Environmental effects of vegetable production on sensitive waterways

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Department of Agriculture, Fisheries and Forestry - Queensland Government

HAL project VG09041

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Project Aim
The project aims to identify the potential for losses of nutrient (focussing on nitrogen) from vegetable farms and to develop knowledge on nutrient dynamics and optimisation of inputs and the effective engagement with the community on issues associated with sensitive waterways and to provide tools that will assist growers in addressing these.

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Media Summary

This project aimed to develop processes that enable vegetable farmers to address environmental concerns, with respect to sensitive waterways, at a farm and community level. This has been achieved by identifying nutrient [nitrogen (N)] losses, validating nutrient application practices and developing tools to better manage nutrient application in vegetables and processes to engage with communities on issues associated with waterways. The activities were focussed in several vegetable growing regions that impact on sensitive waterways including Watsons Creek (Victoria), Lockyer Valley (Queensland) and Bowen (Queensland).

The project developed a process for engaging with the community on issues associated with waterway management. This included the identification of key collaborators, conducting surveys to identify community perceptions of the main contributors to waterway pollution and a method to resolve these issues.

This was further underpinned by survey data, replicated research trials and vegetable grower case studies over three seasons. Nutrient budget surveys conducted in the Lockyer Valley highlighted growers there apply fertiliser at rates at or below crop total nutrient uptake meaning losses of N to the environment are low. For example in lettuce, N application was the same as removal in harvested products but for some brassica crops, application was below crop removal.

Further case studies were conducted in the key regions and this shows some variability in the extent to which nutrients are lost from the farming systems. A series of research trials were conducted that validated crop nutrient requirements for the key crops broccoli, cabbage, cauliflower and celery were greater than the standard grower application rates in the Lockyer Valley. However, for lettuce (Cos and Iceberg) the critical rate for lettuce growth was equivalent to the standard grower practice. Nutrient budgets at Watsons Creek highlighted that use of chicken manure can lead to over-application of N.

The project has developed several key publications and tools including

- A good agricultural practice guideline for vegetable farmers that farm in sensitive waterways
- The vegetable nutrient removal calculator (“Nutricalc”)
- Fact sheet - Fertiliser use efficiency - Matching fertiliser inputs to vegetable crop removal
- Fact Sheet - Optimising nitrogen fertiliser use efficiency in vegetables
- SafeGauge for nutrient management

Technical Summary

Agriculture is under increasing pressure to demonstrate that its practices do not present a major pollution risk to the environment. This is particularly the case for vegetable industries that are often located on or near sensitive waterways. The industry needs to demonstrate that it actively implements improved production practices to safeguard the environment particularly for the highly mobile nutrient nitrogen (N).

This project addressed the issue of nutrient management in vegetable production in a holistic manner by:-

- Surveying community attitudes and developing a method for effectively engaging with communities
- Reviewing nutrient use efficiency data for key vegetables
- Assessing the opportunities for optimising nutrient application
- Conducting case studies to evaluate fertiliser efficiency and identify the extent to which nutrients are lost
- Developing science based knowledge and tools to underpin crop nutrient management strategies in vegetable production

The project operated in several key production areas including the Bowen/Burdekin and Lockyer Valley regions (Queensland) and Watsons Creek (Victoria) each of which are identified as impacting on waterways.

The project developed and evaluated a process on how to work with the community and to gain an insight of community understanding of issues related to sensitive waterways. Community attitude surveys about waterway pollution were conducted in each region as well as the Bundaberg region in Queensland. None of the regions surveyed identified agriculture (vegetable production) as the primary factor in impacting on waterway health though in Watsons Creek it rated more highly than in the Queensland surveys; the latter essentially did not identify vegetable production as a main contributor. In Watsons Creek a manual was developed by the Mornington Peninsula and Western Port Biosphere Reserve Foundation Ltd that provides a process for community engagement on issues of sensitive waterways that is suitable for vegetable growers all over Australia. Furthermore, the project has prepared a tailored good agricultural practice guide for vegetable farming near sensitive waterways and has assembled a detailed suite of reference information on vegetable crop nutrient requirements.

Partial nutrient budget surveys were conducted at several sites to identify total crop nutrient uptake, nutrient removed in harvested product which was matched with applied nutrient. Extensive partial nutrient budget surveying was conducted in the Lockyer Valley, and a suite of budgets was developed for a large range of vegetable crops. These data essentially showed that for lettuce crops Lockyer Valley farmers closely match N application with that removed in harvested product; application was less than whole crop requirement. However, for the other crops (brassicas, celery and carrots) applied N tended to be less than total crop uptake. The survey and case studies with key grower collaborators essentially showed that Lockyer

Valley vegetable farmers apply N at rates that would be considered marginal for optimal crop growth. This was particularly the case for cabbage and cauliflower where total crop N uptake was in the order of about 350 kg N ha^{-1} but application was only about 100-120 kg N ha^{-1}. Further case studies of crop nutrient dynamics with two growers over 3 years confirmed negative nutrient budgets over a range of vegetables and showed that soil nitrate reserves to 1.0 m were strongly depleted.

In contrast, the study on lettuce in Watsons Creek found that excessive nutrient was applied to the soil before planting and there was scope to reduce the amount of fertiliser used. Subsequent to this survey, a grower substantially reduced the rate of manure input, which had greatly contributed to nutrient loading. Nutrients were measured in stream water samples from Watsons Creek (Victoria) in proximity to this vegetable grower but it was difficult to draw conclusions since the sample variability was high. The variability related to dynamic changes in nutrient levels depended on stream flow, which varied with wet and dry weather cycles.

A series of research station trials evaluated N effects on vegetables including;

- Effect of rate of application from 0-280 kg N ha^{-1} on lettuce (Cos and iceberg), celery, broccoli, cabbage and cauliflower;
- Timing of fertiliser application and formulation effects on vegetables;
- Effect of density and N rate on broccoli production.

The data developed confirmed the nutrient budget survey findings that for the Lockyer Valley region the standard application rate of N across six key vegetable crops was below the optimal rate. This positive result indicates that the region carefully manages N and the systems are unlikely to lose N. However, at these standard application rates, N supply is marginal for crop growth and crop productivity could be reduced. Evidence of crop growth response to increasing N rate highlights this effect. Application of 200-300 kg N ha^{-1} combined with plant densities higher than industry practice (about 60-80,000 plants ha^{-1}) gave high crop yield in broccoli.

For some crops the amount of N removed in harvested product is low in relation to applied N. These crops have a low harvest index where only 25-30% of the crop biomass is harvested (eg. sweetcorn, broccoli) and considerable amounts of nutrient are returned back to the soil as crop residues which is available for the subsequent crops. Hence the use of soil mineral nitrate in the pre-plant phase for the subsequent crop would be useful in developing a full nutrient management budget. This highlights that a whole of cropping approach is required to ensure N continues to be supplied at appropriate rates that take into consideration N extraction by various crops within the rotation. Vegetable crops may require extra N when grown after crops where extraction of N is high with low fertiliser input (e.g., low input grain crops). In contrast, where the N return rate in residues is high, such as in broccoli, the N inputs in a subsequent crop may be reduced depending on that crop’s demand.

The project has developed a range of tools and publications that can be used by vegetable growers to improve nutrient management and community engagement on issues associated with sensitive waterways.

1. Introduction

The Australian vegetable industry is coming under increasing pressure to demonstrate that its production systems do not present a major pollution risk to the environment and where a risk is seen to exist, to demonstrate that they are actively implementing improved production practices to safeguard the environment. Of particular concern is the potential for off-site movement of nutrients, particularly nitrogen (N) into 'sensitive waterways'. In Queensland this includes the catchments draining into the Great Barrier Reef (GBR) Marine Park (Bowen/Burdekin), the RAMSAR-listed Moreton Bay (Lockyer and Fassifern Valleys); and in Victoria, the Yaringa Marine National Park (Watsons Ck). Melbourne Water has identified vegetable growers at Watsons Creek as significant contributors to water quality and in South East Queensland the Lockyer Valley is also identified by SEQ Water as a major contributor to poor water quality. In Queensland, legislation was enacted to ensure that graziers and cane producers in coastal catchments associated with the GBR lagoon are having minimal environmental impact on the GBR. Hence the issue of GBR water quality is a key political concern and in Queensland about 60% of vegetable production is in the catchments that drain to the GBR and about 30-35% is in the catchments draining to Moreton Bay.

Protection of the environment and farm profitability are not mutually exclusive as research and technology for improving productivity in many cases also address environmental issues. For example, improving nutrient management and monitoring reduces input costs and off-site movement of nutrients. Similarly, limited availability of water in many vegetable production regions of Australia has led to improvements in water use efficiency through water scheduling and improved irrigation and fertigation systems.

There are however major challenges to growing quality vegetables in Australia. These include high summer rainfalls on fallowed land in the north as well as extended droughts alternating with flood events, salinisation of the soil profile due to water quality and quantity issues, and low soil organic carbon levels impacting on nutrient cycling, water-holding capacity and erodibility of the soil. Furthermore, horticultural production operates mostly in peri-urban regions where their potential environmental impact evokes extra sensitivity, and practices may be closely scrutinized by the community that shares the land and water resource.

Recommendations for fertilizer use in vegetable crops have largely been based on empirical data built up over decades, and some limited evidence suggests that fertiliser use efficiency can be improved. Several recent studies also indicate that nutrients applied to vegetables may exceed crop requirements (Chan *et al.* 2007, Stork *et al.* 2003), and that nutrient levels in soils under vegetable production can be relatively high (Harper and Menzies 2006). Water quality monitoring of flood events of rivers and creeks draining into the Great Barrier Reef Marine Park also show elevated levels of P and N for catchments with intensive agricultural cropping (sugar cane and horticulture) (Bainbridge *et al.* 2007). Similarly, the intensive agricultural production region of the Lockyer Valley has been identified as delivering substantial nutrient and sediment to Moreton Bay during sporadic intense flood events

(Moreton Bay Partnership 2006). Data from Harper (2009) show that soil nitrate levels in the Lockyer Valley are historically high at 25 mg kg^{-1} averaged across 750 samples over a 12 year period. A study by Basakran *et al.* (2001) found incidence of elevated nutrients in some samples analysed as part of a systematic assessment of the groundwater quality of Bowen aquifers. Similarly, elevated groundwater nitrate levels have been identified in association with intensively managed vegetable production systems in the Lockyer Valley (Wills *et al.* 1996). In Victoria, a recent survey of manure usage has shown that growers are not using scientific approaches to manure application, and usage rates per hectare vary by as much as 100% (Premier *et al.* 2004).

There is an urgent need to develop science-based data and tools to enable the vegetable industry to objectively assess and facilitate improvements in soil and nutrient management on a soil, site and crop-specific basis. Furthermore, vegetable growers as an industry must be able to substantiate that they follow responsible and sustainable management practices that minimize their impact on the environment.

To address these issues the vegetable industry in 2008 made a general call for project submissions to address the issue of environmental effects of vegetable production on 'sensitive' waterways. Three project applications were received from teams and the Vegetable Industry Advisory Committee organized a meeting in Brisbane from which a consortium of two teams [Queensland (Burdekin Burnett and Lockyer Valley regions) and Watsons Creek, Victoria] developed the final joint project.

For the vegetable industry this project addresses the issue of nutrient management in a holistic manner by evaluating and developing strategies to minimise nutrient losses from the paddock in the first instance, reviewing the current status of nutrient use efficiency in vegetable production, assessing the opportunities for optimising nutrient application, and delivering tools that growers can use to achieve this. Finally, the project develops a method for effectively engaging with communities to demonstrate the vegetable industry's capacity to effectively manage fertilisers and mitigate off site losses.

2. Literature review of nitrogen management in lettuce, broccoli, cabbage, cauliflower and capsicum.

2.1. Introduction

Worldwide, the use of nitrogen (N) fertilisers is under increased scrutiny (Breschini and Hartz 2002; AbuRayyan 2004). Vegetable crops are intensively produced and in conventional production systems require considerable inputs of fertiliser N. Nitrogen that is not converted into crop biomass is at risk of contaminating the environment (Broadley *et al.* 2003). The perception that high nitrate-containing crops, in particular lettuce and spinach, may be detrimental to human health (Reinink 1992) has led to the definition of maximum allowable nitrate levels by the Commission of European Communities (Broadley *et al.* 2003). In evaluating fertiliser responses by broccoli, increasing the price of N fertiliser largely does not affect the economics of N application to the crop (Bakker *et al.* 2009a). In support of this, the cost of N fertiliser in lettuce production at an application rate of 140 kg ha^{-1} represents less than 1% of total cost and though important, is small relative to other costs (Harper unpublished). Hence the drivers for adoption of improved nutrient management do not generally relate to cost of fertiliser product but rather environmental and human health factors.

Many strategies are available to more efficiently manage fertiliser inputs into vegetable crops including improved genetics of uptake (Reinink 1992), varietal selection for N use efficiency (Rather *et al.* 1999), understanding crop N uptake profiles (Sullivan *et al.* 1999), and use of diagnostics such as soil and tissue nitrate and total N (Huett and White 1992; Everaarts and DeMoel 1995; Breschini and Hartz 2002). Furthermore, other crop agronomic factors such as crop harvest index, irrigation, form of fertiliser, and plant density also affect nutrient use efficiency (Sanchez *et al.* 1994; Abu-Rayyan *et al.* 2004; Erley *et al.* 2010).

This literature review identifies nutrient removal rates for the key vegetable crops of lettuce, brassicas (cabbage, cauliflower and broccoli) and capsicum, strategies to better manage nutrient inputs, and issues associated with nutrient management in these crops.

2.2. Lettuce

2.2.1. Lettuce growth

The N requirements of lettuce plants correlate well with plant relative growth rate; the amount of dry matter produced per existing unit of DM over time (Broadley *et al.* 2003). Dry matter accumulation and N uptake are intrinsically linked, hence growth and N uptake over time show a similar response. This is illustrated in figure 2.1 (from Sullivan *et al.* 1999) for broccoli which shows the same response for both N uptake and dry matter accumulation over time. Nitrogen uptake can essentially be broken into 3 different stages over time: an initial slow uptake at crop establishment, a second linear uptake stage and a final low uptake phase as the crop approaches full maturity. Many of our vegetables are harvested at varying stages of maturity (Figure 2.2) and lettuce is essentially harvested at the end of the second rapid linear N uptake phase. Hence N uptake continues throughout the development of a lettuce crop.

Some published yield data for lettuce are presented in table 2.1. The maximum photosynthetic rate for lettuce occurs at a leaf N concentration of 3.6% and net photosynthetic rate ceases at an N concentration below 2% (Broadly *et al.* 2001). The partitioning of N to various plant parts also depends on N supply. Under low N supply, lettuce root systems contained about 13.6% of the plants N, but at a luxury N supply the root system contained a lower proportion of N (about 4-5.5%) (Holness *et al.* 2008). Soundy *et al.* (2005) evaluated effects of N supply on leaf N content and root to shoot ratios in Iceberg lettuce (cv. South Bay) seedlings. At 28 days after sowing the root to shoot ratio decreased from about 1 at 0 mg N L^{-1} to about 0.1 to 0.2 at 120 mg N L^{-1}. Excessive N application favoured shoot development at the expense of root system development.

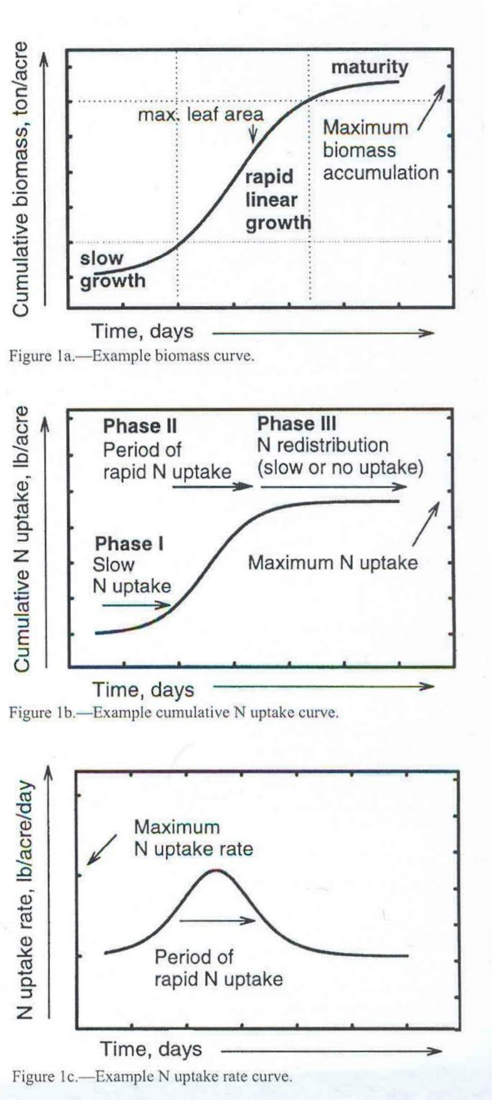

Figure 2.1 Typical plant cumulative biomass and N uptake over time and rate of N uptake. (from Sullivan *et al.* 1999).

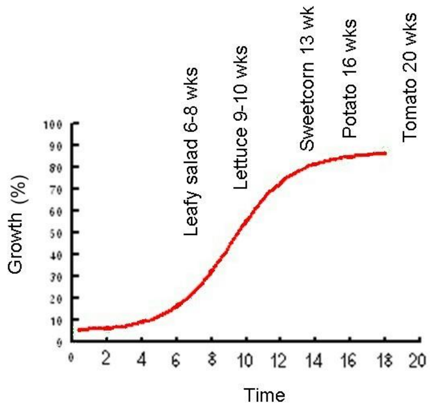

Figure 2.2 Typical vegetable crop growth responses and maturity.

In support of this Broadley *et al.* (2003) grew lettuce plants (Lactuca sativa var. capitata cv Kennedy) hydroponically up to 74 days under treatments where N was supplied throughout (control) or N was removed at 35 days or 54 days. Shoot fresh and dry weights were substantially reduced when N was withheld at 35 and 54 days highlighting the direct relationship between N and lettuce growth.

Table 2.1 Lettuce crop fresh yields obtained from the literature.

Crop and Variety	Yield (t ha^{-1})	Reference	Comments
Lettuce – Romaine cv. Lital	61-66	(Bozkurt *et al.* 2009)	Irrigation optimal
Lettuce (Various types)	33.5-46.9	Breschini and Hartz 2002)	Sampling from 15 farms 56-72,000 plants per ha
Lettuce (not specified)	24-38	(Thorup-Kristensen 2006)	Marketable product yield
Lettuce - Butterhead	13.8	(Simonne *et al.* 2001)	
Lettuce - Romaine	17.0	(Simonne *et al.* 2001)	
Lettuce - Looseleaf	18.6	(Simonne *et al.* 2001)	
Lettuce Iceberg cv. Salinas	93-100	McPharlin *et al.* 1995	

2.2.2. Effects on Dry Matter

Broadley *et al.* (2003) evaluated shoot relative growth rate and shoot total N and nitrate concentration in hydroponically grown Butterhead lettuce (Lactuca sativa capitata cv Kennedy). The withdrawal of N increased the ratio of DM to fresh matter (DM% increased). The dry matter content in the control lettuce at maturity was about 4%, with removal at 35 days about 8%, and in the 54 day removal treatment about 16%. Total carbon content as a percentage of dry matter was similar in the Control and 35 day (40%) treatments but was slightly higher in 54 days at about 42% (Broadley *et al.* 2003). They found that shoot fresh and dry weights increased as a function of cumulative effective day-degrees but the rate of increase declined in plants where N was removed early. The leaf weight ratio increased in control plants over time but decreased in treatments where N supply was restricted. Similarly, the shoot to root ratio decreased in treatments where N supply was restricted. In contrast, Gunes *et al.* (1994) reported a narrow range of dry matter concentrations (DM%) in two lettuce cultivars, ranging from 2.77% -2.93% at 8 weeks. In most studies evaluating yield of lettuce, dry matter production is not reported.

2.2.3. N concentration

In the experiment of Broadley *et al.* (2003), the total N concentration in the control was between 4 and 5% over the duration of the experiment, whereas in the 35 and 54 day treatments total N was similar up to the point when N removal was imposed, but declined rapidly to less than 2% for the duration of the experiment. In all treatments, nitrate N decreased until midseason growth (from 2% to about 0.2% nitrate-N per unit dry weight) and then increased only in the control to a maximum of about 1.5 % nitrate-N per unit dry matter). The relationship between organic N or total N and growth rate was a better indicator for growth than was the nitrate relationship (Broadley *et al.* 2003).

Broadley *et al.* (2000) determined the N concentration in lettuce plants 62 days after planting was about 5.8% in well-supplied plants and only 2.2% in nitrogen-limited plants where N was withheld at 47 days after sowing. In contrast, Soundy *et al.* (2005) determined leaf tissue N concentration in 4 week old seedlings was relatively stable at about 2.4%.

2.2.4. Rates of application and responses

Worldwide, the identified optimal and recommended application rates for N in lettuce vary considerably (Walworth *et al.* 1992; Simonne *et al.* 2001). A wide range of N application rates is recorded in the literature (Table 2.2).

Walworth *et al.* (1992) determined that maximum lettuce (cv. Salinas) head weights were obtained at between 56 and 112 kg N ha^{-1}, plateaued at 112 kg N ha^{-1} and did not increase with further N rate increase to 280 kg N ha^{-1}. Optimising the N application rate reduced the time to maturity by about 1-2 days compared with other higher N treatments.

Stone (2000) evaluated the effects of 0, 30, 60, 120 and 180 kg N ha^{-1} on lettuce cv Saladin (an iceberg type) over two seasons. A treatment with N as 20 kg ha^{-1} liquid urea was also evaluated. The pre-plant soil nitrate N was equivalent to 67 kg ha^{-1} in 0-30 cm in year 1 and 41 kg ha^{-1} in year 2. Lettuce dry matter yield increased from 11.6 to 12.2 tonnes per ha from 0-30 kg N ha^{-1} but then declined linearly with an N rate increase to 180 kg N ha^{-1} (a yield of 9.5 tonne ha^{-1}). Lettuce total fresh yield increased linearly from 39 tonne ha^{-1} at 0 kg N ha^{-1} to a yield of 45 tonne ha^{-1} at 120 kg N ha^{-1}. In the subsequent year's trial, lettuce marketable yield (total yield not reported) increased linearly from 5 tonne ha^{-1} at 0 kg N ha^{-1} to 20 tonne ha^{-1} at 80 kg N ha^{-1}.

