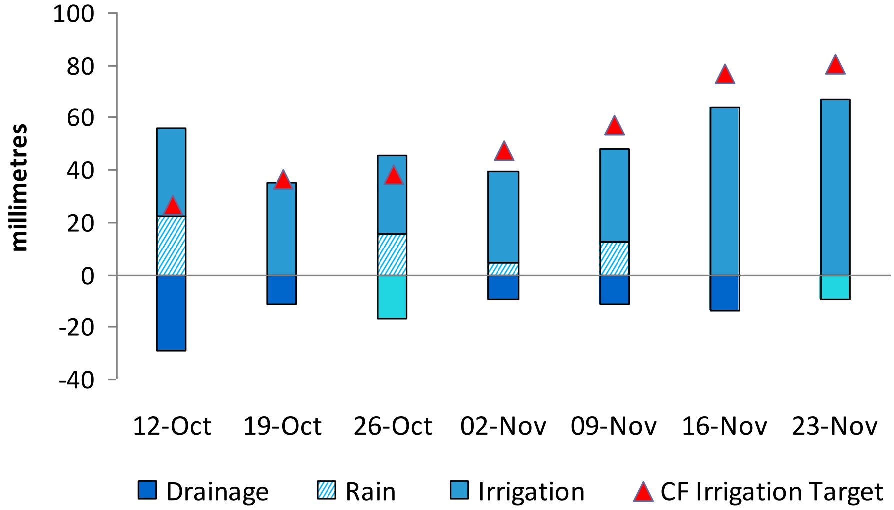

Figure 7. Good irrigation scheduling for spring lettuce crop

The efficiency of grower fertiliser practice was demonstrated by charting weekly rapid soil nitrate analysis against nitrogen fertiliser applied and the amount of nitrate nitrogen collected in lysimeters (Figure 8). This enabled growers to develop an understanding of how closely their crop's apparent nitrogen demand was being met and identified periods of surplus and deficit nitrogen supply.

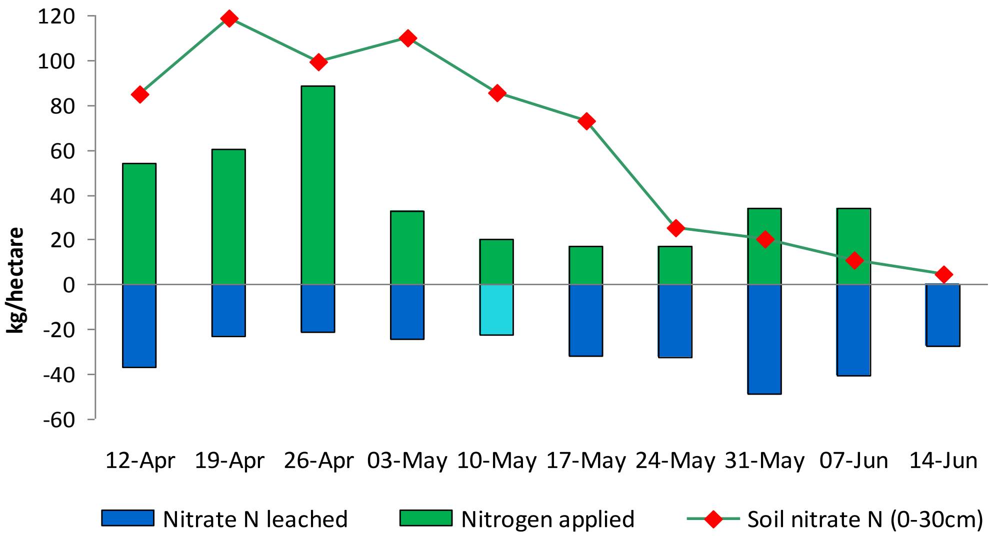

Figure 8. Poorly scheduled fertiliser - autumn broccoli.

Crops sown or transplanted into soil containing the equivalent of 40 – 45 kg of nitrate nitrogen/ha in the top 30cm did not respond to additional fertiliser and low plant demand and good irrigation control meant that levels could be maintained at 20 – 40 kg/ha with fertiliser additions equivalent to 20 kg of nitrogen each week until plant growth increased. Weekly fertiliser rates equivalent to 55kg of nitrogen quickly increased soil nitrate nitrogen content to greater than 85 kg/ha and this appeared to be sufficient to achieve maximum growth for most crops (Figure 9).