McPharlin *et al.* (1995) found maximum lettuce yields were 93-100 tonnes ha^{-1} at an N application rate of 288 and 344 kg N ha^{-1} in a trickle irrigated crop. In contrast, under broadcast N application and sprinkler irrigation, between 86 and 93 tonne ha^{-1} was recorded and required applications of 230 and 321 kg N ha^{-1}. These rates were about 30-60% of that recommended for coastal sands in Western Australia.

Table 2.2 Nitrogen application rates (kg ha^{-1}) for lettuce, obtained from literature.

Crop and Variety	N Rate (kg ha^{-1})	Reference	comments
Lettuce – Iceberg cv. Salinas	230-344	(McPharlin *et al.* 1995)	
Lettuce Iceberg cv Salinas	56-112	(Walworth *et al.* 1992)	
Lettuce - Butterhead Romaine and looseleaf	126	(Simonne *et al.* 2001)	
Lettuce - Romaine	224-370	(Thompson and Doerge 1995	
Lettuce – Romaine cv. Green Romaine	140	(Holness *et al.* 2008)	
Lettuce Iceberg cv Saladin	80-120	(Stone 2000)	(optimal rate trialled)
Lettuce – Various	178 - 380	Breschini and Hartz 2002	Survey of 15 grower across various cultivars

Thompson and Doerge (1995) showed that maximum marketable yield (60 tonne ha^{-1}) for romaine lettuce was obtained at an N rate of 200 kg ha^{-1}, but at this rate only 120 kg N ha^{-1} could be accounted for in lettuce biomass, giving a low N use efficiency of 60%.

The N uptake for above ground parts of romaine lettuce and iceberg lettuce were 107 kg N ha^{-1} and 130 kg N ha^{-1} respectively (Breschini and Hartz 2002). Ludwig (2001) cites N removal in lettuce at 0.24 kg N per 100 kg fresh weight. On a 50 tonne ha^{-1} crop, this gives an N removal in harvested product of about 120 kg N ha^{-1} and interestingly for potassium, the reported figure is 250 kg ha^{-1}.

2.2.5. N forms

Considerable research has evaluated the release rates of mineral N from cover crops including legumes and cereals and specifically in relation to lettuce nutrition (Wyland *et al.* 1995; Thorup-Kristensen 2006; Holness *et al.* 2008).

Holness *et al.* (2008) applied N at 26, 52 and 78 kg ha^{-1} as a rye and clover cover crop amendment combined with 70, 140 and 210 kg N ha^{-1} to lettuce as ammonium nitrate in a glasshouse pot study. The cover crop did not improve yield but contributed 15% of the crop's N requirement. Despite this, they showed that the rate of mineralisation of N from crop residues was not sufficient to meet the N requirements for high demand crops including lettuce and broccoli.

In contrast to this, Thorup-Kristensen (2006) found that legume cover crops accumulated between 100-135 kg N ha^{-1} which, after incorporation, resulted in a soil inorganic N concentration of 75-108 kg ha^{-1} to a depth of 50 cm. With this soil mineral N, all vegetable crops showed increased N uptake, and particularly in lettuce and cabbage, significantly higher yield was recorded. Their data showed that about 14-45% of the fixed N was released as mineral N from the green manures. The total N contained in the above ground plant product was 64-101 kg ha^{-1} for cabbage, 64-89 kg ha^{-1} for onion and 45-72 kg ha^{-1} for lettuce.

Wyland *et al.* (1995) evaluated the uptake of N from a cover-cropped field and found that only about 28% of the 15N, labelled in the cover crop, was recovered in the lettuce crop indicating mineralisation of organic matter did not sufficiently meet lettuce crop N requirements.

Research into the effects on lettuce growth of various mineral N fertiliser forms is limited. Stone (2000) found that lettuce yield under a 30 kg ha^{-1} N as urea-ammonium-nitrate treatment was the same as in a treatment with about 80 kg N ha^{-1} as broadcast ammonium nitrate. Shoot dry weight at 4 weeks was also significantly higher in the urea-ammonium-nitrate treatment, injected below the seedling at transplant at 30 kg N ha^{-1}, compared with a broadcast application of ammonium nitrate at 30 kg N ha^{-1}. The application of small rates of starter N fertiliser below the seedling increased N fertiliser recovery.

Abu-Rayyan *et al.* (2004) conducted a trial to evaluate the optimum planting density, N form and irrigation in lettuce, aiming to lower nitrate content and environmental impact. They evaluated three fertiliser forms: calcium nitrate, ammonium sulphate and urea, which were applied at 3 times to a rate of 100 kg N ha^{-1}. The highest dry matter yield was recorded with ammonium sulphate, then calcium nitrate, then urea (plant yields of 44, 36, 26 g $plant^{-1}$ respectively). However, the experiment was not balanced for sulphur and calcium inputs and part of this fertiliser form effect could have been attributed to a specific mineral nutrient response. The highest NUE was recorded for ammonium sulphate, perhaps suggesting there may have been a sulphur limitation.

Notwithstanding, the nitrate content varied with N fertiliser form. The highest nitrate N concentration was recorded with calcium nitrate (198.5 mg N kg^{-1} inner leaf and 710 outer leaf mg N kg^{-1}), then (ammonium sulphate 52 mg N kg^{-1} inner leaf and 417 outer leaf mg N kg^{-1}) and then urea (66 mg N kg^{-1} inner leaf and 519.5 outer leaf mg N kg^{-1}). In support of this, Gunes *et al.* (1994) compared the effect of different solution N constituency on nitrate content of nutrient film technique (NFT) grown lettuce. The use of a predominantly nitrate based solution (94%) resulted in much higher plant nitrate concentrations than did an ammonium-based solution (with 74% nitrate) or a proteinate-based solution (with 74% nitrate). Lettuce from the high nitrate treatment had 0.44% nitrate on a fresh weight basis whilst the other 2 treatments had 0.37% and 0.36% for the ammonium-N and proteinate-N treatments, respectively.

2.2.6. Lettuce nutritional diagnostics

Considerable research has been conducted to develop diagnostic criteria for lettuce nutrition and particularly N (eg. Huett and White 1992, Breschini and Hartz 2002, Broadley *et al.* 2003).

2.2.6.1. Soil nitrate

Breschini and Hartz (2002) developed soil mineral N diagnostic criteria for lettuce production in California. They conducted trials in 15 commercial fields in California to evaluate pre-sidedress soil nitrate as an index for N sidedress requirements for iceberg and romaine lettuce. Prior to sidedress, a composite soil sample to 30 cm was taken and nitrate-N determined. If the soil nitrate N was greater than 20 mg kg^{-1} no N was applied and if it was below this threshold, N was applied at an amount to increase it to 20 mg N kg^{-1}. Across the 15 cooperating growers, the averaged total rate of N application was 257 kg N ha^{-1} including 1-3 sidedressings of 194 kg ha^{-1}. Using the pre-sidedress soil nitrate criterion, total N application was reduced by 43% and the sidedressing by 57%. Importantly, total yield was unaffected and net N uptake was similar for the grower's standard practice and the criterion-based practice. At harvest, the pre-sidedress soil nitrate plots had on average 8 mg kg^{-1} less nitrate-N in the top 90 cm, indicating much lower N leaching risk. Despite the large difference in fertiliser application (178-380 kg ha^{-1}), the nitrate in midrib did not vary considerably, averaging about 7.7 g NO_3^--N kg^{-1} (dry weight basis) and well above the sufficiency level of 6 g NO_3^--N kg^{-1} suggested by Lorenz and Tyler 1983. In 2 fields, midrib nitrate was well below this at 3.1 and 3.4 g NO_3^--N kg^{-1} but yield was not affected and total leaf N was above the sufficiency critical value of 3.0%. The use of midrib nitrate was not correlated with total N and total N in heads at harvest was above the sufficient level of 2.5% set by Lorenz and Tyler (1983).

2.2.6.2. Plant nitrate

Despite a large difference in fertiliser application (178-380 kg ha^{-1}) to lettuce across 15 sites, the nitrate in midrib did not vary considerably, averaging about 7.7 g NO_3^--N kg^{-1} (Breschini and Hartz 2002). This value was well above the sufficiency level of 6 g NO_3^--N kg^{-1} suggested as a critical value by Lorenz and Tyler (1983). In support of this sufficiency level, Fontes *et al.* (1997) found that maximum plant dry weight was determined at leaf nitrate concentration of 6.0 g NO_3^--N kg^{-1} (dry weight basis). However Breschini and Hartz (2002) found that the midrib nitrate was well below this critical value at 3.1 and 3.4 NO_3^--N kg^{-1} but yield was not affected. The use of midrib nitrate was not correlated with total N and was not a reliable diagnostic tool for lettuce N status.

Stone (2000) showed lettuce nitrate-N increased linearly from about 0.5 NO_3^--N kg^{-1} (dry matter basis) to about 5 NO_3^--N kg^{-1} with increasing N applications from 0 up to 240 kg N ha^{-1}, irrespective of the form in which N was applied. Though other research shows that nitrate N concentration varies considerably with form of N applied (Gunes *et al.* 1994), Abu-Rayyan *et al.* (2004) showed that nitrate-N concentration varied considerably with form of applied N fertiliser and the maturity of leaf. The total leaf N concentration (on a dry matter basis) is a far more reliable diagnostic tool for N sufficiency in lettuce (Breschini and Hartz 2002).

2.2.6.3. Total plant N

Concentrations for total N in lettuce obtained from the literature are presented in Table 2.3. Gunes *et al.* (1994) reported total N concentration in two Romaine lettuce cvs at 8 weeks varied from 6.07-6.46%.

Holness *et al.* (2008) found the total N concentration in lettuce shoots was 1.4%, 2.1%, 3.1% and 3.5% at application rates of in 0, 70, 140 and 210 kg N ha^{-1} giving an optimal N value in the order of 2.6%. The reported lettuce total N concentrations also vary considerably with plant age (Table 2.4, Huett and White 1992). Since the volume of non-photosynthetic biomass of plant tissue increases proportionally over time the relative plant growth and plant N concentration effectively decrease over time since the non-photosynthetic tissue contains less N (Broadley *et al.* 2003). Consistent with this, the heart tissue of lettuce contains less N than does the outer leaf tissue.

Table 2.3 Nitrogen concentrations in dry lettuce tissue (%) obtained from literature.

Crop and Variety	N Concentration (%)	Comments	Reference
Lettuce Butter head Berlo Kirsten	 6.26-6.46 6.07-6.35	Adequacy range	Gunes *et al.* 1994.
Lettuce – Iceberg cv. Salinas	4.7%-5.2%.	Adequacy range	McPharlin *et al.* 1995)
Lettuce – Romaine cv. Green Romain	1.4% - 3.5%	0 kg -210 kg ha^{-1} applied N	Holness *et al.* 2008
Lettuce cv. Brasil 202	4.27% 3.75	8 th leaf stage Maturity	Fontes *et al.* 1997
	3.1-3.5	Adequacy range	Piggott 1986
Lettuce - Various	4.3-4.4	Adequacy range	Breschini and Hartz 2002

Huett and White (1992) conducted a comprehensive study of N nutrition in lettuce and evaluated the effects of a range of N solution concentrations (30-500 mg N L^{-1}) in potted sand culture. The data from this study are presented in Table 2.4. Petiole sap N concentration increased over the 8 week growing period and the critical sap nitrate value in the youngest fully expanded leaf was about 1.0 g nitrate-N L^{-1} at 4-5 weeks. In the deficient plants it was about 0.5 g L^{-1}. Nitrogen at the highest rate resulted in greatly increased nitrate N (2.4 g L^{-1}) compared with about 1.2 g L^{-1} in the optimal N treatment. Plant total N increased with increasing N rate but decreased in all index leaves over time. The critical total N concentration was about 5% at 3 weeks, 4.8% at 4 weeks and 4.4% at 5 weeks. In contrast in deficient plants total N declined from 4% at 3 weeks to about 3% at 5 weeks. In marginally supplied plants total N concentration was 4.5% at 3 weeks and about 3.7% at 5 weeks. In bulked samples the total N in adequately supplied plants was greater than 4% at 3 weeks and 3.3% at 5 weeks. The results indicated that critical total N values could be used to differentiate between deficient and adequately N-supplied lettuce but total N could not differentiate toxicity from adequacy.

Piggott (1986) reported 3.1-3.5% as critical total N values for lettuce. The concentration of N in leaves increased up to the highest N treatment even though plant dry weight concentration declined at an N rate greater than 380 kg ha^{-1} indicating that as N is increased, leaf concentration increases despite declining dry matter, thus indicating luxury uptake of N at excessive application.

Table 2.4 Lettuce leaf tissue N concentrations critical for growth at 90% maximum yield at 1 and 2 weekly intervals after transplanting. YFOL, youngest fully opened leaf; YFEL, youngest fully expanded leaf; OL, oldest green leaf [from Huett and White (1992)].

Plant part	Weeks after transplanting					
	1	2	3	5	7	8
Nitrate-N concentration in petiole sap (g/L)						
YFOL	0.50	0.30	0.43	0.57	0.87	0.97
YFEL	0.50	0.30	0.50	0.80	0.95	0.90
OL	0.40	0.70	1.60	1.20	0.90	1.00
Total N concentration in leaves (%)						
YFOL	5.03	5.45	5.60	4.25	3.90	3.83
YFEL	5.03	5.30	4.90	4.25	4.05	4.00
OL	4.15	3.90	3.30	3.00	3.18	3.23
Bulked leaf	3.9	4.38	3.33	4.15	3.65	3.78

The total N content in lettuce varies depending on the source and rate. At harvest, the total N content in lettuce was about 1.19% for calcium nitrate, 1.47% for ammonium sulphate and 1.14% for urea whilst in a nil applied N treatment, the N content was only 0.47% (Abu-Rayyan *et al.* 2004).

2.2.7. Strategies for reducing N application in lettuce

N efficiency can be achieved by growing N efficient genotypes and optimising N supply to meet crop requirements. Genetic variability has been demonstrated for N uptake in lettuce germplasm (Reinink 1992). Breschini and Hartz, (2002) evaluated the use of pre-sidedress soil nitrate testing as a basis for N application and showed that, using the criteria, nitrogen accumulation in total above ground biomass was 5-6 kg ha^{-1} higher and total N application 110 kg N ha^{-1} less than that in the growers standard fertiliser practice.

Thorup-Kristensen (2006) evaluated the rooting depth of 4 vegetables in an organic production system. The rooting depths of key vegetables were: lettuce (0.6 m), onion and carrot (0.3 m) and cabbage 1.1 m. They suggested that NUE could be improved by matching crop root system development to soil N to depth. Using a mini-rhizotron and mini video camera they determined that the rate of root development was fastest for cabbage and lettuce (1.19 and 1.25 mm day $^{o}C^{-1}$) compared with onion and carrot. This, combined with root system development, could be used to tailor vegetable production to optimise N recovery.

2.2.8. Lettuce quality and N

There is an understanding that over-application of N reduces quality in lettuce (Cuppett *et al.* 1999; AbuRayyan 2004; Bozkurt *et al.* 2009). Bozkurt *et al.* (2009) identified that N applied as ammonium sulphate increased lettuce core diameter, root wet weight and head tightness compared with N as ammonium nitrate. Increasing N application in hydroponic lettuce gave greener and softer, less crispy lettuce (Cuppett *et al.* 1999), but had no significant effect on flavour and bitterness. From a health perspective, the form and rate of N fertiliser alters the amount of nitrate in the harvested products. Nitrate-based fertilisers tend to result in higher nitrate levels than alternative, mostly ammonium-based forms (AbuRayyan 2004). Breschini and Hartz (2002) found that lettuce storage quality, visual quality, decay and discolouration were not affected by N rate.

2.3. Brassicas

2.3.1. Brassica growth

Both the growth and N uptake of brassicas follow a typical sigmoidal response (Sanchez *et al.* 1994). Broccoli head yield increases curvilinearly with increasing N rate to a maximum of about 400 kg ha^{-1} (Toivonen *et al.* 1994). Similarly, a quadratic relationship between N rate and DM yield was shown where dry matter production levelled off with increasing N rate (Everaarts and Booij 2000).

However, despite this response, net dry matter production is more greatly affected by seasonal variability in growing conditions. For example, Erdem *et al.* (2010) showed that broccoli cv Jade yield was considerably higher in a spring crop (11.02 t ha^{-1}) compared with an autumn crop (4.55 t ha^{-1}) at the same rates of N application. The net accumulation of dry matter also varies considerably within a season and across N treatments. Within season N accumulation in broccoli cvs Decatholon and Captain varied considerably from 1-16 kg N ha^{-1} d^{-1} (Bakker *et al.* 2009b). Despite there being these levels of variability, there was no effect of N on crop maturity in brassicas (broccoli) (Zebarth *et al.* 1995). Similarly, cauliflower curd maturity across cvs was not affected by N application rate but average curd weight was (Rather *et al.* 1999).

2.3.2. Effects of N on Brassica yield and dry matter

Within the literature, the effect of N on yield of broccoli, cabbage and cauliflower is substantial (Toivonen *et al.* 1994; Csizinszky 1996; Batal *et al.* 1997; Everaarts and De Moel 1998; Bowen *et al.* 1999; Alt *et al.* 2000; Everaarts and Booij 2000; Vagen *et al.* 2004; Yoldas *et al.* 2008; Erley *et al.* 2010). Data taken from the literature for broccoli, cabbage and cauliflower, including rate of N application, fresh and dry matter yield, dry matter content (DM%), N concentration (N%), Crop N uptake (kg ha^{-1}), references, cultivars and plant parts are presented in Tables 2.7, 2.8 and 2.9.

In two seasons, dry matter yield of cauliflower cv. Fremont was 2.50 and 2.80 tonne ha^{-1} in a 0 N treatment but increased substantially in the higher N treatment (450 kg ha^{-1}) where the dry matter yield was 7.0 and 4.0 tonne ha^{-1} (Alt *et al.* 2000).

The effect of N on brassica tissue dry matter is less well defined and is not only influenced by N rate but also seasonal variability (Erdem *et al.* 2010; Erley *et al.* 2010). The head DM% in white cabbage also varies considerably; across the same treatments the averaged DM% was 6.26 and 7.25 in 2 separate seasons (Erley *et al.* 2010). Brassica (white cabbage) DM content varied considerably across late maturing varieties (6.9% to 9.17%) under high N application (Erley *et al.* 2010). In general, most literature indicates that brassica DM% decreases with increasing N application (Csizinszky 1996; Everaarts and de Willigen 1999). In a series of experiments, head dry matter content (Broccoli cv Emperor) was consistently highest in the 0N treatments (10.4-12.2%) compared with that at N rates of 212-372 kg ha^{-1} where the DM% was 8.6-10.7% (Everaarts and de Willigen 1999). The effect of increasing N rate on reducing DM% was consistent across all plant parts (curd, leaf and stem) in broccoli (Csizinszky 1996). Furthermore, brassica dry matter content decreased linearly with tissue N concentration (Everaarts and Booij 2000). In contrast to other studies, McKeown *et al.* (2010) found cabbage DM% increased with increasing N rate to 400 kg ha^{-1} but the data were not specified.

2.3.3. N forms and methods of application

The form of applied N also affects the N concentration of brassica plant tissue (Liu and Shelp 1993; Atanasova 2008). Varying nitrate to ammonium concentrations resulted in considerable differences in N concentration in broccoli (Liu and Shelp 1993). Furthermore, broccoli plants fed solely with ammonium were stunted and maximum biomass yield was recorded at a nitrate to ammonium ratio of 75-25 (Liu and Shelp 1993). Across treatments, the total N% in mature leaves decreased with increasing nitrate from 7.55 to 3.0%, in young leaves it declined from 7.2 to 5.5% and in the florets it decreased from 7.0% to 6.0%.

Atanasova (2008) compared the effects of two N fertilisers (calcium nitrate and ammonium nitrate) on N concentration in white cabbage cv Balken. Under both forms of N, N concentration increased with increasing rate. However, under the highest N treatment (1000 kg N ha^{-1}) the N concentration in the calcium nitrate treatment (3.96%) was considerably higher than that in the ammonium nitrate treatment (3.0%), which was in contrast to the results for Broccoli of Liu and Shelp (1993).

Irrigation water can contain considerable amounts of nitrate-N and Bakker *et al.* (2009b) reported 27 kg ha^{-1} N was contained in irrigation water.

Various research projects have evaluated effects of split application, banded and broadcast N fertiliser application in brassica crops (Everaarts and DeMoel 1995; Everaarts *et al.* 1996; Everaarts and de Willigen 1999; Everaarts and Booij 2000). Across many trials no consistent benefit in fertiliser efficiency was determined between banded and broadcast application and N uptake across treatments was similar. Furthermore, split application also did not infer increased yield or fertiliser use efficiency (Everaarts and de Willigen 1999).

Holness *et al.* (2008) evaluated the role of cover-crops in supplementing broccoli N requirement. They applied N at 26, 52 and 78 kg ha^{-1} as rye and clover cover crop in pots with additional treatments of 112, 224 and 336 kg N as ammonium nitrate. The cover-crop did not improve yield and contributed only 17% N for broccoli. They concluded that the rate of mineralisation of N from crop residues was not sufficient to meet the N requirements for broccoli- a high demand crop.

2.3.4. Rates of application and responses

The recommended N rate for broccoli in Ontario, USA is 130 kg N ha^{-1} (Bakker *et al.*

2009b). The recommended rate of N application for cauliflower in the Netherlands is 225 kg N minus the residual soil nitrate to 60 cm (Everaarts 2000). Despite this, within the literature, broccoli biomass production increases to N rates in the order of 300-400 kg ha^{-1}(Toivonen *et al.* 1994; Zebarth *et al.* 1995; Bakker *et al.* 2009a).

Over 3 separate experiments, broccoli (cv Emperor) head weight increased with increasing N rate generally to about 375 kg ha^{-1} (Toivonen *et al.* 1994). Bakker *et al.* (2009a) evaluated the effects of N at 0, 50, 100, 150, 200, 300, 400 kg ha^{-1} on marketable yield of broccoli cv Decatholon and Captain across 2 years. Yield was about 6 t ha^{-1} in the 0 kg ha^{-1} treatment and increased with increasing N to about 14-16 t ha^{-1} at about 200 kg ha^{-1}. They determined that the most economic rates were about 298-309 kg ha^{-1}. Maximum yield of broccoli cv Emperor across three seasons was at 375 kg N ha^{-1} and ranged from 13-19 t ha^{-1} fresh weight (Zebarth *et al.* 1995). Total number of broccoli heads harvested was not affected by N application up to 196 kg ha^{-1} but average head weight increased with increasing N (Everaarts 1994).

Visual symptoms of N deficiency in cabbage were observed at N rates below 300 kg ha^{-1} (Zebarth *et al.* 1991). Above ground DM yield in white cabbage cv Heckla at final harvest varied from 11.0-14.6 t ha^{-1} and increased progressively across N treatments of 0-250 kg N ha^{-1} and N uptake by the whole plant ranged from 165-296 kg ha^{-1} in the 250 kg ha^{-1} treatment (Ekbladh *et al.* 2007). Total plant N uptake was 270 kg ha^{-1} in the 250 ha^{-1} N treat and 140 kg ha^{-1} N in the 0 ha^{-1} N treatment. McKeown *et al.* (2010) evaluated the effects of N at 0, 59, 200, 341 and 400 kg ha^{-1} on Brassica oleracea capitata cv. Huran and found marketable yield increased with increasing rate of N application with maximum yield recorded at 333 kg ha^{-1} N (based on regression analysis). Yield in the 0 kg ha^{-1} N treatment was 30 t ha^{-1} and 100 t ha^{-1} at 400 kg ha^{-1}.

2.3.5. Brassica Diagnostics

2.3.5.1. Soil nitrate

Soil nitrate is a useful tool in evaluating brassica crop N requirements (Everaarts and DeMoel 1995; Alt *et al.* 2000). Good correlation between yield and N availability (mineral N in the 0-60 cm at planting) was determined in Dutch cauliflower production (Everaarts and DeMoel 1995). On this basis the optimum application rate is recommended as 225 kg ha^{-1} N less the mineral N content in the 0-60 cm soil zone. This highlights the significance of pre-plant mineral N soil test values as a tool for optimising N application rates. However, the estimated crop requirement rate of 225 kg ha^{-1} is on the low end of literature data on brassica crop N requirement (Tables 2.7, 2.8 and 2.9). However, the within season mineralisation of N may contribute substantial amounts of N depending on soil temperature and the size of the soil organic matter pool. In support of this, Bakker *et al.* (2009b) found that during the season N supplied from soil to a broccoli crop was estimated to be in the order of about 130 kg N ha^{-1}.

Despite the increase in yield associated with higher rates of N fertiliser, soil mineral N at harvest is also higher under high fertiliser N application (Everaarts and Booij 2000; Bakker *et al.* 2009b). In the study of Bakker *et al.* (2009b) the increase of nitrate N was most evident in the 0-30 cm soil zone.

The N recovery from soil by brassica crops is very high (Erley *et al.* 2010) and total residual nitrate content was about 40 kg ha^{-1} at 0-90 cm after harvesting a cabbage crop. The majority of N in Ccauliflower is taken up from the 0-30 cm soil zone (Everaarts 2000).

2.3.5.2. Plant nitrate

The application of N fertiliser increases brassica tissue (leaf and curd) nitrate-N concentrations (Zebarth *et al.* 1995; Alt *et al.* 2000; Belec *et al.* 2001; Šturm *et al.* 2010).

With the application of 200 kg ha^{-1} N, nitrate concentration of cabbage (Šturm *et al.* 2010) increased substantially and the concentration of nitrate in leaves of cabbage varied considerably depending on the position of leaf (inner , middle and outer) (Table 2.5). In unfertilised plants, the nitrate concentration between leaf parts was not significantly different and was lower than in fertilised treatments. In the treatments that received fertiliser, outer leaves had considerably higher nitrate concentrations than the middle and inner leaves; the latter which had the lowest concentrations. In contrast to this finding, cabbage head nitrate N was close to 0 mg kg^{-1} up to 200 kg ha^{-1} applied N and from this rate increased linearly to 83 and 41 mg kg^{-1} nitrate-N FW at 500 kg ha^{-1} applied N in 1987 and 1988 (Zebarth *et al.* 1991). Even at the considerably higher N rate in the study of Zebarth, the nitrate concentrations were considerably lower than that recorded by Šturm *et al.* (2010) in their 0 kg ha^{-1} N treatment, highlighting considerable variability in nitrate concentrations.

Table 2.5 Nitrate content in different leaves of cabbage at final harvest from Šturm *et al.* (2010).

Nitrogen rate (kg N ha^{-1})	NO_3^- (mg kg^{-1} Fresh Weight)[a]		
	inner	middle	outer
0	344	228	324
200	544-775	753-1305	1,222-1,686

[a] For conversion to nitrate-N multiply by 0.266

In a similar way, high variability in broccoli head nitrate concentration is recorded. The nitrate concentration in broccoli cv Emperor heads increased substantially with increasing N rate (Zebarth *et al.* 1995). Across 3 seasons the nitrate concentration in broccoli heads ranged from about 80 to 140 mg kg^{-1} FW at N application rates of 375-625 kg ha^{-1} (Zebarth *et al.* 1995). In the 0 N treatment the nitrate concentration varied from about 4 to 20 mg kg^{-1} fresh weight. Bakker *et al.* (2009a) found that broccoli head nitrate concentration increased linearly from 0-15 mg nitrate-N kg^{-1} (dry weight) in a 0 kg ha^{-1} N treatment to 463-1,539 mg nitrate-N kg^{-1} in a 400 kg N ha^{-1} treatment; however the values varied considerably across years. Allowing for an average of 11% dry matter content in broccoli curd (Harper unpublished) these values in equivalent fresh weight terms are approximately 0-1.6 mg nitrate-N kg^{-1} in the 0 kg ha^{-1} N treatment and 51-169 mg nitrate-N kg^{-1} in the 400 kg ha^{-1} treatment. High year-to-year variability in broccoli nitrate N was recorded, suggesting that environmental factors play a major role in accumulation of nitrate in plant tissue.

In support of this Belec *et al.* (2001) found that the nitrate concentration in broccoli plant tissue was consistently related to N rates but environmental factors precluded its use for developing an absolute threshold for nitrate sufficiency in the sap. In contrast to this finding and other findings on brassica total N concentration, Alt *et al.* (2000) found the leaf nitrate concentration increased with growth over time in cauliflower cv. Fremont whilst total N content declined.

2.3.5.3. Brassica tissue total N concentration

Irrespective of N treatment the N concentration of brassica plant tissue decreases from early growth through to maturity, but the decrease in N concentration tends to be greatest in treatments where no N is applied (Vagen *et al.* 2004; Ekbladh *et al.* 2007).

Within the literature, data on the N content of plant tissue varies considerably across deficient and adequate rates of application in brassicas (Tables 2.7, 2.8 and 2.9). Importantly, in various studies N concentrations that are deficient in some studies were shown as adequate in others. For example, Vagen *et al.* (2004) showed N concentration in broccoli at 240 kg N ha^{-1} was 3.0-5.0% whilst in an N deficient treatment (0 kg N ha^{-1} applied) Bowen *et al.* (1999) found similar plant tissue N concentrations which ranged from 3.16-4.55%. This highlights that considerable seasonal variability or genetic uptake differences more greatly influence brassica tissue N concentration than N application rate alone. Notwithstanding, Vagen *et al.* (2004) determined a critical N deficiency concentration for biomass yield of about 2% for broccoli.

The N content in the young leaf of cauliflower cv. Fremont (Alt *et al.* 2000) was 4.8% in a 0 N treatment and increased to 6.0% in the 150, 300 and 450 kg N ha^{-1} treatments. At 300 and 450 kg N ha^{-1}, leaf N content declined during growth and nitrate-N increased, but leaf N content remained the same in the 0 N treatment. In all treatments, the N concentration decreased with growth over time but tissue N concentration was highest in the 450 kg N ha^{-1} treatment (4.2 %) and progressively decreased with decreasing N rate; 3.7% in the 300 kg N ha^{-1}, 2.0% in the 150 kg N ha^{-1} and 1.9% in the 0 kg N ha^{-1} treatments. Despite the application of 150 kg N ha^{-1}, the difference in N concentration between the 0 and 150 kg N ha^{-1} treatments was not substantial.

The concentration of N within the plant varies considerably, with the outer leaves having a higher N concentration than the middle or inner leaves in cabbage (Šturm *et al.* 2010) (Table 2.6).

Table 2.6 Total nitrogen content (%) on a dry matter basis in different leaves of cabbage at final harvest from Šturm *et al.* 2010.

Nitrogen rate (kg N ha^{-1})	Total N (%)		
	inner	middle	outer
0	1.62	1.30	1.93
200	2.38-2.71	2.11-2.60	3.06-3.26

2.3.6. Brassica Root system N

White cabbage has a large and evenly distributed root system that can reach a depth of 2-2.5 m (Erley *et al.* 2010) and consistently reaches 1.1 m (Thorup-Kristensen 2006), giving cabbage a strong ability to absorb N from across the soil profile.

Bowen *et al.* (1999) evaluated root system growth in broccoli and found that dry matter production in the roots was variable and not significantly affected by N treatment. Broccoli root system growth was not affected by N application rates from 0-625 kg ha^{-1} (Bowen *et al.* 1999). The net root dry matter production varied from only 0.30 to 0.37 t ha^{-1}. The root system as a percentage of total plant dry matter was 6.8% in the 0 N treatment and lower in the other treatments where N was well supplied (4.4 to 4.8%). At optimal/luxury N rates, about 5.1 to 7.5 kg N ha^{-1} was taken up in the root system representing about 1.4-2.6% of the plant's total N uptake. Hence root systems operate effectively with relatively small amounts of N partitioned to their growth. In contrast to this finding, Abdul-baki *et al.* (1997) determined root systems in broccoli contain about 14% of the plant's total N uptake. The brassica root tissue N concentration is in the range of 1.76-2.5% when N is adequate (Alt *et al.* 2000; Bowen *et al.* 1999). At low rates of N (0 and 112 kg N ha^{-1}) the root system contained about 9.4% of the plant's N but at the higher rate of 336 kg N ha^{-1}, the root contained a lower proportion of N at about 7% (Holness *et al.* 2008).

2.3.7. Better management of brassica nutrient inputs

Knowledge of whole crop N uptake and harvest indices is essential in developing nutrient budgets for brassica crops where N application is matched to whole crop requirement so as to minimise potential losses to the environment.

The extraction of N by brassica crops is high. In cauliflower crops not receiving N about 150-200 kg ha^{-1} N was taken up in a relatively low yielding crop (Everaarts *et al.* 1996). Under N application at 200 kg ha^{-1} crop, N uptake was 300 kg ha^{-1}. At harvest (for broccoli) the soil mineral N in the 0-30 cm zone for a 0 N treatment was equivalent to only 4-9 kg ha^{-1} and in a high N treatment (196 kg ha^{-1} applied N) soil mineral N ranged from 14-68 kg ha^{-1} (Everaarts and de Willigen 1999). At the high N rate (196 kg ha^{-1}) the loss of N (unaccounted for N) ranged from 8-52 kg ha^{-1} but the loss mechanisms were not related to leaching and it was suggested that immobilisation and N contained in roots accounted for this loss since losses of this magnitude are unlikely to be due to volatilisation (Everaarts and de Willigen 1999).

The efficiency of brassica crop N uptake is demonstrated by results that show crop N uptake often exceeds that of applied N (Bakker *et al.* 2009b). Bakker *et al.* (2009b) showed that more than 300 kg N ha^{-1} was accumulated at only 200 kg ha^{-1} N application and about 400 kg ha^{-1} accumulated at 400 kg ha^{-1} N application in broccoli cv Decatholon and Captain.

In comparison with other vegetable crops, the harvest index of brassica crops is quite variable. Under adequate fertiliser application the harvest index over a range of 8 cabbage cultivars was in the range of 43-65% at an average of 54.4% (Erley *et al.* 2010). In contrast, the harvest index for broccoli is substantially lower at about 14.2-14.7% (Everaarts 1994) and the harvest index for cauliflower is intermediate at about 38-40% (Idnani and Thuan 2007).

In Australia, the harvest index for various vegetable crops is: broccoli ≈20%, cabbage ≈65-70%, wombok (Chinese cabbage) ≈75%, cauliflower ≈40-50%, lettuce ≈ 75-85% and celery ≈ 60-65% (Harper unpublished). The significance of harvest index is that though the whole crop requirement for N in brassicas can be high (200-400 kg ha^{-1}), a substantial amount of this N is returned to the system as crop residues. In broccoli essentially about 80-85% of the N in the crop is returned to the soil. This N becomes available for subsequent crops and hence, after rotations with crops of low harvest index, soil mineral N testing is useful for determining subsequent crop N requirements. This essentially forms the basis for Dutch recommendations for determining cauliflower nutrient requirements where the optimum application rate is recommended as 225 kg ha^{-1} N (presumably whole crop requirement) less the mineral N content in the 0-60 cm soil zone (Everaarts and DeMoel 1995). The figure for crop uptake can be modified for different crop species. In crops with a high harvest index such as cabbage, relatively smaller amounts of N are returned to the soil system and hence soil mineral N will be lower for subsequent crops.

The harvest index in broccoli increased with increasing N rate (Vagen *et al.* 2007) which the authors ascribed to the extra N having a greater effect on head yield than on the total plant yield. In contrast to this, Bakker *et al.* (2009b) found in two Broccoli cvs (Decathlon and Captain) that N use efficiency, on a marketable head basis, decreased substantially with increasing N because of the low proportion of the crop as a harvested product. Zebarth *et al.* (1995) also found that whole crop fertiliser recovery in broccoli decreased with increasing rate of N application, but was variable across seasons from about 30% to about 70%.

The N harvest index is defined as the proportion of applied fertiliser N contained in the harvested product. Under adequate N, the N harvest index for cabbage ranges from 37-66% with an average of 56.9 (Erley *et al.* 2010), indicating that some 43.1% of applied fertiliser is lost from the system or returned to the system in the form of brassica crop residues. Consistent with this, Everaarts and Booij (2000) noted the N harvest index was 54-60% in cabbage. The N harvest index for broccoli is in the range of 27-30% (Everaarts and de Willigen 1999) which is somewhat higher than the harvest index defined by Everaarts (1994), whilst that of cauliflower is similar to that for cabbage at 46-52% (Everaarts *et al.* 1996).

Fertilised broccoli crops return in the order of 120-155 kg ha^{-1} of N as crop residues though in nil N treatments only 31-63 kg ha^{-1} is returned (Everaarts and de Willigen 1999). In cabbage experiments, about 58 kg N ha^{-1} (45-75 kg N ha^{-1}) was returned in residues in a 0 N treatment and about 142 kg N ha^{-1} (125-168 kg N ha^{-1}) was returned in treatments receiving about 300-350 kg ha^{-1} applied N (Everaarts and Booij 2000).

At 200 kg applied N ha^{-1} broccoli extracted essentially all available N from the soil (Bakker *et al.* 2009b) and hence there was little risk of loss during the growing season. However, since soil and crop residues can be high in brassica production systems (96-330 kg ha^{-1}) (Bakker *et al.* 2009b) mineralisation of N from these residues can represent a risk for loss during a fallow period.

Finally Sanchez *et al.* (1994) demonstrated that the careful application of irrigation according to evaporative loss not only minimised N losses to the environment but also optimised cabbage production. Efficient irrigation management is critical in ensuring that N losses are reduced.

2.3.8. Genotypic differences in brassica N uptake

Reductions in N application rates to cabbage can be achieved by precise prediction of N demand, including the time course for crop growth and N uptake and the breeding of N efficient genotypes (Erley *et al.* 2010). Genotypic differences and genetics of N uptake have been assessed in various vegetable crops. For brassicas, some limited research has investigated genotypic differences in response to N levels. Rather *et al.* (1999) evaluated the efficiency of N utilisation and yield over a range of cauliflower cultivars (cvs Marine, Lindurian, and Linford). These cultivars were grown under N limiting conditions and adequate N. Irrespective of the N treatment cv. Marine grew best and was identified as having either a root system with higher N uptake capacity or had greater internal utilisation of N. Linford was classified as an N inefficient cultivar.

Erley *et al.* (2010) evaluated the effects of no added N and 300 kg N ha^{-1}over 8 white cabbage cultivars. The cultivars grown at 300 kg N ha^{-1} tended to mature 5-7 days earlier than the same cultivars in the 0 applied N treatment. Head fresh weight varied considerably across seasons for the cultivars in the 0 applied N treatment (62.0 tonne ha^{-1} to 95.8 tonne ha^{-1}) and in the 300 kg N ha^{-1} treatment (91.5 to 131 tonne ha^{-1}). Nitrogen uptake varied across cultivars and in the 0 applied N treatment was 77 kg N ha^{-1} in the early cultivar, 131-178 kg N ha^{-1} in the midseason cultivar and 213-232 kg N ha^{-1} in the late season cultivar. In the 300 kg N ha^{-1} treatment, crop N uptake was 149 kg N ha^{-1} in the early cultivar, 199-323 kg N ha^{-1} in midseason cultivars and 368-395 kg N ha^{-1} in the late season cultivars. The specific N rates required to maximise yield are likely to vary across cultivars (Batal *et al.* 1997).

2.3.9. Brassica quality and N

The quality of brassica crops is affected by N application and manifested in a range of attributes including uptake of other minerals (Csizinszky 1996; Yoldas *et al.* 2008), hollow stem (Belec *et al.* 2001), amino acid profiles (Liu and Shelp 1993; Atanasova 2008), head rot in broccoli (Everaarts 1994) and head shape and quality (Bakker *et al.* 2009b)

Increasing N rate increased the uptake of K, Ca, Mg, Fe and Zn and the highest rate of removed nutrients was observed at 300 kg applied N ha^{-1} (Yoldas *et al.* 2008). Increasing the N rate (from 98 to 294 kg N ha^{-1}) increased the uptake of other minerals (P, Zn and Fe) in cauliflower curd and Mn concentration in the leaf (Csizinszky 1996).

Hollow stem in broccoli cv Arcadia increased with increasing N application rate (0, 50, 100, and 150 kg N ha^{-1}) (Belec *et al.* 2001). However, yield also increased with increasing N rate suggesting that rate of growth was a key factor in expression of hollow stem. Bakker *et al.* (2009a) also found that hollow stem increased with increasing rate of N application.

The constituency of amino acid profiles in plant tissue is affected by N (Liu and Shelp 1993) where the concentration of serine (specifically) decreased with an increasing nitrate to ammonium concentration whilst other amino acids were largely unaffected.

Cabbage fertilised with ammonium nitrate at various rates increased total amino acids and essential amino acids from about 50 mg kg^{-1} DW in the nil applied N treatment to about 140 mg kg^{-1} DW in the 1000 kg N ha^{-1} treatment, and particularly aspartate, proline and alanine (Atanasova 2008).

Everaarts (1994) found that head rot in broccoli cv Emperor increased from between 2 to 6 times with increasing N to 196 kg N ha^{-1}. The incidence was 39% in the nil applied N treatment, 72% in the 49 kg N ha^{-1} treatment and > 88% at an N rate greater than 98 kg ha^{-1}. In contrast, Zebarth *et al.* (1995) found that soft rot infection in broccoli cv Emperor was not correlated with rate of N application. Bakker *et al.* (2009a) found that head rot was only weakly related to N rate and it is likely other factors influence the expression of the disorder.

The visual quality of broccoli, including numbers of misshapen heads and colour, was improved when rate of N application increased (Bakker *et al.* 2009b). The number of misshapen broccoli heads decreased substantially with increasing N rate from a high of 50% in a nil applied N treatment to less than 4% at N application rates greater than about 150 kg N ha^{-1}(Bakker *et al.* 2009a). Furthermore, Bakker *et al.* (2009a) determined that the broccoli physiological disorder brown bead was also not related to N application rate. A reduction in N supply to cauliflower resulted in loose curds of low market quality indicating that low N favoured bolting (Rather *et al.* 1999). In contrast, Everaarts and DeMoel (1995) found the curd quality of cauliflower was unaffected by N application rate or method of application.

Table 2.7 Data taken from the literature for broccoli including rate of N application, fresh and dry matter yields, dry matter content (DM%), N concentration (N%), crop N uptake (kg ha^{-1}), the reference, cultivars and plant parts studied. Blank sections indicate no available data.