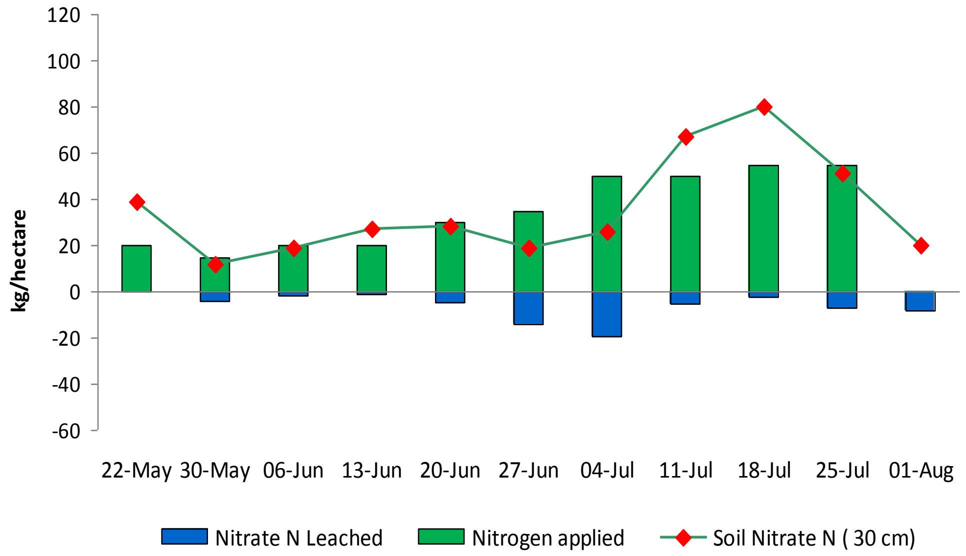

Figure 9. Good fertiliser scheduling winter broccoli crop.

Monitoring Results

Monitoring results are shown in tables 3 and 4. A water use index was computed by expressing the crops water requirement as a percentage of the total water applied. Despite substantial rainfall most crops recorded good levels of water use efficiency i.e. a water use index of 90% or better. The notable exception was the tomato crop and there is an obvious need for further work with this crop.

The majority of growers involved with the project embraced evaporation based irrigation scheduling and in general successfully applied recommended crop factors to daily evaporation recordings. Some growers increased efficiency further, during the mid growth stages when crop requirement was less than 6mm a day, by taking advantage of the quantity of plant available water stored in the root zone after rain.

Soil moisture monitoring verified that recommended crop factors maintained good levels of plant available moisture in poor sand and could potentially be lowered in sands with above average levels of finer particles and/or when soil carbon levels were above 0.5 per cent. These water savings, in the order of 10 – 15 per cent, result from the better use of stored rainfall during the winter months and irrigation efficiency savings made by watering less frequently during summer.

To achieve a water use index of 100% watering times needed to be adjusted daily and adjustments made for rain stored in the crop root zone.

Table 4 clearly shows the strong relationship between correct irrigation scheduling and the level of nitrogen leached. In general crops with good irrigation control leached less nitrogen. Exceptions occurred when large amounts of fertiliser or manure were applied pre plant and when mineralisation of existing soil reserves of organic nitrogen or crop residues occurred before crops were mature enough to take advantage of higher soil nitrate concentrations.

While the amount of plant available nitrate nitrogen being mineralised from crop residues, fresh manures and carbon enriched soils is often difficult to predict rapid soil analysis frequently showed that excessive levels of nitrate following bed preparation combined with too much irrigation led to high leaching losses in the first few weeks of the crop. Developing practices to effectively utilise the nutrients contained in crop residues will be essential in any action to reduce fertiliser use and nutrient leaching.