Cultivar	N rate (kg ha^{-1})	Plant part	Fresh yield (tonne ha^{-1})	Dry matter yield (tonne ha^{-1})	DM%	N%	Crop N uptake (kg ha^{-1})	Author & no. of expts.
Milady F1	0	Whole plant		1.58-5.17		1.2-2.5		(Vagen *et al.* 2004)
Marathon F1	120	(at maturity)		3.65-6.76		2.2-3.9		(6)
	240			4.52-7.48		3.0-5.0		
Emperor	0	Leaf		1.47-2.05		3.16-4.55	46.4-86.0	(Bowen *et al.* 1999)
	125			1.84-2.63		4.15-5.29	75.6-126.0	(3)
	250			2.36-2.71		4.89-5.72	115-155	
	375			2.15-2.50		5.30-8.85	126-159	
	500			2.07-2.77		5.47-6.13	124-170	
	625			2.50-2.64		5.63-6.41	148-167	
	0	Inflorescence		0.60-1.10		4.24-5.21	25.7-51.0	
	125			0.66-1.55		4.98-5.67	34.6-76.9	
	250			0.82-1.63		5.58-5.76	45.9-89.9	
	375			0.95-1.83		5.40-5.75	54.2-98.4	
	500			1.09-1.86		5.58-5.73	61.0-106	
	625			1.18-1.98		5.47-5.79	67.2-114	
	0	Whole plant		4.59-6.26			101-202	
	125			5.21-7.54			169-303 (203.5%)	
	250			6.36-7.43			262-354 (128.9%)	
	375			6.55-7.94			309-389 (91.1%)	
	500			6.42-8.13			323-419 (71.7%)	
	625			7.12-7.97			338-425 (60.3%)	
	0	Root		0.33-0.45		1.08-1.58	4.6-7.0	
	125			0.23-0.34		1.60-1.83	3.8-6.2	
	250			0.28-0.33		1.76-2.16	5.4-7.0	
	375			0.30-0.37		1.60-2.71	5.4-8.0	
	500			0.31-0.33		1.68-2.47	5.5-7.0	
	625			0.28-0.37		1.80-2.59	7.0-8.4	

Emperor	0	Inflorescence	6.2	0.59	9.5			(Everaarts 1994)
	49		7.4	0.70	9.4			
	98		7.9	0.70	8.8			
	147		8.8	0.76	8.6			
	196		9.4	0.77	8.2			
	0	Leaf blade			13.9			
	49				12.9			
	98				11.7			
	147				11.5			
	196				11.0			
	0	Stem			11.8			
	49				11.5			
	98				9.8			
	147				9.4			
	196				8.9			
JadeF1	0	Inflorescence	7.2		7.3	5.7		(Erdem *et al.* 2010)
	150		10.5		7.5	6.3		
	200		10.0		7.6	6.6		
	250		10.0		7.2	6.4		
	0	Leaf			6.5	2.1		
	150				7.6	2.8		
	200				7.8	2.9		
	250				8.4	3.0		
Marathon	0	Main heads	10.6			3.06	83.1 (all Heads)	(Yoldas *et al.* 2008)
	150		14.3			3.62	118.9	
	300		13.9			4.09	141.6	
	450		13.3			5.08	150.6	
	600		12.1			4.82	134.6	
	0	Head	4.05					(Burket *et al.* 1997) (2)
	140		7.80					
	280		8.65					

Table 2.8 Data taken from the literature for cabbage including rate of N application, fresh and dry matter yields, dry matter content (DM%), N concentration (N%), crop N uptake (kg ha^{-1}), the reference, cultivars and plant parts studied. Blank sections indicate no available data.

Cultivar	N rate (kg ha^{-1})	Plant part	Fresh yield (tonne ha^{-1})	Dry matter yield (tonne ha^{-1})	DM%	N%	Crop N uptake (kg ha^{-1})	Author & no. of expts.
	0 206 207 205	Heart	47 58 72 93		11.03 8.79 9.32 9.02	1.62 2.70 2.52 2.86	84.2 137.7 168.8 246.0	Sturm *et al.* 2010
Bartolo	0 100 200 300 400 500	Marketable head		3.8-6.4 5.6-8.9 8.1-9.7 9.4-9.6 9.9-10.5 11.1-11.3			40-65 60-100 105-120 150-175 175-185 195-230	(Zebarth *et al.* 1991)
Bently	0 80-90 158-180 237-270 316-360	Head	≈45.0-51.8 ≈52.9-70.5 ≈73.3-87.2 ≈74.9-100.0 ≈75.2-111.0	≈5.1-6.1 ≈5.8-8.1 ≈7.2-9.3 ≈7.8-10.4 ≈7.8-10.5	11-12.5 10.3-12.2 9.8-11.2 9.6-10.4 8.9-10.3	≈1.1-1.5 ≈1.2-1.8 ≈1.5-2.0 ≈1.8-2.4 ≈1.9-2.5	≈110-180 ≈160-205 ≈250-270 ≈280-325 ≈300-380	(Everaarts and Booij 2000) (6)
Heckla	0 250	Head	Not specified			1.5 3.7	165 296	(Ekbladh *et al.* 2007)

Table 2.9 Data taken from the literature for cauliflower including rate of N application, fresh and dry matter yields, dry matter content (DM%), N concentration (N%), crop N uptake (kg ha^{-1}), the reference, cultivars and plant parts studied. Blank sections indicate no available data.

Cultivar	N rate (kg ha^{-1})	Plant part	Fresh yield (tonne ha^{-1})	Dry matter yield (tonne ha^{-1})	DM%	N%	Crop N uptake (kg ha^{-1})	Author & no. of expts.
Pant-Subhra and Narendra-Gohbi 1	100 150 200	Curd	9.62 11.78 13.99		7.81 8.24 8.77			(Singh *et al.* 1994)
Fremont	0 150 300 450 0 450	Plant Plant Plant Plant Curd Curd		≈3.6 ≈6.1 ≈6.8 ≈7.0		3.4 5.3 6.01 6.01 2.5 3.8		(Alt *et al.* 2000)
	150	Total Leaves Stem Residues		5.71 2.81 0.92		 2.24 1.78	170-210 62.9 16.4 88-124	(Akkal-Corfini *et al.*) (3)
Green cauliflower cv Alverda	98 294 98 294 98 294	Curd Leaf Stem 			10.8 9.4 10.9 9.2 12.9 11.0	3.7 5.5 2.3 4.3 1.4 3.6		(Csizinszky 1996)
White Empress Stovepipe	101 213 269 157 213 381	Curd	7.0 9.1 9.9 10.4 12.0 12.9					(Batal *et al.* 1997)

Marine Lindurian Linford Marine Lindurian Linford	0 (mean soil nitrate 70 kg ha^{-1}) 250 (Added fertiliser plus soil nitrate)	Whole plant		≈4.1-6.2 ≈4.2-6.0 ≈3.0-5.7 ≈5.8-8.9 ≈4.5-9.1 ≈4.5-6.7		>2.4 >2.4 >2.4 3.2-4.2 3.2-4.2 3.2-4.2		(Rather *et al.* 1999) (4)

2.4. *Capsicum*

2.4.1. Capsicum growth and nitrogen requirements

Capsicum dry matter accumulation rates from a number of studies are similar, with approximately half the mass accumulated in leaves and stems and the remainder as fruit. Scholberg *et al.* (2009) found the roots accumulate 11% of the total dry matter; shoots and stems 42%; and fruit, 47%. Hegde (1987) found, not including roots, stems and leaves account for 45 to 50% of total plant dry matter, with 50 to 55% accumulated in fruit. Bowen and Frey (2002) concluded a slightly higher rate of 60% attributed to fruit.

Locascio *et al.* (1985) found capsicum grown under plastic mulch utilises less than 10 kg N ha^{-1} during the first 4-5 weeks after transplanting. This is confirmed by Hegde (1987) where dry matter accumulation is slow in the first 45 days after transplanting (DAT) of capsicum cv. California Wonder under field conditions. After this, growth increases linearly to 105 DAT, with the peak of dry matter accumulation occurring between 60 and 75 DAT. Up to harvest (135 DAT), plants continue to accumulate dry matter, but at a slower rate. These rates will be somewhat cultivar dependant with Qawasmi *et al.* (1999) finding the peak dry matter accumulation occurring between 90 and 150 DAT of capsicum cv. Lamuyo. This lag in development could be an effect of the root system's ability to fully utilise fertiliser based on speed of development and size.

Increasing N rate in capsicum crops has been shown to increase uptake of phosphorus, potassium and other nutrients (Qawasmi *et al.* 1999) and stimulation of vegetative growth but not overall yield (Hegde 1988; Olsen and Lyons 1994; Olsen *et al.* 1993; Qawasmi *et al.* 1999). This indicates the plants store luxury N in leaf tissue (Qawasmi *et al.* 1999). Hartz *et al.* (1993) found capsicum leaf N decreases during fruit development and concluded that leaf translocation was the primary N source for fruit development and not soil supply which suggests capsicums have an inherent ability to exploit high nutrient supply. Despite this, some authors concluded capsicum plants had low N recovery rates and consequently high rates are needed to be applied to achieve the maximum yield (Hartz *et al.* 1993; Tei *et al.* 1999).

2.4.2. Fertiliser rates used

According to the Queensland Government's Agrilink Capsicum and Chilli Information Kit, capsicums require a total of up to 180 kg of N, 110 kg of phosphorus and 200 kg of potassium ha^{-1} (Meurant *et al.* 1999). Research by Olsen and Lyons (1994; Olsen *et al.* 1993) in Bundaberg, Australia, found average rates used in the region ranged from 210 to 280 kg N ha^{-1}. There are currently few published data based on rates used in the Bowen area, but studies throughout the world range from 50 kg N ha^{-1} to over 300 kg N ha^{-1}. A summary of these rates and the consequent yields of capsicum, are presented in table 2.10. Sotomayor-Ramirez and Macchiavelli (2002) have collated eight other data sources on nutrient application and subsequent yields research on capsicum crops.

Table 2.10 Summary of nutrition rates and potential yields of capsicum crops.

Crop/Variety	Yield (t ha^{-1})	N rate (kg ha^{-1})	Reference	Comments
Marketable yield of mature colour harvested fruit				
Capsicum cv. Bell Tower	38.4	210	(Olsen and Lyons 1994) (Olsen *et al.* 1993)	Average of Spring/Autumn yield, not significantly different (P=0.05) to 280 kg N ha^{-1}, which indicates the yield plateau was reached. 200 kg K ha was also applied. Grown under plastic mulch.
Capsicum	1.8 kg/plant	50	(Aminifard *et al.* 2010)	Spilt application of three equal parts at 10, 30 and 50 DAT. Grown under plastic mulch.
Capsicum cv. Heldor	38	310	(Tei *et al.* 1999)	Resulted in excessive soil mineral N of 223 kg ha^{-1}.
Capsicum cv. Lamuyo§	2.5 kg/plant	180	(Ruiz *et al.* 2000)	Reduce economic and environmental costs without sacrificing yields. Includes 40 kg K ha^{-1}.
Marketable yield of mature colour harvested fruit				
Capsicum cv. Lamuyo§	0.6 kg/plant 0.7 kg/plant	60 120	(Baghour *et al.* 2000)	
Capsicum cv. Lamuyo§	2.4 kg/plant	240	(Ruiz *et al.* 2000)	This rate: 240 kg N ha^{-1} and 120 kg K ha^{-1}, yielded the highest number of total fruit but did increase the weight of yield. Rates above this were found to cause toxicity, reducing yield.
Marketable yield of mature green harvested fruit				
Capsicum cv. California Wonder	16.9 18.0	120 180	(Hegde 1988)	Treatment yield means were not significantly different at 5% probability.
Capsicum cv. King Arthur	9.5	135	(Guertal 2000)	Two out of the three years, pepper yield was maximised at this rate.
Capsicum cv. Lumayo§	60.7	150	(Qawasmi *et al.* 1999)	Yield peaked at this rate, lower than some authors which may be attributed to high soil fertility.
Marketable yield of mature harvested fruit (colour not specified)				
Capsicum cv. Lamuyo§	40 39.6	180 240	(Moreno *et al.* 1996)	180 kg N ha^{-1} gave the highest first class yield with the lowest second class yield. Colour of harvested fruit not specified. 400 kg K ha^{-1} was also applied and rates exceeding this reduced fruit quality at harvest.
Total yield of mature green* / coloured† / not specified‡ harvested fruit				
Capsicum cv. California Wonder	17.9* 17.2*	180 120	(Hegde 1987)	Yield difference between 180 and 120 kg N ha^{-1} of applied N was not significant.
Capsicum cv. Bell Boy	1.9† kg/plant 1.7† kg/plant	31.5 63.0	(Bowen and Frey 2002)	1992 crop (1991 crop results not significant)
Capsicum cv. Brigadier§	8.4‡ (1DPL) 23.2‡ (3 DPL) 33.2‡ (7 DPL)	238.5	(Scholberg *et al.* 2009)	Fertiliser was applied 1, 3 and 7 days prior to a weekly leaching event. Rate is applied 1, 3 and 7 days prior to a leaching event (DPL) for three yield results.
Marketable yield of other Solanaceae crops				
Chilli, green	10.2	150	(Kacha *et al.* 2008)	Total yield of 150 kg N ha^{-1} treatment was not significantly different. Capsicum compound concentration decreased with increases in N.
Tomato	46.7	196	(Locascio *et al.* 1997)	Rate applied by fertigation, with no basal dressing.
Eggplant	4.1 kg/plant	100	(Aminifard *et al.* 2010)	Spilt application of three equal parts at 10, 30 and 50 DAT. Grown under plastic mulch.
§ Greenhouse production value; all unmarked values are field production				

2.4.3. Nitrogen use efficiency

Fruit quality has a direct relationship to N application; however as rates increase, N use efficiency (NUE) can decrease (Tei *et al.* 1999; Zhang *et al.* 2010). Some authors claim NUE can be as low as 24% (Tei *et al.* 1999) in capsicum. Scholberg *et al.* (2009) found with application of 106 kg N ha^{-1}, NUE peaked at 45%. Olsen *et al.* (1993) found with applications of 140 kg N ha^{-1}, soil reserves are utilised by capsicum plants and with 280 kg N ha^{-1}; 54% and 36.5% of the applied N, respectively, was recovered in these treatments. Early season N recoveries are much lower with only 5% recovered in the first 4 weeks after transplanting (Scholberg *et al.* 2009). This is attributed to the inability of the small root system of transplants to access soil nutrients and the slow expansion of the canopy.

2.4.4. Nitrogen uptake rates and accumulation by capsicum plants

Reported values for N uptake by capsicum are variable. Locascio *et al.* (1985) and Tei *et al.* (1999) state total uptake can range from 193 to 234 kg N ha^{-1}. Miller *et al.* (1979) found capsicum crops can accumulate 90 kg total N ha^{-1}; while Olsen *et al.* (1993) reported 140 kg N ha^{-1}, with 106 kg N ha^{-1} reported by Scholberg *et al.* (2009). Qawasmi *et al.* (1999) found total uptake of a capsicum crop fertilised with 150 kg N ha^{-1} was 283 kg N ha^{-1}. This rate also maximised the plant's uptake of phosphorus and potassium when compared with N rates as high as 350 kg N ha^{-1}. Tei *et al.* (1999) concluded capsicum uptake rate of N is 2.3 kg ha^{-1} day^{-1}; a figure similar to that found by Locascio *et al.* (1985). Approximately 30-65% of all N uptake by the plant is accumulated in the fruit (Santiago and Goyal 1985). Scholberg *et al.* (2009) attributed 30.4% of N uptake to roots, 34.4% to shoots and stems and 35.2% to fruit.

2.4.5. Sap and dry matter sufficiency ranges

Many of the sufficiency ranges for N and other nutrients in capsicum plant parts are based on unpublished survey type information produced by fertiliser companies and soil and plant testing laboratories, rather than through critical nutrient concentration studies. Guertal (2000) suggests a range of 35-60 g N kg^{-1} on a dry matter basis is an adequate N concentration in capsicum to maximise economic yields. Many other authors state ranges of N concentrations based on fertiliser treatments, but these vary highly between studies. Critical nutrient ranges of capsicum sap and dry matter have been studied by Olsen and Lyons (1994) and are presented in (Table 2.11).

2.4.6. Application methods

The application methods play a vital role in the uptake, plant development, NUE and risk of nitrate leaching in capsicum cropping. Locascio *et al.* (1997) showed yields of tomato can be maximised by applying a portion of the fertiliser as a basal application. This was achieved by applying a nitrogenous basal fertiliser at 40% of total requirements and 60% as fertigation in sand-textured soils. The concept of split application of fertiliser is not a new one, with many authors agreeing this can maximise yields and quality of capsicum as well as NUE (Locascio *et al.* 1985; Locascio *et al.* 1997; Meurant *et al.* 1999; Olsen and Lyons 1994; Olsen *et al.* 1993; Scholberg *et al.* 2009).

Table 2.11 Petiole sap and dry leaf matter nutrient concentration recommendations for capsicum to achieve 95–100 % of maximum yield.

Crop	Stage	Nitrate range (mg l^{-1})	Total N range (% of dry weight)	K range (mg l^{-1})
Capsicum cv. Bell Tower	Bud development	4980 – 6000	5.9 – 7.2	
	First Anthesis	5550 – 7065	6.3 – 6.9	
	80% Flowering	4620 – 6000	5.8 – 6.5	
	Fruit set (20 mm)	520 – 2800	5.4 – 6.4	
Capsicum cv. Bell Tower	Throughout			> 4800

Studies researched for this paper promote the splitting of nitrogenous fertilisers into a weekly fertigation schedule (Scholberg *et al.* 2009). Some studies have found capsicum can utilise fertilisers containing the nitrate form more readily over ammonium-based fertilisers (Marti and Mills 1991a; b).

The timing of fertiliser application also has an impact on the development of the crop. High N rates at flowering alter the plant's physiology, causing it to develop a larger canopy and delaying and reducing fruit development (Scholberg *et al.* 2009). Olsen and Lyons (1994) suggest 60% of total N be applied before fruit set. This coincides with the period of the highest rate of dry matter accumulation before fruit set (Qawasmi *et al.* 1999).

Although suggested fertiliser application rates vary widely between studies and authors, it is clear from the information presented here that many recommendations may be excessive. Providing adequate nutrition will maximise capsicum yields but timing and application methods are also important.

3. Analysing the situation - community engagement and objective data.

This chapter outlines a process for developing the knowledge required to understand the issues around sensitive waterways and the potential for concerns to be attributed to vegetable production. To achieve this, a four step process is identified. This commences with the initial identification of whether a problem exists achieved by conducting surveys of community perceptions of whether vegetable production, in the target regions, critically impacts on waterways. Then a context analysis was undertaken to identify key parties that are interested in waterway management. To broadly identify the potential for the vegetable production to contribute nutrients to waterways a nutrient budget was intensively conducted in one region, the Lockyer Valley (Queensland), and comparisons from the budgeting exercise were made with that from another region (Victoria).

3.1. Community Perceptions Survey of Waterway Issues

An important aspect of understanding the social issues associated with sensitive waterways is to identify the perceptions people in those communities have about waterway management and responsibilities. An attitudinal survey was undertaken in three separate vegetable locations across Queensland (Bowen, Bundaberg and the Lockyer Valley) and one in Victoria (Watsons Creek). The survey investigated the sentiments of communities toward the condition of their local waterways. In particular, the survey looked at how local residents perceived the impact of farming (horticulture specifically) on the health of their waterways. The main concern prompting this research was the risk of off-site nutrient movement at the farm-block scale.

The three focal regions in this study provide a diverse suite of production environments including tropical (Bowen, North Queensland), sub-tropical (Bundaberg and Lockyer Valley, South East Queensland) and temperate (Watsons Creek, Central Victoria). The Bowen and Bundaberg, Lockyer Valley and Watsons Creek regions are of particular interest regarding sensitive waterways as they drain into the Great Barrier Reef Marine Park, RAMSAR-listed Moreton Bay and Yaringa Marine National Park, respectively. Despite varying hugely in size and scale, all are highly sensitive and ecologically valuable marine environments.

3.1.1. Method

When developing the survey for the Sensitive Waterways project the management team determined that a simple three-question survey was required. The answers to these questions would provide a useful reference point for future community engagement by the vegetable industry and the development of a process for engaging with community. After proofing the concept the number of questions was expanded to five questions (no optional answers were provided).

Respondents in each region were asked essentially the same questions; the only difference being some slight changes in wording of questions was made in order to make the questions clearer. For example, waterways were defined as creeks, rivers, reef and beaches in Bowen and Bundaberg, but as creeks, rivers and dams in the Lockyer Valley. In the cane growing area of Bundaberg, farming was specified as vegetable farming to remove confusion with cane farming. In each region a research officer approached local residents in communal areas (eg. main streets, plazas etc.) where respondents were casually interviewed. Tourists and visitors were excluded from the survey as it was deliberately a community survey of residents. One hundred respondents were interviewed in each region.

For the Queensland component the survey included the following 5 questions:

- What is the main issue(s) of concern for waterways in your region?
- Who/what do you think is the main contributor to these issues?
- What impact does farming have? Minimal? Moderate? Significant?
- How does farming affect your waterways?
- Do you think the farming industry is addressing any of these concerns and if so how?

In Watsons Creek the questions were essentially the same with slight modifications to include:

- Do you know where Watsons Creek is?
- Have you heard anything about the Watsons Creek in the past 12 months?
- What are the main issues of concern for waterways in your region?
- Who or what are the main contributors to these issues?(Agriculture (animal, grain, vegetable or fruit farming), Urban development, Industry or Tourism)
- Do you think that local vegetable growers are environmentally responsible when it comes for caring for waterways?

3.1.2. Results and discussion

3.1.2.1. Bowen Region

What is the main issue(s) of concern for waterways in your region?

Who/what do you think is the main contributor to these issues?

In response to questions 1 and 2 respondents in Bowen identified the key Issues were Flooding (25%), no concerns (21%), Pollution (20%), fishing (10%), biodiversity (7%), sedimentation (5%), Reef health and tourism (7%) and other minor issues. The only group of respondents that identified farming as a major contributor was in the respondents who nominated pollution as a major issue and this accounted for just 6% of respondents. Across all response categories farming was not considered to be a major contributor and 62% of respondents believed farming's impact was in the lowest category of minimal impact and 32% nominated farming's impact to be moderate. In response to the question How does farming affect your waterways the majority of interviewees elected not to respond indicating no knowledge on the issue. However the formal responses included Chemical run-off (19%), responded with did not know (9%), responded with 'Give the farmers a break!' (8%), Farming doesn't contribute (7%), Ecosystems damage (5%) and Plastic disposal (3%). Responses to question 5 included; formally answering yes (20%) with responses of 'Farmers are adopting Better practices' and 'Most farmers do the right thing'. A large number of respondents were unaware of farmer activities (9%) whilst 57% responded positively to the farming sector without specification. A common theme amongst specific responses to this question was that a lot of the responsibility for how the vegetable industry should address concerns should fall to those who regulate the industry rather than the farmers themselves.

Respondents exhibited a general sentiment of positivity toward the horticulture industry. This was evidenced by responses to the first and final questions of the survey which highlighted no major concerns regarding sensitive waterways. When farming's role was questioned, a strongly parochial support was expressed for the important role played by horticulture in the community. These responses were not so much making excuses for the farming industry, rather suggesting the obvious that an intensive agricultural practice in the region must have some impact and that the impact comes part and parcel with the positives reaped from farming; namely food, jobs and livelihoods.