Table 3. Individual crop water use

Crop	Planting	Recorded (millimetre depth)			Calculated*	Drainage		Water use
	Date	Irrigation	Rain	Total water	Requirement	mm	%	Index**
Potato	03-Jul	320	360	680	616	299	44%	91%
Cos Lettuce	17-Feb	351	5	356	346	165	46%	97%
Cabbage	12-May	301	426	727	372	427	59%	51%
Seeded Spinach	17-Feb	210	2	212	225	52	25%	106%
Broccoli	09-Apr	192	330	522	315	256	49%	60%
gourmet lettuce	08-Sep	191	69	260	230	88	34%	88%
gourmet lettuce	15-Oct	263	85	348	354	NR	NR	102%
gourmet lettuce	10-Dec	347	2.5	349.5	339	NR	NR	97%
Seeded Spinach	13-Jan	113	0	113	135	NR	NR	119%
Seeded Spinach	10-Feb	158	7	165	130	NR	NR	79%
Seeded Spinach	12-May	79	79	158	107	80	51%	68%
Rocket	07-Jul	51	189	240	102	275	115%	43%
Rocket	04-Sep	45	64	109	98	45	41%	90%
Rocket	22-Oct	138	15.5	153.5	156	18	12%	102%
Broccoli	28-Feb	458	15	473	451	132	28%	95%
Tomato	14-Oct	1783	127	1910	1129	1081	57%	59%
Potato	16-Feb	437	258	695	690			99%
Carrots	17-Feb	553	375	928	819	490	53%	88%

* Irrigation requirement calculated by multiplying recommended crop factors by the previous days evaporation.

** Irrigation requirement expressed as a percentage of total water applied (target 100%).

Table 4. Individual crop water use and leaching

Crop	Planting	N Applied	leachate	Nitrogen use	Water use
	Date	kg/ha	kg/ha	Index**	Index*
Potato	03-Jul	na	133.5		91%
Cos Lettuce	17-Feb	295.5	391.0	-32%	97%
Cabbage	12-May	na	382.1		51%
Seeded Spinach	17-Feb	174.0	24.7	86%	106%
Broccoli	09-Apr	574.0	323.3	44%	60%
gourmet lettuce	08-Sep	288.0	45.3	84%	88%
gourmet lettuce	15-Oct	NR	NR		102%
gourmet lettuce	10-Dec	NR	NR		97%
Seeded Spinach	13-Jan	NR	NR		119%
Seeded Spinach	10-Feb	NR	NR		79%
Seeded Spinach	12-May	98.3	103.7	-5%	68%
Rocket	07-Jul	134.0	109.0	19%	43%
Rocket	04-Sep	85.0	12.0	86%	90%
Rocket	22-Oct	85.0	4.0	95%	102%
Broccoli	28-Feb	434.0	139.0	68%	95%
Tomato	14-Oct	NR	678.0		59%
Potato	16-Feb	NR	NR		99%
Carrots	17-Feb	NR	148.0		88%

* Water required expressed as a percentage of total water applied.

** % of applied nitrogen not lost to leaching.

Water Quality

The quality of irrigation water on most farms was good but 3 of the 10 samples analysed had notable levels of plant available nitrogen (25 – 34 mg/L) and this contributed significant amounts of nitrogen to their crop fertiliser programs (Table 5.). All 3 properties had a history of long term use of poultry manure. Department of Water monitoring of bores located within the Carrabooda ground water area has confirmed high nitrate concentrations in groundwater underlying a number of vegetable growing properties and strategies to reduce levels are being developed.

Total dissolved salt of between 500 and 900 mg/L was recorded on 3 properties and one recorded a level of 1300 mg/kg. Soil monitoring showed that the level of leaching provided by recommended crop factors was sufficient to avoid any build up of salt and soil electrical conductivity (Ec) was maintained below 100 mS/m.

Table 5. Analysis of irrigation water.

Analyte	Method	Average*	Min	Max	Preferred	Critical	Unit
CO3	iALK1WATI	11	<1	103			mg/L
Ca	iMET1WCICP	66	16	138			mg/L
Cl	iCL1WAAA	155	85	408	<175	700	mg/L
ECond	iEC1WZSE	102	40	242	<150	200	mS/m
HCO3	iALK1WATI	117	53	191			mg/L
Hardness	iHTOT2WACA	247	45	600	<60	350	mg/L
K	iMET1WCICP	18	3.7	49			mg/L
Mg	iMET1WCICP	19	8	38			mg/L
N_NH3	iAMMN1WFIA	4	0.01	34			mg/L
N_NO3	iNTAN1WFIA	9	0.02	34			mg/L
N_total	iNP1WTFIA	12	0.2	38	<5	25	mg/L
Na	iMET1WCICP	91	47	222	<115	460	mg/L
OH	iALK1WATI	<1.5	<2	<1			mg/L
P_SR	iP1WTFIA		<0.01	0.05			mg/L
P_total	iPP1WTFIA		<0.01	0.07			mg/L
SO4_S	iMET1WCICP	114	8	442			mg/L
TDS_calc	iSOL1WDCA	558	220	1300	<500	1500	mg/L
aION_BAL	ixIONBAL2		-7	9.2			%
pH	iPH1WASE	8	6.9	8.9	>6	9	