3.1.2.2. *Bundaberg Region*

Overwhelmingly, 41% of respondents attributed problems in sensitive waterways to natural systems, events or climate change which were essentially out of anyone's control. It was generally considered that nothing individuals or anyone else (governments, industries, scientists etc.) did in the region could have any great impact on correcting the problems. A further 28% of respondents directly nominated flooding of their waterways; a perception that was likely to be linked to the inconvenience and damage due to recent flooding events. This survey was taken in 2011 prior to the major flood event in 2013 which is likely to have further changed perceptions more in favour of this issue. Other important issues with waterways included Tourism (11%) linked with Impact on Livelihoods (11%) and respondents further linked these issues with the impact of flooding. These two concerns were isolated from flooding as they represented a more specific concern that looms as a significant challenge for parts of the local community and its economy. A further 17% of respondents expressed No Concern.

Farming was identified as a major contributing factor in only two of the 100 responses and both respondents considered the primary problem of farming's impact to be pollution. Of the respondents 64% indicated farming's impact on waterways was minimal and 34% moderate.

In identifying 'How does farming affect your waterways' respondents nominated Pollution (chemical run-off and plastics) (20%), agriculture is part of a bigger system (15%), some impact but can't specify (12%), don't know (8%) and Poor management and practices (4%); the remainder did not tender a response.

Forty-five percent 45 % of respondents had the perception that environmental awareness, general attitudes and farming practices were being considered and improved across the industry. No respondents indicated agriculture was not addressing concerns and a large number had no opinion either way.

Farming was not pointed out as being a major impact on sensitive waterways but was universally acknowledged as being an on-going co-contributor to the overall health of local waterways; including tributaries and the Great Barrier Reef in general. There appeared to be a sound understanding of farming's impact on the environment in this particular area and respondents had substantial knowledge of up-stream activities and development. In particular this focussed on the capacity of dams and weirs to mitigate effects of flooding and the view that this aspect of farming (vegetable included) generated a net positive return in relation to sensitive waterway issues.

There was an understanding that farming had some detrimental effect on the overall health of waterways, but many respondents could not accurately illustrate what those impacts were. Many respondents suggested a legitimacy and respect for farming in the region. This highlights the continuing need to acquire hard data and evidence in order to support and further guide the practices of the horticulture industry. Education of the general public on these matters, and the steps being taken, may prove a key strategy in improving or even correcting widely held misconceptions.

Being such a significant cane producing region, the responses in Bundaberg often made some connection with the cane farming industry despite the survey stressing the role of vegetable farming. Where responses mentioned improved farming practices these often referred to the perceived improvements in cane farming practices.

3.1.2.3. Lockyer Valley Region

Given the level of devastation experienced by residents of the Lockyer Valley in January 2011 it was expected that flooding would be a core concern for respondents. Flooding was not always the most prominent concern but if not raised specifically, many responses were given in light of effects of the floods.

In the Lockyer Valley Flooding per se was the major nominated concern (29%) and these related not to waterway quality but rather the hardship experienced by the respondent. The major contributing factor identified by this group of respondents was poor government planning (all levels) (9%) and a further 12% attributed blame to a mix of climate change, freak weather events and natural systems at work. Pollution was identified by 14% of respondents as a major issue and just 2% indicated agriculture as partly responsible. Essentially, the floods were considered freak events that no level of preparation and management could have avoided and that individuals and industry (not specifically farming) were taken off guard and had inadvertently become polluters.

The management of creeks was a key issue (13%) that mostly centred on the inability of landholders to appropriately manage the waterways. The causes of this were attributed to legislation not allowing landholders to maintain creeks as they would have liked. Erosion in the form of creekbank slumping was a further major issue (10%). Other responses to the key issues were, Not Aware (12%), Recreational waterway use (11%), Ground water management (4%) and Sedimentation (4%).

In responses to what the impact of farming is, 7% indicated significant impact, 56% moderate and 37% considered it minimal. This requires further scrutiny as it is likely the majority of respondents had either a direct or very close association with farming production and hence well-formed opinions on creek management (respondents were not asked any personal details to evaluate this). Furthermore, it is likely the concerns are not so much environmentally focussed but rather focussed on hardship associated with flooding damage.

Of the responses 26% indicated pollution as the major agricultural impact. This included chemical run-off, plastics, dumping excess produce and rubbish in dry creek beds, failure to clear debris from dry creek beds and materials (including fencing) and machinery that was swept up in flood waters and dumped downstream. Erosion and land degradation was recorded for 19% which the majority of respondents related to farming practices that placed cultivated land at higher risk to damage by flows in local waterways. Fifteen percent indicated horticulture was considered to be one component of a complex system that farming affected along with a number of other activities. Interestingly, a small number of responses considered some aspects of farming to have a positive impact on the health of waterways (eg arresting overland flows). A large number of respondent (13%) indicated the effects of farming were unavoidable given the nature of activities but the benefits derived from food production outweighed any adverse affect on waterways.

On the issue of whether the farming industry is addressing the concerns the responses were Don't know (25%), Not doing anything (19%), Believe farmers are doing what they can (18%), farmers are using better practices (17%) and Yes Greater awareness (12%).

In the Lockyer region there was generally a strong personal identification made with the industry. Many respondents were happy to discuss the last two questions at length sharing feedback on ways they had been trying to address the issues at hand, how they'd seen improvements over time, challenges they were facing and frustrations or hurdles being met in the process.

3.1.2.4. Watsons Creek

In the Watsons Creek survey a total of 156 people were questioned and out of these 49 people had no knowledge of where Watsons Creek was. They either did not associate Watsons Creek with being a waterway near their homes or they were from another area where this creek is not known. The survey was carried out at a supermarket after the tourist season was officially over. To get a better representation of ideas on the next series of questions respondents that said they did not know where Watsons Creek was were eliminated from the rest of the survey.

This left a remaining group of 107 people who when questioned only 32 had heard something about the creek in the previous 12 months but when questioned about the main issue related to the waterways in the region, 87 respondents indicated pollution as the main issue. This was a surprising finding as almost everyone said pollution even though 12 people said "no water". So the fact that the waterways in the area are polluted resonated with most people even though there had been little water flowing through these creeks in the previous 8 years. The majority of respondents identified the main cause of pollution was attributed to urban development (43), agriculture (18) (9 animal farming, 3 grain farming, 5 vegetable farming, 1 fruit farming), industry (12), tourism (11) and no idea (3). Animal farming was identified as the main form of agriculture responsible for pollution. There is a strong anti-farming lobby in some parts of the peninsula region that are related to chicken and egg farming since there are many chicken sheds that impact on the environment and is the most visible form of animal farming. Vegetable growing, however, was the second highest answer given by respondents.

Only 25 respondents out of the 107 thought that vegetable growers were environmentally responsible. This leaves the majority of respondents thinking that vegetable growers are not environmentally responsible. These results indicate three key things. Many people in the area did not know much about Watsons Creek despite many newspaper articles that have been written about that creek over the years. However, it is possible that many people surveyed at the particular time were not from the immediate area. Urban development is perceived as the major cause of concern for many of the respondents in terms of pollution. Animal farming is identified by respondents as a much greater concern than vegetable farming in terms of causing pollution to waterways in the area.

A further survey of 63 people was conducted at the end of the project and this showed

Question 1: 25 did not know where Watsons creek was.

Question 2: 14 out of the 38 who knew where Watsons Creek was had heard something about the creek in the previous 12 months.

Question 3: 17 respondents indicated pollution was the major issue and 5 said not enough water.

Question 4: Urban development (16), agriculture (8) (animal farming 5, grain farming 1 and vegetable farming 2), no idea (3), industry (7) and tourism (4).

Question 5: 9 respondents said that vegetable growers are environmentally responsible.

In both surveys there was a large number of people who knew something about Watsons creek or had heard about the creek in the past 12 months. Credit must be given to newspaper reports and environmental groups in local media that present local issues to the community. Despite this at the start of the study 31.4% of people interviewed did not know where Watsons Creek was and at the end of the study 39.7% did not know where Watsons creek. These results suggest that overall Watsons Creek is not well known in the area. The community survey identified that Urban development was the main issue for Watsons Creek and agriculture (and particularly vegetable production) was perceived to have much less impact. Very few people interviewed said that vegetable farmers were environmentally responsible. There is real scope here to educate the community on what the vegetable industry is doing in the area of environmental management through programs like EnviroVeg and Freshcare environmental.

3.1.2.5. General conclusion

The Queensland Survey demonstrated the most common concerns directed toward the vegetable industry, were the issues of pollution and erosion/land degradation. Almost all responses attributed the main cause of their pollution concerns (with respect to respondents who nominated farming) to the impact of chemical run-off. Given that the industry is continually embracing improved chemical products and application there is an opportunity to improve adoption of practices such as the use of 'soft' chemicals in pest management and varying spray applications to combat resistance. It was not always clear what exactly was meant by chemical run-off whether it was leaching of residues or loss of concentrates in flooding. The other major facet of pollution directly identified by respondents was the quantity of plastics that made their way into waterways. Primarily this took the form of chemical drums, trickle tape and plastic mulch. The recent floods exacerbated this problem, which was commonly acknowledged but respondents were concerned at how some of these materials were managed.

The major flood events of the summer of 2010/2011 undoubtedly influenced responses and in the absence of pre-flood data it is not known how strongly this has biased the survey. Whilst the results of this survey provide a useful and interesting insight into general public perceptions on waterway management, they are not exhaustive. Importantly, respondents in all three Queensland regions essentially did not consider the vegetable industry to be a major problem in relation to their waterways. The importance of the industry to communities and economies was acknowledged and that farmers, individually and collectively, were doing their best to manage their resources and environment. Most respondents indicated natural systems, climate change, planning and policy issues, development or other industries were the key factors influencing waterways.

In Watsons Creek Victoria a very large percentage (about 40%) of respondents were not aware of the existence of Watsons Creek. For those respondents who were aware of it Development was considered to be the major impact with Agriculture of lower importance. Within respondents identifying Agriculture as impacting the majority of respondents considered animal production as most important.

Overall the surveys in the four regions indicated that community members do not specifically identify vegetable production as being a major contributor to waterway health and in the Queensland regions that generally these industries are important in providing employment in small rural communities. The interpretation of waterway issues varied across regions and within communities would not always be interpreted on the basis of environmental health. This was clear in the Lockyer region where waterway impact was consistently interpreted as the personal hardship associated with flooding.

The survey outcomes highlight that the process of engaging with the community on issues with water way management is an important step in identifying what level of conflict exists and the issues that are of highest priority and whether the responsibility for the problem is ascribed to the vegetable industry. The survey process was effective in identifying community perceptions of vegetable production impacts but as a process could be expanded as required to obtain a deeper understanding of community sentiment.

3.2. Context analysis of stakeholders in waterway management

At the commencement of the project it was acknowledged that an important process in ensuring issues associated with sensitive waterways were broadly addressed was to identify all groups that held interest in the issue. In each of the priority regions (Bowen/Gumlu, Bundaberg and Lockyer Valley in Queensland and Watsons Creek Victoria) a detailed review of all interested parties was conducted and a list of these collated in the event that broader community consultation was required to resolve potential disputes. During the development of the project community conflict in Watsons Creek, Victoria was identified as a major issue but not in Queensland. Hence the process of conducting a context analysis is to identify a process that can be followed to help resolve disputes when these arise.

The aim of this analysis was to identify within the regions:

- all organisations involved in monitoring water quality and/or engaging the catchment community to address water quality issues, including diffuse pollutant losses from agricultural production systems (especially vegetables) to sensitive waterways.
- existing and past activities of these organisations that relate to the management of sensitive waterways and links the project into related regional activities and external support, building on established relationships with key players in the wider community.

A list of groups interested in waterway management was formulated and expanded following broad discussions across this community of parties. These parties were broadly grouped into the following; Community Groups, Industry and Resource management groups, government and universities agencies.

The numbers of groups identified as potentially having interest in waterway issues is outlined (Table 3.1) and a full listing of the individual groups and their focus and aims for each region is included in Appendix 1.

Table 3.1 Numbers of groups identified in each focal region as having interest in waterway management.

	Lockyer	Bundaberg	Bowen	Watsons Creek
Community Groups	5	4		2
Industry and resource management groups	5	4	4	6
Government	5	6	3	5
Universities	4	1	2	

3.3. Nutrient budgeting survey – obtaining objective data

In resolving community issues associated with waterway management an important step for vegetable production at a regional level is to broadly identify the potential risk or contribution it makes to nutrient pollution in waterways. Furthermore, obtaining this information can allow growers to improve resource inputs including the identification of the potential for under-application of key nutrients. To obtain information on the overall efficiency of fertiliser application on vegetables, a series of surveys were conducted in key regions across a range of vegetable crops. As a case study the survey was centred across crops in the Lockyer Valley region where a large number of vegetable crop species are grown though a smaller number of samples was taken from the adjacent Fassifern Valley region.

The aim of this component of the project was to develop background information on the status of crop nutrient use efficiency, typical nutrient use profiles for key vegetables and nutrient return rates in high residue crops. This information is deemed important in an assessment of the potential for nutrients to be lost from farming systems and in the formulation of nutrient budgets that can better match nutrient application to crop demand. Furthermore this example provides a case study for how a whole of region survey can provide data to substantiate the industries potential to impact on sensitive waterways.

3.3.1. Material and methods

The technique for conducting the partial nutrient budget depended on the crop. For crops where the individual plant is harvested just once (e.g. lettuce, cauliflower, broccoli) a single sample was taken at harvest. This consisted of 12 randomly selected plants within the planting. The total fresh weight of the plants was determined and the plants were then divided into the marketable and residue components. For cauliflower, the marketable product was further divided into the curd and bract components to allow separate nutrient analyses for these. The total fresh weights of the marketable product and residues were determined and subsamples were dehydrated at 72^{o}C, weighed and held for analysis. The samples were analysed for total N, P and K. The crop yield was determined by calculating the actual plant population and converting the sample fresh weight yield to a yield per ha. The dry matter content of the subsamples was determined to allow calculation of the amount of nutrient contained in the marketable components and field residues. The crop dry matter yields for marketable product and field residues were determined by multiplying the fresh yield by the dry matter content. The nutrient content of the marketable product and field residues was obtained by multiplying the dry matter yield by the sample nutrient concentration (for N, P and K this is expressed as a percentage). Finally, the fertiliser regimen used by the farmer was obtained from their records and the nutrient application for N, P and K in kg per ha was calculated. The applied nutrient was then matched with whole crop requirement as well as nutrients removed from the field in the marketed product. A more detailed description of the process for determining the nutrient budget is provided in the nutrient budgeting guidelines (O'Halloran and Harper 2011). A nutrient use efficiency was calculated as a percentage of nutrient removed divided by nutrient applied. There was no allowance for mineralisation of N and P from soil organic matter, nor for inorganic nutrient content of the soil.

3.3.2. Results and Discussion

Data for the yield components of a range of vegetable crops (broccoli, cabbage, cauliflower, celery, lettuce and carrots) as well as plant tissue nutrient content (N, P and K) and uptake are presented in table 3.2 and Appendix 2.

3.3.2.1. Broccoli

The total biomass yield for broccoli was in the order of about 67 tonne ha^{-1} of which about 20% was contained in the marketable product (harvested curd). Though the total crop uptake of N was about 200 kg ha^{-1} only 44 kg N ha^{-1} was removed in harvested product, leaving about 156 kg N ha^{-1} that is returned to the soil as incorporated residues and available to subsequent crops. The mean total crop uptake for K (220 kg ha^{-1}) was greater than that for N, and removal of K (47.3 kg ha^{-1}) in the harvested curd was about 8% more than that for N.

The application of N to broccoli was about half of the total crop N uptake but was about twice that of crop removal reflecting the relatively low harvest index for broccoli of 20.1%. Hence for broccoli the monitoring of pre-plant soil mineral N would be useful in assessing crop fertiliser N rate requirements. The mean application rate of K as fertiliser was 63 kg ha^{-1} and was well short of total crop K uptake (220 kg ha^{-1}) but slightly in excess of removal (47.3 kg ha^{-1}) by about 16 kg ha^{-1}.

The mean application of P was 34.7 kg ha^{-1} and slightly in excess of the mean total crop uptake (32.4 kg ha^{-1}), with removal in harvested product of 9.6 kg ha^{-1}. Though P application on average was in excess of removal in harvested product, the rates of application were relatively low particularly against an inherently high background of soil P in Lockyer Valley soils.

3.3.2.2. Cabbage

Total biomass production for cabbage was variable across types with exceptionally high biomass production in Wombok (165.8 tonne ha^{-1}), high biomass yield in drumhead cabbage (about 120 tonne ha^{-1}), and somewhat lower biomass yield in sugarloaf cabbage (79.6 tonne ha^{-1}) (Appendix 2). Notwithstanding, Wombok had a relatively low DM% (5.3% for residues and 6.1% for head) compared with drumhead cabbage (11.6% for residues and 8.6% for head) (Appendix 2). Since drumhead cabbage had an overall higher DM%, the dry matter yield (a measure of net biological productivity) was greater. Wombok had the highest plant tissue N concentrations (3.24% for residues and 3.66% for head) with sugarloaf next highest (2.74% for residues and 3.09% for head) and drumhead cabbage had the lowest (2.41% for residues and 2.30% for head) (Appendix 2). A similar pattern was also evident for cabbage K concentration across types. However, across the three samples for drumhead cabbage the range is considerable, indicating high variability.

The total crop N uptake for all cabbages was high (Wombok 320.6 kg ha^{-1}, drumhead 279.5 kg ha^{-1} and sugarloaf 194.7 kg ha^{-1}) which, combined with high harvest indexes (since the harvested head is about 69-78% of total crop biomass), means that high rates of nutrient (N, P and K) are removed in the harvested product. The removal rates for N were 173.4 kg N ha^{-1} for drumheads, 139.4 kg N ha^{-1} for sugarloaf and 247.5 kg N ha^{-1} for Wombok. In contrast, the application of N was significantly lower than removal at only 93.7 kg ha^{-1} for drumheads, 102.5 kg ha^{-1} for sugarloaf and 85.0 kg ha^{-1} for Wombok let alone the higher requirement for whole crop growth.

The total crop K uptake and removal data for each cabbage type essentially matched that for N since the requirements are close to a 1:1 ratio. However, the application of K to cabbage crops (28.2 kg ha^{-1} for drumheads, 50.2 kg ha^{-1} for sugarloaf and 45.8 kg ha^{-1} for Wombok) was considerably lower than N application. Application of P in relation to crop removal varied across samples but essentially P is managed at levels appropriate to maintain soil P levels given the inherently high soil P in Lockyer Valley alluvial soils.

3.3.2.3. *Cauliflower*

The yield and nutrient uptake dynamics for cabbage and cauliflower were very similar though the total crop biomass for cauliflower was less than drumhead cabbage and more than sugarloaf whilst overall the harvest index for cauliflower (43.3%) was considerably lower than for cabbage (69-78%) (Appendix 2) indicating higher residue and nutrient return to the soil. The total N uptake was substantial (262.5 kg ha^{-1}) but N removal in harvested product (99.6 kg ha^{-1}) closely matched applied N fertiliser (98.6 kg ha^{-1}) giving a near neutral budget on a removal basis. The total crop K uptake (219.4 kg ha^{-1}) was somewhat (about 43 kg ha^{-1}) lower than that for N but removal of N and K in harvested product was about the same 99.6 and 94.4 kg ha^{-1} respectively. Application of K as fertiliser (57.0 kg ha^{-1}) was considerably lower than the amount of K removed in the harvested product. Removal of P in harvested product was only 16 kg ha^{-1}.

3.3.2.4. *Lettuce*

The mean total crop biomass fresh weight yield for iceberg lettuce was about 83 tonne ha^{-1} with a high harvest index of 79.3%. Total N uptake was 115 kg ha^{-1} with 87.0 kg N ha^{-1} removed in harvested product and 87.7 kg N ha^{-1} applied as fertiliser. The nutrient budget for lettuce is near neutral giving a NUE of 100%. The difference between total N uptake and N applied was only 27.3 kg ha^{-1} and presumably the difference is supplied mostly as residual soil mineral N at planting. The K demand for lettuce was higher than for N with total uptake being 143.8 kg K ha^{-1} removal at 99.0 kg K ha^{-1} but K application (56.4 kg ha^{-1}) was considerably less than removal. Total P uptake was less than applied P by about 10 kg ha^{-1}.

3.3.2.5. *Celery*

The total crop biomass fresh weight yield for celery was 132 tonne ha^{-1} (Table 3.2) with a harvest index of 72.4%. The total crop N uptake was 177.5 kg ha^{-1} whilst removal in harvested product was 86 kg N ha^{-1}. The mean N application rate was 111.7 kg ha^{-1}; about 25 kg N ha^{-1} more than removal hence the NUE on a removal basis was 77%. On a whole crop basis, N was undersupplied. The total K uptake for celery was very high (350 kg ha^{-1}) and the removal of K in harvested product was also high at 186 kg K ha^{-1} and more than twice N removal. However, application of K was only 72.2 kg K ha^{-1} and only 39% of removal let alone whole crop requirement.

3.3.2.6. *Carrot*

The total biomass fresh weight yield for carrot was 88.9 tonne ha^{-1} with a high harvest index of 84.1%. The DM% for the foliage (19.1%) was much greater than the DM% for the roots (11.2%). The total crop uptake of N was considerable (163.6 kg ha^{-1}) and removal was 111.3 kg N ha^{-1}. The N application rate was 97.5 kg N ha^{-1} and less than removal giving a negative N budget and a NUE of 114%. The total uptake of K in carrot was large at 236.2 kg ha^{-1} and removal was 170.2 kg K ha^{-1}, about 40 kg ha^{-1} more than the amount of K applied as fertiliser.

3.3.3. Summary

Overall the survey indicates that over application of N is not a serious issue in Lockyer Valley crops and where previous crops have depleted soil mineral N supply as fertiliser, based on the surveyed rates, may be insufficient to meet crop requirements. The regional crop survey provides a good tool to develop data to identify the potential for vegetable production to impact on sensitive waterways.