Information Transfer

Staff involved with project VG04009 and in particular, project officer Rohan Prince, worked on farm one-on-one with vegetable growers to promote the adoption of efficient irrigation design, evaporation based 'crop factor' irrigation scheduling and '3Phase' fertiliser strategies. Information was tailored for individual properties and promoted to the industry through field walks, workshops and regular articles published in local grower magazines.

Field Days and Workshops – Appendix 1

Presentations on irrigation scheduling, soil moisture monitoring and better fertiliser practice were made at field walks and workshops organised in conjunction with vegetablesWA as part of a collaborative approach within a number of projects, across organisations, aimed at improving grower irrigation and fertiliser practice.

March (2009) *Help us help you – research to practice*
Yanchep Inn, Yanchep National Park, Yanchep

May (2009) *Improving your farms viability – research to practice*
Peel-Waterways Centre, Suite 6, 21 Sholl Street, Mandurah

August 2009, *Small changes making a big difference* – vegetablesWA Demonstrating good practice field day 1, Medina research station and Baldivis Market Garden. (*reported WA Grower V. 42 No 3. September 2009*.)

September 2009. *Field walk and demonstration of monitoring equipment*. vegetablesWA Demonstrating good practice field day 2, Gingin West and Gingin. (*Reported WA Grower V.42 No 4. December 2009.*)

October 2009. *Field walk – soil moisture and leachate monitoring*. *Biofumigants*. VegetablesWA Demonstrating good practice field day 3, Myalup. (*Reported WA Grower V.42 No 4. December 2009*.)

With the exception of the May workshop, where only 2 farms were represented, all functions were well attended by industry and generated a useful exchange of information.

Reports on the 3 field walks published in the WA Grower are shown in Appendix 1 and a booklet detailing the information extended is available from vegetablesWA, Horticulture House, 103 Outram Street West Perth 6005.

Nitrate in ground water

In May 2009 a meeting was held to address Community concern over the level of nitrate in ground water within the Carabooda water mound and the contribution vegetable production was making to increasing levels. A presentation of monitoring results defined the amounts of nitrate being lost by growers and demonstrated the reductions achieved by adopting better irrigation and fertiliser practice (Table 6.).

The data clearly showed that the use of raw poultry manure prior to planting caused high levels of nitrogen to be leached during the establishment phase of transplanted crops. Its current method of use is highly inefficient and represents a significant localised source of nitrate enrichment of the superficial aquifers under farms.

Table 6. Summary: Nitrogen leached from commercially grown and '3Phase' method (Medina Research Station) head lettuce crops from bed formation until harvest for crops monitored from 2006 – 2009.

Crop practice	Average nitrogen leached (kg N/ha)	% of applied nitrogen leached
No poultry manure	172	60
With poultry manure	642	96
3Phase method	126	45

Note: '3Phase' method is new approach to strategic rate and timing of applications of mineral fertiliser for transplanted leafy and Brassica crops.

Articles – Appendix 2

Project VG04009 published 17 extension articles detailing techniques to improve use water and fertiliser use in magazines read by vegetable growers. This project published a further 3 articles.

Prince, R (2009) Surviving a cut in your water allocation. *WA Grower V. 42, no. 3. pp. 19*

Prince, R (2009) Irrigate efficiently – save water and money. *The Overflow No*. 20, Spring 2009 pp. 16

Prince, R. and Mc Kay, A. Text for Success. *WA Grower V. 42 no. 4. pp. 26*

Interstate visit September 2009

An aim of the project was to extend the findings of Project VG04009 and focus the work nationally by demonstrating the equipment and techniques being used to improve water and fertiliser practice on vegetable farms to vegetable service personnel in other Australian states.