On a whole of crop basis, the N budgets for each vegetable crop tended to be negative where N application did not meet whole crop uptake. However, on the basis of N removed in the harvested product the budgets were somewhat (slightly) negative for carrot, celery and Cos lettuce but strongly negative for the cabbage crops. This indicates that the application of N to these crops is not meeting the amount of N removed in the harvested product let alone the higher requirement for whole crop growth. The application of N to iceberg lettuce and cauliflower was close to matching the N removal in harvested product giving an NUE of close to 100% for these crops. For broccoli the application of N was considerably greater than that removed in harvested product since broccoli has a very low harvest index and a considerable amount of N is returned in crop residues.

This highlights that a whole of cropping approach is required to ensure N continues to be supplied at appropriate rates taking into consideration N extraction by various crops within the rotation. Vegetable crops may require extra N when grown after crops where extraction of N is high with low fertiliser input (e.g., low input grain crops such as sorghum). In contrast, where the N return rate in residues is high, such as in broccoli, the N inputs in a subsequent crop may be reduced depending on that crop’s demand. The evaluation of soil mineral N at planting would be a useful index for benchmarking expected crop N requirements. Since the harvest index of many vegetable crops can be low with high return rates of N in residues, continual monitoring is required to balance inputs and reduce the potential for losses whilst maximising crop growth rate and yield.

The application of K was consistently lower than crop K uptake and removal in harvested product. This was particularly so for crops with very high uptake and removal in harvested product including, carrot, celery and cabbage (all types). Addressing the issue of K depletion and marginal K supply is a priority as it is likely that marginal inputs will reduce crop growth, yield and quality which limits uptake of N and predisposes the system to N losses.

Table 3.2 Total crop fresh yield (FY) (tonne ha^{-1}), marketable product fresh yield (FY) (tonne ha^{-1}), total crop nutrient uptake (kg ha^{-1}), nutrient removed in harvested product (kg ha^{-1}), and nutrient use efficiency (%) (expressed for total crop uptake and removal in marketed product) for vegetable crops surveyed from farms in the Lockyer Valley 2010. (The number of samples collected is included in brackets next to the crop type and the range of values is included where the sample number is 3 or more).

Crop	Total crop FY (t ha^{-1})	Marketable FY (t ha^{-1})	Total crop nutrient uptake (kg ha^{-1})			Nutrient removed in harvested product (kg ha^{-1})			Fertiliser nutrient applied (kg nutrient ha^{-1})			Total crop nutrient use efficiency (%)			Marketable crop nutrient use efficiency (%)		
			N	K	P	N	K	P	N	K	P	N	K	P	N	K	P
Broccoli (5)	67.0	13.5	204	220	32	44	47	10	113	63	35	180	349	93	39	75	28
Drumhead Cabbage (3)	121.9	84.3	280	252	34	173	149	23	94	28	37	298	892	92	185	528	63
Purple Cabbage (1)	123.2	85.8	224	232	35	162	177	27	111	33	74	202	697	47	146	531	36
SugarLoaf Cabbage (2)	79.6	57.0	195	169	24	139	119	18	103	50	13	190	337	187	136	237	142
Wombok (2)	165.8	128.5	321	309	59	248	212	48	85	46	17	377	674	349	291	462	283
Cauliflower (6)	96.1	40.9	263	219	44	100	94	16	99	57	32	266	385	140	101	166	51
Lettuce (11)	83.0	66.0	115	144	19	87	99	16	88	56	27	131	255	69	99	176	57
Cos Lettuce (1)	63.9	54.8	130	177	18	118	159	17	91	89	20	143	198	91	129	179	84
Celery (2)	132.0	82.8	178	351	37	86	186	22	112	72	21	159	486	175	77	258	104
Carrot (4)	88.9	74.6	164	236	22	111	170	18	98	129	34	168	183	65	114	132	52

4. Working with vegetable growers – Case studies to monitor farm nutrients

4.1. Lockyer Valley Grower case studies

Historical evidence has been presented that suggests that overuse of fertiliser in key Queensland vegetable production systems is an issue and particularly in the Lockyer Valley. In addressing this, research by Harper and Menzies (2009) showed that this might not be the case which is reinforced by the data collected in the nutrient budget survey. The project identified that a more definitive study over time was required to evaluate the movement of nitrogen in vegetable farming systems using individual case studies that evaluated nitrogen inputs, uptake and losses (as product and in soil movement) over 2011 to 2013 giving 3 full seasons of vegetable production.

4.1.1. Materials and methods

Two collaborating farmers were selected to participate in the Lockyer Valley study based on interest in the work, size of operation and diversity of rotations. These are referred to as Grower A and Grower B.

The soil sampling regimen comprised about five in-crop samples and further samples during the fallow. Samples included:

- A preplant sample prior to fertilizer application
- A post-plant sample immediately after first nutrient application
- Two mid-growth samples
- Final harvest sample

Each soil sample was taken from the same block which was divided into four sub-blocks which were essentially reps. A single soil profile sample was taken from each sub-plot at the above 5 sampling times during the crop phase and in fallow. The samples were collected manually using an auger from the centre of the bed. The soil samples were taken at the following increments to a depth of 1.0 m: 0-10, 10-20, 20-40, 40-60, 60-80 and 80-100 cm. Soil samples were bagged and oven dried for 48 hours at 40^{o}C. The samples were analysed for nitrate and ammonium and phosphate in a selection of surface soils.

In the first season ceramic cups and 'FullStops™' (refer section 4.3) were placed in field at depths of 30 cm and 50 cm, but in the short season crops of the Lockyer valley (8-12 weeks) these were less reliable in function. There were several issues with using these samplers, including matching collection timing with farmer irrigation (which was not practical) and the equipment consistently suffered physical damage by farm workers (chipping) when the crop developed and they were not visible. On a technical note, the technology does not allow for an objective calculation of nutrient loss as the volume of soil from which extract is taken cannot be quantified. The deep soil sampling gave more definitive data on nutrient movement and quantifying losses.

The sampling of plant material was conducted at the same time as the in-crop soil samples and other extra samples were taken (depending on the crop) during growth to develop nutrient uptake and growth profiles for the key collaborating farmers. Plant samples comprised the entire above-ground biomass and usually included 2 representative plants in each of the sub-plots. At crop maturity (final harvest), 6 plants were sampled from the sub-plots and split into harvested material and remaining residue. Fresh weights were recorded, samples dehydrated at 72^{o}C and dry weights recorded. The at-harvest samples were ground and a full nutrient analysis conducted. The plant population was determined by accurately measuring the average width of beds (over about 7 beds width) and counting the number of plants in a 50 m length of bed. From this the plant population was determined and yield calculations made.

4.1.2. Results

4.1.2.1. Grower A

The details and data for Grower A's production, nutrient inputs, yield components, nutrient composition and uptake for N, P and K are presented in Appendix 3. The data on nutrient levels in this table are within the expected values for healthy crops. A complete schedule of nutrient inputs and outputs is presented in table 4.1 for N, P and K. The schedule includes the residual soil nitrate at planting, nutrient added as fertiliser, nitrogen added in irrigation water and nutrient uptake and removal. On the basis of applied fertiliser the budget for N in lettuce on a crop removal basis was slightly negative (-9 kg ha^{-1}) but on a total crop requirement basis the added fertiliser (85 kg N ha^{-1}) was less than the total crop uptake (134 kg N ha^{-1}). The presence of residual mineral nitrogen at planting and mineralisation throughout cropping are important in meeting lettuce crop nutrient requirements. For the cabbage (2012) and cauliflower (2012), the nutrient budgets were slightly negative on a total crop uptake basis and slightly positive for cauliflower in 2013. In 2012, the total N uptake by sugarloaf cabbage (241 kg N ha^{-1}) was low compared with that of cauliflower (417 kg N ha^{-1}). Importantly, the standard errors on the cauliflower data in this year were high (+123.6) indicating that the results may be high relative to a true mean. This is supported by the 2013 data on uptake for cauliflower (258 kg N ha^{-1}). Notwithstanding, the total crop N uptake for cauliflower on grower B's property in 2013 was 349.9 kg N ha^{-1} with a low standard error (+21.6 kg ha^{-1}) indicating total crop N uptake for cauliflower is very high. The total N uptake and removal for pumpkin was substantially greater than the input, which was only 30 kg N ha^{-1}.

Table 4.1 Nutrient inputs and outputs (kg ha^{-1}) including estimated available soil mineral N at planting (kg ha^{-1}), applied fertiliser, nutrient in irrigation, total available nutrient (TAvN), total crop nutrient uptake (TCNU) and nutrient removed in marketable product (NRMP)at Lockyer Valley Grower A's property for vegetable crops sown between 2011 and 2013.

Nutrient	Estimated available NO_3^- N at planting (kg ha^{-1})		Applied fertiliser	Nutrient in irrigation	TAvN	TCNU	TAvN - TCNU	NRMP *	TAvN - NRMP	Applied fertiliser-nutrient removed
	0-20cm	0-60cm[a]								
Lettuce 2011										
N	63	77	85	0	162	134	28	94	68	-9
P			26		26	19	7	16	10	10
K			56		56	220	-163	138	-82	-82
Cauliflower 2012										
N	42	72	131	0	203	417	-214	149	54	-18
P			26	1	26	74	-48	23	3	2
K			69		69	341	-272	146	-77	-77
Cabbage 2012										
N	42	72	131	0	203	241	-38	159	44	-28
P			26	1	26	28	-2	21	5	4
K			69		69	177	-108	133	-64	-64
Pumpkin 2012										
N	12	18	30	nd	48	113	-66	51	-4	-21
P			13		13	25	-13	13	-1	-1
K			34		34	139	-105	82	-48	-48
Cauliflower 2013										
N	17	32	245	1	278	258	20	116	162	129
P			26	0	26	54	-28	20	5	5
K			176		176	299	-122	140	36	36

nd denotes not determined *indicates head for lettuce cabbage and cauliflower and fruit for pumpkin
[a]The 0-60 cm soil zone represents the effective maximum rooting depth for vegetable crops.

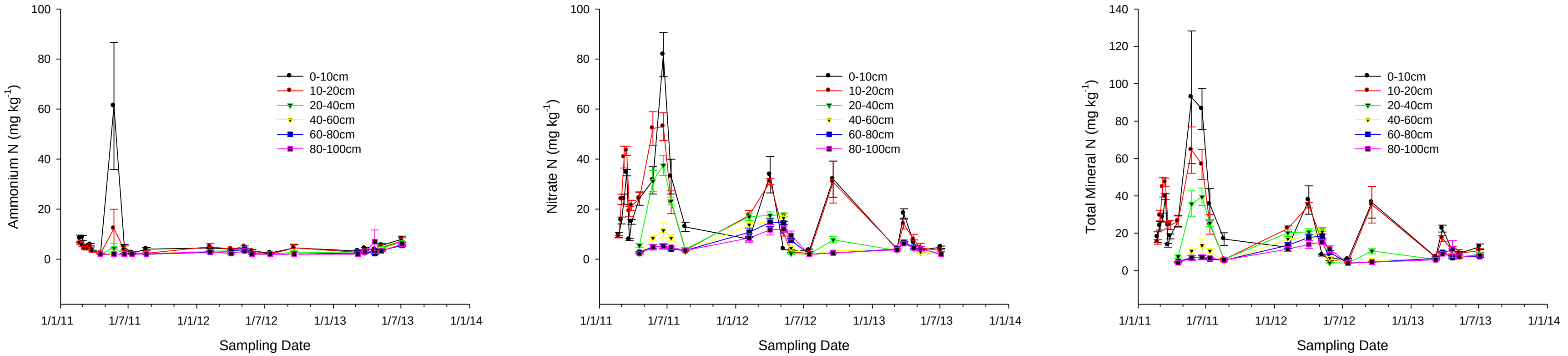

Figure 4.1 Changes in soil ammonium, nitrate total mineral N (ammonium plus nitrate) (including standard errors) from 0-100 cm in the soil sampled for Lockyer Valley Grower A's property for vegetable cropping sequences between 2011 and 2013.

The application of P in each crop was essentially sufficient to meet crop removal. The Lockyer Valley soils are inherently well-supplied with available P and application is essentially not required. Within the confines of sampling variability, the uptake of K matches that of N for most crops. For example, in the 2013 cauliflower crop, total crop N uptake was 258 kg N ha^{-1} while total crop K uptake was 299 kg K ha^{-1}. The removal of N in harvested product was 116 kg N ha^{-1} while that for K was 140 kg K ha^{-1}.

The nutrient budget for grower A's property over the three years is presented as a summary in Table 4.2. On a whole crop requirement (total uptake by harvested product and residues) basis the budget for N, P and K was negative because applied fertiliser did not meet total crop uptake. However, on the basis of nutrient removed in the harvested product the three year budget for N was positive by about 54 kg N ha^{-1}, essentially neutral for P by about 5 kg P ha^{-1} and negative (an overall loss of nutrient) for K of about 189 kg K ha^{-1}.

Table 4.2 Partial nutrient budget including fertiliser inputs and nutrient export as harvested product (kg ha^{-1}) for Lockyer Valley Grower A's property for vegetable crops sown between 2011 and 2013. The cumulative budget is the net loss or gain of nutrients over the 3 years of cropping.

Grower A			Annual budget			Cumulative budget		
Year	Crop		N	P	K	N	P	K
2011	Lettuce	Nutrient removed	93.9	15.6	138.4			
		Nutrient added	85.0	26.0	56.0			
		Balance	**-8.9**	**10.4**	**-82.4**	**-8.9**	**10.4**	**-82.4**
2012	Cauliflower	Nutrient removed	148.8	23.3	145.7			
		Nutrient added	131.0	25.6	68.9			
		Balance	**-17.8**	**2.3**	**-76.8**	**-26.7**	**12.7**	**-159.2**
2012	Pumpkin	Nutrient removed	51.5	13.4	82.5			
		Nutrient added	29.5	12.8	34.4			
		Balance	**-22.0**	**-0.6**	**-48.1**	**-48.7**	**12.1**	**-207.3**
2013	Cauliflower	Nutrient removed	141.9	33.2	158.5			
		Nutrient added	245.1	25.6	176.4			
		Balance	**103.2**	**-7.6**	**17.9**	**54.5**	**4.5**	**-189.4**

The tabulated details for nitrate N with depth over time for grower A's cropping are presented in Appendix 3. Soil ammonium concentrations over the course of the surveyed period did not tend to fluctuate greatly with the exception of the early project sampling when Lablab residues were incorporated. In contrast, the soil concentrations of nitrate varied considerably over the sampling period (Fig. 4.1).

High spikes in nitrate coincided with fertiliser application, particularly in the first sampling immediately after planting in each cropping cycle. The samples were taken in the centre of the bed and the farmer used a fertiliser dropper that drops fertiliser as a band in the central part of the bed so this tends to bias soil samples taken from this zone. However, the placement in this zone is an effective strategy to maximise crop uptake particularly as the crop matures.

Commencing in 2011, high nitrate concentrations were observed in the 0-10, 10-20 and 20-40 cm zones of the profile during the growing season, but by the final harvest the soil nitrate levels in the 10-100 cm zone ranged from 3- 4 mg kg^{-1} and in the 0-10 cm was 13 mg kg^{-1} presumably due to lettuce wrapper leaf breakdown. During the fallow period from 19 Aug 2011 to the next pre-plant sampling on 6 February 2012, considerable accretions occurred throughout the soil profile in the absence of fertiliser application. During the fallow, no cover crop was planted so it is possible that in the absence of a trap crop, N had moved through the profile. Since this crop was harvested in August it is likely cultivation was conducted in mid-September to a depth of 40 cm and with subsequent high summer rainfall (450mm from Oct to Jan) nitrate may have moved substantially in by-pass movement as opposed to leaching. During the 2012 growing season, the levels in the 40-100 cm zone continued to increase through to mid-growth of the cauliflower crop (8 May 2012) and then declined substantially by maturity (16 July 2012) suggesting that crop extraction was effective in removing N though further losses to leaching in the 60-100 cm zone may also have been active. A low rate of fertiliser was applied to the subsequent pumpkin crop planted on 30 July and the soil sample taken on 18 Sept 2012 showed elevated nitrate levels mostly in the 0-20 cm zone but also a slight elevation was observed in the 20-40 cm zone (8 mg kg^{-1}). There was no evidence of nitrate movement into the 60-100 cm zone in 2012. In the interim to the next sampling, severe flooding was again recorded with the region receiving in the order of more than 220 mm of rain over a 3 day period. Hence the soil nitrate levels at the 8 March sampling were consistently low throughout the profile (around 4 mg kg^{-1}).

4.1.2.2. Nitrogen inputs from lablab residues

At the commencement of the project the selected site was cover cropped to lablab. Prior to incorporation, a soil sample was taken on 10 Feb 2011. The lablab was incorporated on about 14 Feb 2011. Soil samples were subsequently taken at 7 day intervals up to the 29 March after which the standard soil sampling regimen commenced as described earlier. The details of the volume of fresh and dry matter incorporated along with the rates of N and C fixed and N and C concentrations are presented in Table 4.3.

Table 4.3 Mean fresh yield (tonne ha^{-1}), dry matter content (DM%), dry matter yield (DMYld) (tonne ha^{-1}), N and C composition (%) and N and C fixed for a lablab cover crop incorporated at a survey site for Grower A's property in the Lockyer Valley 2011.

	Fresh Yield	DM%	DMYld	N%	C%	N fixed (kg ha^{-1})	C fixed (t ha^{-1})
Mean	25.1	20.1	5.0	2.35	44.0	119	2.2
se	2.56	0.29	0.49	0.26	0.21	20.7	0.22

The soil nitrate concentration increased from the time the lablab was incorporated reaching a maximum of about 40 mg N kg^{-1} at 29 days after incorporation (15 March 2011) (Fig. 4.2). In contrast, the ammonium concentration did not alter greatly over the period after incorporation. The nitrate concentration then declined rapidly until 22 March (13 mg N kg^{-1}) before again rising to the end of the study period (18 April 2011). This indicated that cycles of mineralisation and immobilisation were active in the soil over the period of this study. A better understanding of the mineralisation dynamics of soil organic matter is important in understanding the contribution that legume cover crops can make to vegetable crop N uptake. The total contribution of the lablab was about 120 kg N ha^{-1}.

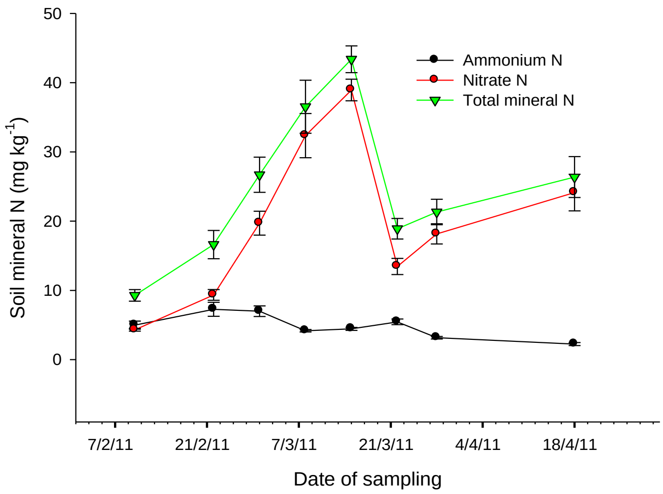

Figure 4. 2 Changes in soil ammonium, nitrate, and total mineral N (ammonium plus nitrate) from 0-20 cm in the soil sampled for Lockyer Valley Grower A's property after a lablab cover crop was incorporated in 2011. The lablab was incorporated on 14 Feb 2011.

4.1.2.3. Cover cropping effects on soil N

To highlight the effectiveness of cover cropping to mitigate N losses, a paired site comparison was made of the soil profile N levels in the datum area (without cover crop) and an area 35 m away from the datum (cover cropped with forage sorghum). The forage was planted in September 2011 and sampled on 6 Feb 2012. The ammonium levels through the profile were similar across the forage and non-forage samples. However for nitrate there was a considerable difference between the forage and non-forage samples throughout the soil profile (Table 4.4). Under forage the mean values from the 20-100 cm depth were 2 mg kg^{-1} which is the lower detection limit for the analysis, and in the 0-20 cm zone soil nitrate concentrations were only 3 mg kg^{-1}. At each soil depth in the non-forage samples, the soil nitrate concentration was substantially greater (ranging from 8-18 mg kg^{-1}) than in the forage samples.

Table 4.4 Effect of cover cropping with and without forage sorghum on mean soil ammonium, nitrate and total mineral N concentrations (including standard errors) over soil depth in a vegetable cropping system in the Lockyer Valley 2012.

Soil depth	Ammonium-N (mg kg^{-1})				Nitrate N (mg kg^{-1})				Total Mineral N (mg kg^{-1})			
	Forage		No Forage		Forage		No Forage		Forage		No Forage	
0-10cm	5	±0.5	4	±0.3	3	±0.5	8	±0.7	8	±0.71	12	±0.6
10-20cm	4	±0.2	5	±1.3	3	±0.5	17	±2.0	7	±0.41	22	±1.4
20-40cm	5	±1.3	3	±0.5	2	±0	17	±1.5	7	±1.35	20	±1.9
40-60cm	3	±0.6	3	±0.6	2	±0	14	±0.9	5	±0.65	17	±0.4
60-80cm	2	±0.5	2	±0.2	2	±0	11	±1.7	5	±0.48	13	±1.7
80-100cm	3	±0.4	3	±0.4	2	±0	8	±1.7	5	±0.41	11	±1.3

4.1.2.4. Lockyer Valley - Grower B

The details for Grower B’s production, yield components and nutrient composition and uptake for N, P and K are presented in Appendix 3. The nutrient content data in this table are within the expected values for healthy crops. For cauliflower and lettuce the values presented are similar to those for Grower A’s crops. A complete schedule of nutrient inputs and outputs is presented in Table 4.5 for N, P and K.