Project Officer Rohan Prince led the Irrigation technology discipline team which reviewed the RD & E plan developed as part of the National Horticulture Research Network. It is part of the Primary Industry Standing Committee's (PISC) development of a national framework for the delivery of RD&E to primary industry.

Contact was made with Bill Yiasoumi and Tony Napier, DPI New South Wales, Adam Buzza. Julio Vargas and Ian Goodwin, DPI Victoria, Craig Henderson, DPI Queensland, and Rural Solutions, SA. All parties showed interest in the work and an interstate visit was made to New South Wales and Victoria in September 2009.

2 September 2009, University of Western Sydney, New South Wales. Project VG04009 results and the methods and techniques being used to improve water and

fertiliser practice on vegetable farms was presented to members of the Water and Nutrient Smart Farms and the Hawkesbury River Recovery projects.

3, 4 September 2009, *Improving water and nutrient use efficiency- Working on farm with growers.* VIC DPI, Bacchus Marsh, VIC

Benefit Cost Analysis – Appendix 3

A major milestone was a benefit cost analysis for the future of the program. This was conducted by Paul Mattingley, economist, Department of Agriculture and Food Western Australia (DAFWA).

The analysis was conservative in its estimates of the benefits generated by the project with small costs savings (<10%) for irrigation and fertilizers and yield increases (<8%) and no projected increase in area produced. The analysis focused only on the benefits to the SCP and not in the Eastern States production areas. The main benefit of the project was found to be increased yield through better crop management rather than cost saving for irrigation and nutrient use. The project activities led to faster rates of adoption amongst growers of improved systems and higher levels of cost savings and yield improvements than would happen without the project.

The project had a benefit cost ratio of 3.96 with a net present value of $3,373,844 indicating that it was an effective use of research and development funding by HAL and DAFWA.

Conclusions

Grower attitude toward evaporation based irrigation scheduling and '3Phase' fertilising improved and the momentum for uptake of the technologies increased.

The equipment, software and techniques developed to monitor plant available water, soil nitrate levels and leaching proved to be reliable and effective. The system keeps growers informed and enables timely irrigation and fertiliser adjustments to be made throughout the crop.

Growers gained greater confidence in the levels of soil nitrate being recommended to achieve good commercial yields of vegetables. The monitoring demonstrated how irrigation, rainfall and fertiliser application interacted to determine plant available nitrate levels in their soil and gave growers the confidence to adjust fertiliser programs. It also allowed the impact of any changes made to existing practices to be demonstrated in terms of plant available water and nitrogen and reinforced the growers' confidence in the program.

While growers have been receptive and there has been a notable change in grower attitude toward irrigation and fertiliser scheduling some growers continue with old inefficient practices. Implementing change without effective drivers has required careful negotiation when dealing with older well established growers and in most cases has proved to be difficult and slow. However, younger progressive growers have been keen to adopt the new technologies and experiment with smarter fertiliser practices. The close interaction of vegetable grower, project officers and government agencies facilitated by the project has resulted in an appreciation by all parties of the common ground required to meet the needs and commercial pressures of vegetable production and the environmental and social responsibilities of government.

The value of monitoring soil moisture has been universally acknowledged by the participants and while the majority of growers acknowledge the value of evaporation based irrigation scheduling precise application at the farm level is often difficult.

The value of monitoring soil nitrate to validate and adjust fertiliser practice has been clearly demonstrated and has given farmers the knowledge and confidence to adjust existing fertiliser programs or adopt '3Phase' fertilising.

The project collected additional information on soil nitrate levels and fertiliser rates required to achieve good commercial crops and benchmark water and fertiliser use in vegetable farming on sandy soil.

Recommendations

Work to assist growers improve their water and fertiliser scheduling and demonstrate improvement should continue. While growers have shown knowledge and acceptance of evaporation based irrigation scheduling its practical application to fit within farm operations has proved difficult.

The vegetablesWA web based Vegetable Irrigation Scheduling System is an excellent tool and training and guidance on its adoption should continue.

Ways to better utilise the substantial quantities of plant nutrients remaining in crop residues need to be researched and promoted to industry.

The production and environmental gains achieved by growers who meet recommended water and fertiliser schedules need better documentation and promotion.