For each crop, the total crop uptake for N and K was substantially greater than the amount applied as fertiliser, and total uptake was consistently greater than the total available nutrient. At Grower B’s site there were consistently high nitrate levels in irrigation water in 2012 and 2013 indicating that within the region some nitrate is reaching the aquifer. This nitrate would be supplementing the grower’s crop fertiliser requirements, but further objective research on this would as a dedicated study would be required as the nitrate concentrations in the irrigation water varied considerably within the season.

The cumulative nutrient budget over 3 cropping seasons was strongly negative for Grower B where the shortfall in nutrients was 148 kg N ha^{-1}, 20 kg P ha^{-1} and 383 kg K ha^{-1} (Table 4.6). The shortfall in P is minimal and the Lockyer Valley soils are inherently very high in available P but the issue of the K deficit is important as intensive cropping continues to remove large amounts of K without replacement. The shortfall in N is a concern at this site as presumably mineralisation of soil organic matter is an important source of crop N but in the long term would lead to soil organic matter decline.

The full details for the soil nitrate N with depth over time for Grower B’s cropping are presented in Appendix 3.

Table 4.5 Nutrient inputs and outputs (kg ha^{-1}) including estimated available soil mineral N at planting (kg ha^{-1}), applied fertiliser, nutrient in irrigation, total available nutrient (TAvN), total crop nutrient uptake (TCNU) and nutrient removed in marketable product (NRMP) at Lockyer Valley Grower B's property for vegetable crops sown between 2011 and 2013.

	Estimated available NO_3^- N at planting (kg ha^{-1})		Added fertiliser	Nutrient in irrigation	TAvN	TCNU	TAvN - TCNU	NRMP	TAvN - NRMP	Applied fertiliser-removed
	0-20cm	0-60cm[a]								
Cabbage 2011										
N	40	73	69	12	154	216	-62	134	21	-65
P			13		13	41	-28	28	-15	-15
K			28		28	305	-277	189	-161	-161
Lettuce 2012										
N	48	83	45	5	133	153	-20	134	-1	-89
P			16		16	23	-6	28	-12	-12
K			35		35	267	-231	189	-154	-154
Cauliflower 2013										
N	44	77	104	13	194	350	-156	128	66	-24
P			20		20	71	-51	24	-4	-4
K			42		42	388	-346	148	-106	-106

TAvN denotes - Total available nutrient
TCN uptake - denotes Total crop nutrient uptake
NRHP denotes Nutrient removed in harvested product
nd denotes not determined.
[a]The 0-60 cm soil zone represents the effective maximum rooting depth for vegetable crops.

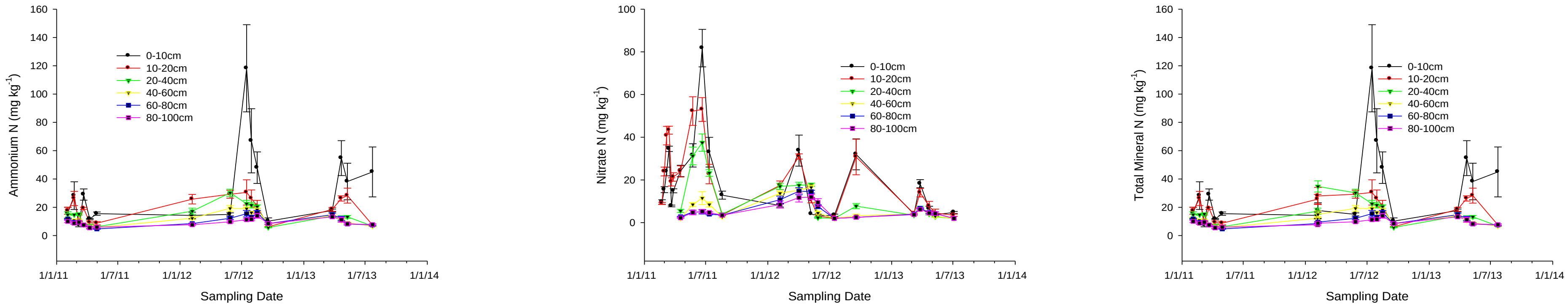

Figure 4.3 Changes in soil ammonium, nitrate and total mineral N (ammonium plus nitrate) (including standard errors) from 0-100 cm in the soil sampled for Lockyer Valley Grower B's property for vegetable cropping sequences between 2011 and 2013.

Table 4.6 Partial nutrient budget including fertiliser inputs and nutrient export as harvested product (kg ha^{-1}) for Lockyer Valley Grower B's property for vegetable crops sown between 2011 and 2013. The cumulative budget is the net loss or gain of nutrients over the 3 years of cropping.

Grower B			Annual budget			Cumulative budget		
Year	Crop		N	P	K	N	P	K
2011	Cabbage	Nutrient removed	133.5	28.3	188.9			
		Nutrient added	69	13	28			
		Balance	**-64.5**	**-15.3**	**-160.9**	**-64.5**	**-15.3**	**-160.9**
2012	Lettuce	Nutrient removed	104.2	17	151.1			
		Nutrient added	45	16	35			
		Balance	**-59.2**	**-1**	**-116.1**	**-123.7**	**-16.3**	**-277.0**
2013	Cauliflower	Nutrient removed	127.9	23.5	148			
		Nutrient added	104	20	42			
		Balance	**-23.9**	**-3.5**	**-106**	**-147.6**	**-19.8**	**-383.0**

Soil ammonium concentrations over the course of the surveying did not fluctuate greatly with the exception of spikes when fertiliser was applied (Fig. 4.3). Spikes in nitrate also coincided with fertiliser application and particularly in the first sampling immediately after planting in each cropping cycle, consistent with the findings for grower A.

In general the higher concentrations of nitrate were observed in the 0-20 cm zone and to a lesser extent the 20-40 cm zone but high concentrations were generally not observed at depths greater than 40 cm. As for grower A, during the fallow period from 2011 to the next preplant sampling in 2012 some accretion occurred throughout the soil profile in the absence of fertiliser application. During the fallow no cover crop was planted so it is possible that in the absence of a trap crop N had moved through the profile. However, in general, Grower Bs soil maintained very low nitrate concentrations in the 40-100 cm zone of the profile reflecting the marginal budget the cropping system operates on. The K budget was strongly negative with an average annual loss of K of about 130 kg ha^{-1} and more than twice that of Grower A.

To supplement this data on nutrition uptake and plant composition data for other nutrients [calcium (Ca), magnesium (Mg), sulphur (S), boron (B), copper (Cu), iron (Fe), manganese (Mn), sodium (Na) and zinc (Zn)] is presented for the cabbage 2011 and lettuce 2012 and cauliflower 2013 is presented for reference in Appendix 3.

4.1.2.5. General Lockyer case study conclusions

With the exception of the 2013 crop for Grower A both Growers A and B operate neutral to negative N budgets in relation to nutrient removal in harvested product. On this basis fertiliser applied in these cropping systems is managed in a way to reduce the potential losses and it is unlikely that substantial amounts of N could be lost. Notwithstanding, at both farms in the fallow of summer 2011-12 the data indicates slightly elevated nitrate levels in the lower profile. It is possible that through mineralisation nitrate accretions may have occurred in the absence of fertiliser application. The movement of this in cultivated soil may have moved rapidly as bypass solute or as evidenced in core samples the movement may have been due to illuviation processes in the self-mulching soil. There was evidence at Grower Bs block in the 2012 season that the aquifer water had levels of nitrate. Since the accretions occurred at both Growers A and B it is possible that a broad landscape process of nitrate movement may have been occurring but this requires a further more detailed study. Overall the long term monitoring of soil nitrtate levels across the properties showed that soil nitrate levels were high at planting in the 0-40 cm and were generally depleted through the profile by crop maturity. Monitoring of soil inputs and crop nutrient uptake and removal is important in understanding crop nutrient dynamics and minimising offsite environmental impacts. Of particular significance in the study was the strong negative budget for K, which represents a serious sustainability issue.

4.2. Watsons Creek nutrient monitoring

4.2.1. Stream water monitoring

A key component of this project in Victoria was the water quality monitoring of Watsons creek at sites above stream and below stream from a large vegetable farm. The aim of this was to identify changes in nutrient levels in the creek in summer and winter over a two year period. Previous work done by the Victorian EPA in April 1998 reported 'greatly elevated' nutrient levels, low dissolved oxygen at 2.5 mg/L, high electrical conductivity at 1980 µs/cm and a neutral pH at 7.34 in Watsons creek just below farming areas. Further issues included a poorly vegetated riparian zone and low base-flow. The EPA blamed agricultural runoff as the cause of the impoverished conditions of the creek. Another important study by Melbourne water conducted in 1999, focused on nutrient levels in the creek. The outcome of the study found that levels of nitrogen and phosphorus were most elevated in the lower reaches of the creek. Melbourne Water concluded that the most likely source of nutrients in the creek was from market garden operations.

Water samples were collected approximately 100 m upstream and downstream from the farm boundary. All water samples were collected in clean water bottles suitable for the purpose of water testing, and extension sampling apparatus was used to collect water just below the surface. The containers were cooled and transported chilled to the laboratory. All tests were carried out at the University of Melbourne and used standard methods described in (APHA 2005; EPA 2009, ANZECC & ARMCANZ. 2000). The nutrient parameters tested included, ammonia-N, Nitrite-N, Nitrate-N, total Nitrogen and Total Phosphorous. Other parameters such as pH, turbidity and total dissolved solids were also measured.

This component of the work measured nutrient levels in the surface water of Watsons creek above and below a large vegetable farm. The purpose of this component was to evaluate the levels of nutrient in the stream over two seasons. The results of the tests (Table 4.7) show that there is very little difference in nutrient levels in the creek water in samples taken above and below the farm. In saying this it is however important to note that in the first season (Table 4.7), sampling of the water occurred after a period of heavy rain. In the preceding 30 days there was a total rainfall of 174 mm for sampling in February and 48 mm for sampling in September. The second year (Table 4.7) had only 34 mm in the preceding 30 days before sampling in February and 54 mm in the 30 days before sampling in September. It is important to note that the second year was much dryer than the first year of the study. Despite this the concentration of nitrate N overall was low in the above farm samples and only marginally greater in the below farm samples.

Table 4.7 Vegetable Grower Property Water tests results for 2011 and 2012 for water samples taken from Watsons Creek above a vegetable grower property (GFa) and below a vegetable grower property (GFb).

Water sample analyte	SEPP	Sampling dates							
		10 Feb 2011		12 Sept 2011		24 Feb 2012		21 Sept 2012	
		GFa	GFb	GFa	GFb	GFa	GFb	GFa	GFb
pH	6.5	7.28	7.31	7.30	7.25	6.95	6.90	6.98	6.95
Turbidity	15	52.5	49.6	29.9	32.7	34.6	32.9	29.9	30.5
TDS (mg/L)	500	470	480	405	430	210	190	125	108
Ammonia as N (mg/L)		<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Nitrite as N (mg/L)		0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Nitrate as N (mg/L)		3.10	3.45	3.95	4.35	1.90	1.65	3.25	3.40
Total Nitrogen as N (mg/L)	0.6	6.1	6.8	5.1	4.6	2.1	1.8	3.7	3.6
Total Phosphorus as P (mg/L)	0.05	0.82	0.88	0.95	0.90	0.49	0.52	0.46	0.48

SEPP – State Environmental Protection Policy objective.
ANZECC-Australian and New Zealand Guidelines for Fresh and Marine Water Quality
Rainfall for previous 30 days 24/2/2012 = 34.4mm
Rainfall for previous 30 days 21/09/2012 = 54.8mm

It is important to note that higher levels of nutrients were found after intense rainfall in the preceding 30 days (2011). Hence heavy rain washed nutrients into the creek from the subdivided residential areas in Baxter and South Frankston resulting in a higher level of nutrient in the creek. Another major source of nutrients that perhaps is not often considered is the large number of livestock that are grazed in the catchment. A census carried out late in 2010 showed approximately 500 cattle/horses and over 300 sheep/alpaca grazed in the catchment area. A conservative estimation is that these animals may be capable of secreting over 1000 tons of manure each year or 45,000 kg of Nitrogen and 9,000 kg of Phosphorous. These nutrients have the potential to leach into the catchment area and are mobilised by large volumes of rain water.

4.2.2. Watsons Creek vegetable farm nutrient budget

The nutrient budgets for lettuce in Watsons Creek showed that these crops were grown on strong positive budgets where N and P inputs were far in excess of total crop uptake let alone that removed in the harvested product. The results (tables 4.8 and 4.9) indicate that nutrient inputs (as manure and fertiliser) were not optimized and there is strong potential for nutrient loss. A substantial part of this imbalance in the nutrient budget data and nutrient inputs was through the use of fowl manure which contributed greatly to the soil nutrient loading. The extent of this loading was not fully appreciated by the participating grower and the results of this study subsequently led to the grower changing some practices in order to optimize fertilizer application; principally by halving the chicken manure inputs.

The results outlined in this report indicate that a review of nutrient management practices through a nutrient budgeting survey on a regional basis would be useful. A more substantial nutrient budgeting survey should verify the assumptions made in calculating the nutrient input from fowl manure applications (data not presented). Options for further work were discussed at the draft results meeting. These include:

- Following a crop rotation program for a block through one year from full rate fowl manure application/celery/lettuce/cover crop
- Analysing fowl manure just prior to application and checking application rates

Table 4.8 Comparison of lettuce crop nutrient dynamics for cos and iceberg lettuce crops grown in Watsons Creek Victoria.

Lettuce	Plant population ('000 plts ha^{-1})	DM%	Fresh Yield	Nutrient Composition (%)			Nutrient Uptake (kg ha^{-1})		
				N	K	P	N	K	P
Iceberg									
Field residue	52.0	10.4	21.7	1.9	4.1	0.29	43	94	7
Heart		3.5	43.5	3.6	7.0	0.79	56	108	12
Cos									
Field residue	52.0	8.6	12.6	2.2	6.2	0.38	24	69	4
Heart		3.8	57.9	4.0	9.0	0.89	87	199	20

Table 4.9 Comparison of lettuce crop nutrient uptake and fertiliser use efficiency for cos and iceberg lettuce crops grown in the Watsons Creek Victoria.

Crop	Total crop nutrient uptake (kg ha^{-1})			Nutrient removed in harvested product (kg ha^{-1})			Fertiliser nutrient applied (kg nutrient ha^{-1})			Total crop nutrient use efficiency (%)			Marketable crop nutrient use efficiency (%)		
	N	K	P	N	K	P	N	K	P	N	K	P	N	K	P
Lettuce	99	202	19	56	108	12	249	159	131	40	127	15	22	68	9
Cos Lettuce	111	268	24	87	199	20	312	153	194	36	175	12	28	130	10

4.3. Bowen nutrient monitoring

In this part of the project, we attempt to identify and evaluate technologies and strategies that can assist in minimising nutrient losses from farms. The nutrition of sweet corn was monitored and evaluated using FullStops™ to quantify nitrate-N concentrations of irrigation wetting fronts at strategic soil depths and supplemented with soil and nutrient analysis and nutrient budgeting.

4.3.1. Crop monitoring tools and strategies

The FullStop™ has been developed by CSIRO to capture irrigation wetting front movement through the root zone at critical depths. FullStops™ are best used in pairs and buried in crop root zones at two depths. When the device has collected a sample, a pop-up flag indicates water has reached that depth. Samples are then collected and analysed for nutrient and salt concentration. Refer to Henderson *et al.* (2011) for more details on FullStop™ operation and interpretation. Growers can use the data obtained to better regulate fertigation schedules in real time. Optimising irrigation and fertigation volumes and intervals maximises nutrient concentration in the root zone during peak requirement stages and prevents leaching and loss of inputs.

Typically, soil water will drain at between 0 kPa and -10 kPa; this water is subject to gravitational, downward movement in soil. Many factors affect water and solute movement between -3 and -10 kPa including soil structure, pore-size distribution, water content and solute concentration. In the event that high nitrate concentrations are detected in the lower section of root zones irrigation and fertigation schedules can be altered to reduce losses.

4.3.2. Methods

The monitoring site was situated in Bowen Queensland on a grey, clay-loam soil with no obvious textural boundaries and organic carbon content of 0.6% at 0-0.15 m declining to 0.4% at 0.4 m. Sweet corn variety Garrison was sown on the June 7th 2011 (0 Days after sowing [DAS]). The collaborating grower performed all agronomic practices as per their standard practice.

Pre-plant soil cores to a depth of 1 m were taken where FullStops™ were installed. The soil core samples were divided into paper bags labelled 0-0.15 m, 0.15-0.4 m, 0.4-0.6 m, 0.6-1 m for nutrient analysis. Follow-up soil cores were collected mid-season (71 DAS) and at harvest (94 DAS). These soil cores were taken from the centre of the same bed, under an emitter in the drip tape 2 to 3 meters from the installed FullStop™. Three sets of FullStops™ were installed at 0.15 and 0.4 m depths according to manufacturer's specifications.

Wetting front samples were collected using a 60 mL syringe to draw samples and the samples stored in labelled plastic bottles, transported with ice packs and immediately frozen at the laboratory and held for later analysis. A Merck RQeasy nitrate meter using NO_3^- Reflectoquant® test strips was used to analyse nitrate-N concentration. All fertiliser applications were documented (supplied by farm records) and nutrient analysis conducted on harvested plant samples. A basal fertiliser application included 64 kg N ha^{-1}, 11 kg P ha^{-1} and 66 kg K ha^{-1}. The grower applied 170 L ha^{-1} of Easy-N® (≈72 kg N ha^{-1}) at 15 DAS, a further 170 L ha^{-1} of Easy-N® (≈72 kg N ha^{-1}) plus 53 kg ha^{-1} of potassium sulphate at 35 DAS and 100 L ha^{-1} of Easy-N® (≈42 kg N ha^{-1}) at 75 DAS. Nitrogen use efficiency on a total crop basis was calculated by dividing total crop N uptake by the applied fertiliser N and expressed as a percentage. Nitrogen use efficiency on a marketable cob basis was calculated by dividing N removal in the marketed cobs by the applied fertiliser N and expressed as a percentage.

At harvest twelve whole plants were cut at ground level, partitioned, weighed and dried at 60°C. The plants were partitioned into stem, leaf, flower, primary cob and immature cob. All primary cobs were de-husked and quality assessed based on Woolworths specifications prior to drying. Nutrient analysis of soil cores and tissue samples were performed by Incitec Pivot Ltd.

4.3.3. Results and Discussion

4.3.3.1. Nitrogen fertiliser scheduling

During early crop development (16 to 28 DAS) nitrate-N concentrations in samples collected from the FullStops™ at 0.15 and 0.4 m showed a similar increasing trend (Fig. 4.4). At this crop growth stage sweet corn growth is slow and can be sustained by pre-plant fertiliser application and the first N fertigation can be delayed until 28 DAS. After 28 DAS vegetative development is rapid and root systems are sufficiently developed to capture and utilise nutrients. FullStop™ sampling results from 52 to 75 DAS revealed low nitrate-N concentration coinciding with high crop nutrient demand. During the two weeks prior to and after tassel emergence, sweet corn requires about 60% of the total nitrogen utilised during its lifecycle (Wright *et al.* 2005) and the present study's data indicates soil nitrate concentrations were low during this critical stage.

In minimising losses it is essential to retain nitrate-N in the high root-density zone between 0 and 0.15 m to prevent nitrate-N movement past 0.4 m. On several occasions nitrate-N concentrations decreased at depths of 0.15 m whilst increasing at the 0.4 m depth. These trends are visible in Figs 4.5 at 47, 57 and 87 DAS. Nitrate in the 0.4 m samples increased from about 20 mg L^{-1} to about 30 mg L^{-1} during the 17 to 47 DAS highlighting the effect of over-irrigation in increasing the leaching risk. Rapid increases in nitrate-N after an irrigation event at 46 DAS indicated a fertigation event; this date was different from the advised date of fertiliser application at 35 DAS. In the ensuing 3 days of sampling sharp decreases occurred in nitrate for samples from 0.15 and 0.4 m resulting in very low nitrate concentrations at both depths. Nitrate was likely to have leached below 0.4 m and out of the root zone and further deep soil sampling is required to better understand the dynamics of nitrate movement. However, it is also possible that nitrate may have been lost by denitrification because of the temporary saturated soil conditions following irrigation.

4.3.3.2. Nutrient budgeting and uptake

Nutrient budgeting, based on fertiliser inputs and tissue analysis, revealed inefficient use of nitrogen fertiliser (Table 4.10). Fertiliser use efficiency for N on a whole crop basis was 67% giving a potential loss of about 80 kg/ha. Sweet corn has a high requirement for N and can store up to 310 kg/ha in above ground plant biomass (Beckingham 1999). Nitrogen concentration in plant tissue was within optimal ranges (data not presented). Soil cores to 1 m (see Fig. 4.5) failed to identify the dynamics of the 83 kg/ha of nitrogen not used by the crop. It is likely this residual nitrogen had leached below 1 m though some atmospheric loss is likely. In the absence of further incremental samples from the lower root zone limit (of about 0.6 m) to at least 1.0 m it is not possible to accurately assess this since the N concentrations at 1.0 m essentially did not change over the course of the study (Fig. 4.5). Indeed the soil nitrate levels were nominally higher at planting than they were at mid-season and post-harvest at all depths of sampling which is inconsistent with the finding that the crop operated on a strongly positive budget.

Nutrient budget calculations indicate phosphorus and potassium mining from soil reserves with FUE percentages well in excess of 100%.

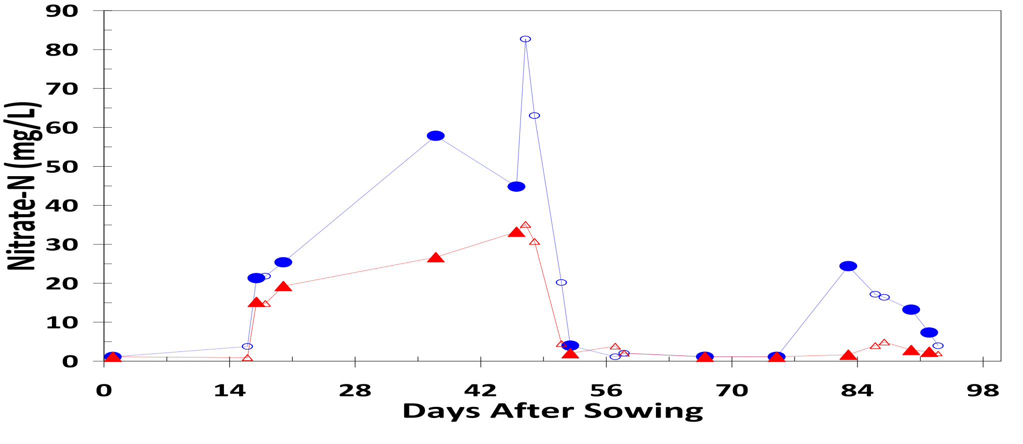

Figure 4.4 Changes in concentrations of nitrate (mg/L) over duration of the cropping cycle in solution extracts from FullStops™ at 0.1 and 0.4 m depths in a sweetcorn crop grown at a Bowen vegetable growers property in 2011. The 0.15 m depth samples are represented by the dotted circle line and 0.4 m represented by the dashed triangle lines. Large filled data points indicate samples where irrigation events were initiated on the day of collection whilst the open data points are residual samples from previous irrigation events.

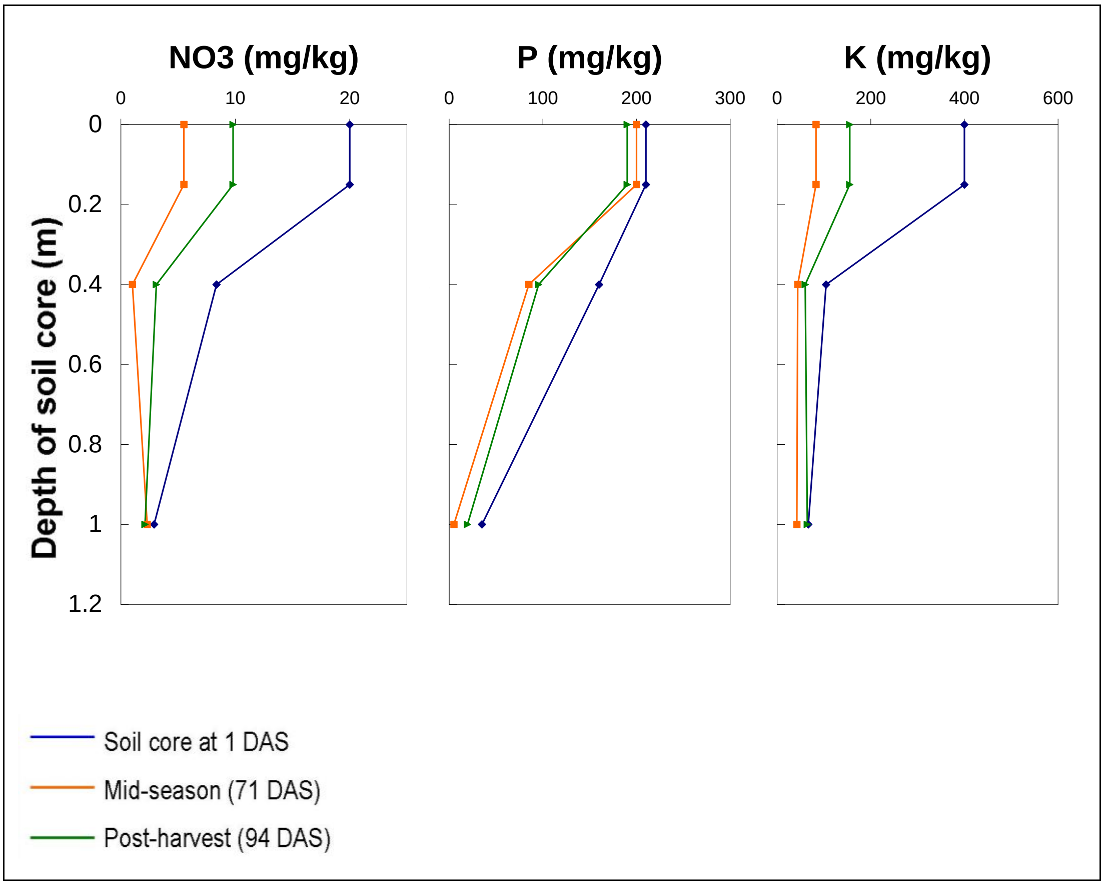

Figure 4.5 Concentrations of N, P and K (mg/l) in soil solution extracts at 0.15, 0.4 and 1.0 m at sowing (1 DAS), mid-season (71 DAS) and harvest season (94 DAS) in a sweetcorn crop grown at a Bowen vegetable growers property in 2011.

Table 4.10 Fresh and Dry matter yields and nutrient inputs and outputs (kg/ha) including nutrient removed in harvested product, total crop nutrient uptake and applied fertiliser at Bowen vegetable growers property for sweetcorn sown in 2011.

Yield	Fresh Yield (t ha^{-1})	Dry Matter Yield (t ha^{-1})	
Marketable Cobs	22	4.2	
Residue	--	6.4	
Nutrient Dynamics	**N**	**P**	**K**
Marketable Cob nutrient removal (kg/ha)	80	17	51
Residue nutrient uptake (kg/ha)	91	23	160
Total uptake (kg/ha)	**171**	**40**	**211**
Applied fertiliser nutrient (kg/ha)	**250**	**11**	**88**
Nutrient Balance (kg/ha)			
(Applied nutrient - Nutrient uptake)	**79**	**-29**	**-123**
Nutrient use efficiency (Whole crop basis) (%)	67	370	240
Nutrient use efficiency (Marketable Cob basis) (%)	32	155	58

4.3.3.3. Environmental risks

Throughout the monitoring period the highest nitrate concentration reading for individual samples was 96 mg/L at 0.15 m on 47 DAS and 53 mg/L at 0.4 m on 48 DAS (data not presented). The Australian and New Zealand Guidelines for Fresh and Marine Water Quality 2000 suggest nitrate-N concentrations remain below 125 mg/L. Infrequent offsite movement of irrigation water with this nitrate concentration is unlikely to greatly contribute to waterway pollution in the short term. However, more broadly across the Bowen region over the growing season, the continuous leaching of nitrate from farms adopting similar fertiliser practices may contribute to increased nutrient levels in streams, rivers and ultimately the Great Barrier Reef Lagoon. This would require intensive surveying to assess.

4.3.3.4. Conclusions and recommendations

The standard practice on this farm shows that system nitrate losses are likely to be relatively high since the application of N was almost 80 kg/ha more than whole crop uptake let alone the marketable crop nutrient removal. The data collected from the FullStop™ samples particularly at 0.4 m highlight elevated nitrate concentrations of up to about 35 mg/L, which although below the critical ANZECC value of 125 mg/L, are cause for concern. Occasional leaching of nitrates below the root extraction zone is inevitable and in the short term might not pose to great a risk, however, continued leaching of on a region-wide basis is likely to be some concern for waterway health. Minimising losses in the system will improve efficiency and reduce inputs as well as contribute to protecting these sensitive areas. The findings in this grower study are in contrast to the findings for the Lockyer Valley case studies where N fertiliser tended to be under-applied.

The use of irrigation scheduling, monitoring water availability and volumes of application are practices that can help mitigate losses of nitrates from the root zone. Early season growth can be maintained on the pre-plant fertiliser application and a delay in the first fertigation until the four-leaf stage (approximately 20-30 DAS for this variety) would ensure a greater proportion of nutrient is present at the commencement of the high vegetative growth stage which could allow reduced fertiliser inputs and reduce the risk of nutrient leaching. This strategy would also minimise the risk of nitrate loss by denitrification. Fertigation quantities should be timed to coincide with the critical demand stages.

The positioning of FullStops™ at 0.4 m allows farmers to manage crop nutrition and irrigation in a way that can maintain nutrients in the high root-density zone. However, in the absence of additional data it can be difficult to determine how far nutrients may be leached. Tensiometers installed at 0.6 m can provide further information on the degree of soil wetness at depth and the extent of drainage after irrigation events. Though FullStops™ can be installed at depths of 0.6 m the limitations of equipment installation and difficulty in retrieving them makes them a more difficult tool for monitoring wetting fronts at depths greater than 0.4 m.

The collection of additional soil cores at a range of depths and with greater frequency would complement the data and help determine the location and movement of any nutrient bulges in the soil profile. This would have been useful in the present study to determine the dynamics of nitrate movement, particularly in the early part of the season when crop uptake was low.

4.4. *Case study summary*

The case studies (and nutrient budgeting data Chapter 3) for the Lockyer Valley demonstrate that nutrient inputs are highly efficient in this region. In contrast the single case studies obtained in Watsons Creek and Bowen showed much lower fertiliser use efficiencies. However, these results might not be representative of the nutrient use practices in their respective regions. Furthermore, it indicates that the comprehensive findings from the Lockyer Valley survey should not be seen as being representative of the whole industries practice. The data indicates that regional differences are likely to exist in how nutrient inputs are managed and this depends on both soil type and the availability of manure products as soil amendments in vegetable cropping.

The monitoring of nutrient inputs, crop uptake and crop removal, irrigation inputs, nutrient solutes in soil and soil analysis to depth are effective tools in identifying nutrient losses from vegetable farms. The results outlined in this report indicate that a review of nutrient management practices through a comprehensive nutrient budgeting survey on a regional basis is required to identify the overall potential for the vegetable industry to impact on waterway health. The case study with Grower A highlighted that a summer rotation of forage sorghum thoroughly depleted the soil profiles nitrate N which is an effective strategy for reducing the risk of N loss and ensuring nutrients are maintained in the surface soil. Importantly, more detailed knowledge of the importance of low nutrient-input rotations and nutrient return in residues from low harvest-index crops (eg. broccoli) needs consideration in evaluating whole of system nutrient budgets.

The case studies and nutrient budgeting identify shortfalls in nutrient application particularly K in many vegetable farms.

5. Research trials on vegetable nitrogen requirements and efficiency

5.1. *Introduction*

The evaluation of nutrient dynamics based on the Lockyer Valley surveys highlighted that farmers tend to operate on neutral to slightly negative crop nitrogen budgets. Objective data to optimise crop responses to N are not available in Australia, particularly for more modern varieties. In this chapter the results are reported on a series of experiments that aim to identify vegetable crop responses to N application rates and the interaction with agronomy aimed at improving crop nitrogen use efficiency. These experiments were conducted at the Qld DAFF Research Facilities during the seasons 2011-2013 and included:

- Experiment 1 An evaluation of the effects of N rates on the growth of broccoli, cabbage, cauliflower, celery, cos lettuce and iceberg lettuce
- Experiment 2 effects of fertiliser rate by plant density were evaluated
- Experiment 3 The effects of timing of fertiliser application on lettuce and broccoli

Results from a further 2 experiments are presented in the appendices. This includes an evaluation of the effects of vegetable crop residues on soil nitrogen availability (Appendix 4) and a comparison of nutrient dynamics in 2 vegetable systems (conventional and organic mulch) (Appendix 5).

5.2. *Experiment 1 - Vegetable crop responses to N rate*

5.2.1. Materials and methods

A field experiment was established in the winter production season in the Lockyer Valley (Queensland Government DAFF Gatton Research Facility) aimed at developing nutrient response profiles for a range of vegetable crops. Prior to planting the vegetable test crops, the trial site was planted to forage sorghum in September 2010 and the forage sorghum was bailed and removed from the site to minimise soil residual nitrate levels and to ensure the site was uniform with respect to mineral N status. The range of crops included Iceberg lettuce (cv. Kong), cos lettuce (cv. Shrek), celery (cv. Sierra), broccoli (cv. Bravo), cabbage (cv. Warrior) (drumhead) and cauliflower (cv. Adventurer). The experiment was planted on 19 April 2011 using seedling transplants. The plant populations for cos, iceberg, celery and broccoli were 60,600 plants ha^{-1} and for cabbage and cauliflower were 22,200 plants ha^{-1}. In the experiment, eight N treatments were imposed: 0, 40, 80, 120, 160, 200, 240, and 280 kg N ha^{-1}. Nitrogen treatments were added as urea and irrigated via overhead solid set irrigation.

The experimental design was a split-plot with N treatments allocated to the main plots and crop species nested within the main plots with 4 replicates. The dimensions of the main plots were 18 m by 3.0 m with each crop species subplot being 6 m by 1.5 m. A minimum buffer between N treatments of 1.5 m was imposed to prevent cross-contamination between treatments. The N treatments were imposed as urea only to avoid confounding the effects of other nutrients, and were added in increments as per Table 5.1. At planting, 80 kg K ha^{-1} was applied as sulphate of potash and the soil is inherently very high in P.

A whole plant sample from each plot was collected at regular intervals, based on the crop's maturity and availability of sufficient plants for sampling. This roughly equated to about 7 day intervals for broccoli and lettuce (short season), 7-10 days for celery (long season high density) and about 14 days for cabbage and cauliflower (long season low density). At each sampling the fresh weight of the whole plant sample was determined and the sample dehydrated at 72°C, weighed and held for analysis as required. At maturity a final harvest was conducted where the whole plant was harvested and partitioned into the marketable component and the field residue component. The weights of the components were determined and the samples dehydrated at 72°C, weighed and analysed for total N content. Initial soil samples were taken from each block prior to planting. All soil samples were dried at 40°C and held for analysis as required. Immediately after the final harvest, deep soil samples to 80 cm were collected for each sub-plot and partitioned into 0-10, 10-20, 20-40 40-60 and 60-80 cm increments and held for analysis as required.

Table 5.1 Timing and rates of nitrogen application (kg ha^{-1}) in the 2011 nitrogen response trial conducted at the Queensland DAFF Gatton Research Facility.

N Treatment	Timing of application (Days after planting)			
	0	14	26	36
0	0	0	0	0
40	40	0	0	0
80	40	40	0	0
120	40	40	40	0
160	40	40	40	40
200	40	53.3	53.3	53.3
240	40	66.7	66.7	66.7
280	40	80	80	80

Nitrous oxide emissions were also measured in the cabbage plots from 42 days after planting (DAP) where two chambers (24 cm in diameter) were installed per plot with one covering the cropping row and the other covering the inter-row area. Total number of chambers was 32 (4 N rates * 4 replicates * 2 positions). Gas samples were taken between 9:00 and 11:00 AM by closing the chambers for ≈1 h. Soil samples were taken from three points per plot on 41, 48, and 56 DAP (0-20 cm), and on 17 August 2011 after harvest (0-10 cm, 10-20 cm, 20-40 cm, 40-60 cm, 60-80 cm and 80-100 cm). Soil moisture content, mineral N (KCl-extractable NH_4^+-N and NO_3^--N) and water-soluble C were determined.

5.2.2. Results and Discussion

5.2.2.1. Celery response to N

Both the fresh yield and dry matter yield of the harvested celery heads increased with increasing N application rate up to 160 kg ha^{-1} above which the response was not significant (Table 5.2). No marketable heads were produced in the 0 and 40 kg ha^{-1} treatments. In contrast to yield, N concentration in the plant tissue increased with N rate up to 200 kg ha^{-1}. Removal of N in the marketable head increased progressively up to the highest N rate (280 kg ha^{-1}). The fresh yield of the field residues tended to be higher in the 0 and 40 kg ha^{-1} treatments since no marketable head was harvested and all biomass produced was included as field residue. The fresh yield and dry matter yield of the trimmed leaf residues increased with N application up to 280 kg ha^{-1} indicating high N application favoured foliage formation.

Total crop biomass production (total fresh yield) increased with N application to 160 kg ha^{-1}. At this N application rate the total crop N uptake was 167 kg ha^{-1} meaning an extra 7 kg ha^{-1} of N was extracted in excess of application giving a crop nitrogen use efficiency on a whole crop basis of 104%; this did not change at 200 kg ha^{-1} N application (102%). The NUE on a whole crop basis only declined when N application increased to 240 and 280 kg N ha^{-1} (90% and 89% respectively). This indicated that the rates at which crop biomass peaked (about 160-200 kg N ha^{-1}) were the rates at which the highest crop NUE was recorded. When expressed on a harvested product basis, the NUE declined since much of the N is used in growing the unmarketable crop parts and the harvest index of celery is in the order of about 70%. Notwithstanding, the NUE on a harvested product basis was also highest at the 160-200 kg N ha^{-1}, the rate at which the total biomass and NUE (on a total crop basis) were maximised. Hence soil nitrate monitoring could be used as a good diagnostic criterion to evaluate celery N application rates. In the event that initial soil nitrate levels are low (e.g. <2 mg kg^{-1}) an application of 160 kg ha^{-1} would be appropriate where losses are minimal. In the nil applied N treatment about 38 kg ha^{-1} of N was taken up by the whole plant but in the 240 and 280 N treatments total crop uptake was about 20-30 kg ha^{-1} less than application. This combined with the amount of N supplied by the soil, as mineralised N, indicated that the nitrogen use efficiency of celery was lower at these rates than for the lower additions because application of N above the optimal rate did not result in increased uptake. The dry matter content (DM%) in all plant tissue samples (head, and residues) decreased with increasing N rate to 120-160 kg ha^{-1}.

5.2.2.2. Broccoli response to N

For broccoli the head fresh yield and dry matter yield increased progressively from 0 up to 120-160 kg N ha^{-1} and then increased again with a further increase in N rate to 200 kg N ha^{-1} above which no further increase was recorded (Table 5.3). However, the total fresh yield and total crop dry matter yield (crop biomass) increased progressively to the highest N application rate of 280 kg N ha^{-1}. At the higher N rates, the average product size increases to 330 g per head compared with the average head yield of 250 g at the N application rates of 120-160 kg N ha^{-1}. The larger product is visually very acceptable in colour and defects though the size is slightly larger than the acceptable limit in retail markets. Hence, though product yield can be increased greatly with N application, the product may be less saleable. At an N rate of 80 kg N ha^{-1}, although yield was reasonable, the head quality suffered from purpling giving a lower quality head; this attribute is often wrongly associated with cold conditions but was clearly a function of marginal N supply. This would suggest that quality attributes are directly related to crop N status. The DM% of the heads and residues was highest at an N rate of 0 to 80 kg N ha^{-1} and lower at 120 through to 280 kg N ha^{-1} (ranging from 9.7% to 10.8%).

Total crop N uptake increased progressively with increasing N application rate to a maximum of 362 kg N ha^{-1} at an application of 280 kg N ha^{-1}. The total crop N uptake was consistently greater than the N application rate and across the treatments ranged from 53 to 87 kg N ha^{-1}. At the optimal N application rate, the removal of N in the head was about 63 and 68 kg N ha^{-1} at application rates of 120 and 160 kg N ha^{-1}, respectively. In the nil applied N treatment, 61 kg N ha^{-1} was taken up by the whole crop suggesting high efficiency of N uptake by broccoli. On a whole crop basis, the NUE was consistently high, decreasing progressively from 301% at 40 kg N ha^{-1} to a low of 129% at 280 kg N ha^{-1}. The decrease in efficiency with increasing N application highlights that regardless of N treatment, about 60 to 80 kg N ha^{-1} was taken up in excess of the application rate. On a harvested head basis the NUE decreased with increasing N application rate, but overall the NUEs, when expressed on the harvested head basis, were in the range of 34 to 53% in the N application range of 120 to 280 kg N ha^{-1}. This is largely a function of the fact that the harvest index for broccoli is low at about 20%, indicating high residue returns and N cycling in the system.

5.2.2.3. Cauliflower response to N

The data for cauliflower nutrient dynamics are presented in Table 5.4. The fresh yield of the marketable head progressively increased with increasing N rate to 280 kg N ha^{-1}. In contrast the DM yield of the marketable head increased to about 200 kg N ha^{-1} above which the response was not significant. This effect reflected that the DM% appeared to decrease (not significantly) with an increasing N application rate from 160 to 280 kg N ha^{-1}. The optimal rate of N application appeared to be in the order of 120 to 200 kg ha^{-1}. However, the average product size in the 120 and 160 kg N ha^{-1} treatments was 1.9 to 2.2 kg and closer to the market requirement than was in the 200 kg N ha^{-1} treatment where the average head size was about 2.6 kg. This would suggest an optimum application rate of about 120-160 kg N ha^{-1}. However the planting density in this experiment (22,000 plants ha^{-1}) was substantially less than the industry standard of 30-36,000 plants ha^{-1} in the Lockyer region, which gives a smaller more marketable head. Hence the optimal application rate under higher density is more likely to be in the range of 160-200 kg N ha^{-1}. Crop N removal in the harvested product also increased with progressive increases in N application to a maximum of about 160-170 kg N ha^{-1} at 240-280 kg applied N ha^{-1} but was in the order of about 90-100 kg N ha^{-1} at an application rate of 120-160 kg N ha^{-1}. The survey data showed that the average N application rate for cauliflower was 98.6 kg N ha^{-1} (refer Chapter 4) confirming growers operate on a negative crop budget.

The total fresh yield of crop residues increased progressively with increasing N application rate to 240 kg ha^{-1} and declined slightly with a further increase in N to 280 kg ha^{-1}. The DM% decreased substantially from the nil applied N treatment (14.5%) to 160 kg applied N ha^{-1} (10.8%) and did not change with a further increase in N application. The N content of the residues increased incrementally from 1.9% in the nil applied N treatment to 3.4% in the 240 kg N ha^{-1} treatment. The total crop fresh yield, as with the marketable head and residues, increased with increasing N rate, but to a maximum at about 200 kg applied N ha^{-1}. The total crop N uptake in the nil applied N treatment was 86 kg N ha^{-1} and the difference between applied N and N uptake progressively increased from 86 kg N ha^{-1} in the nil treatment to 185 kg N ha^{-1} in the 240 kg applied N ha^{-1} treatment. The highest total crop N uptake was recorded in the 240 kg applied N ha^{-1} treatment at 425 kg N ha^{-1}. As with broccoli, this suggested high efficiency of N uptake in brassica crops. The mechanism by which this accretion occurs is not understood.

On a whole crop basis, the NUE across all treatments was greater than 100% reinforcing the notion of high nutrient use efficiency. This suggests that optimal rates of application for N can be reduced. On a marketable head basis the NUE was 62-63% in the optimal application range of 160-240 kg N ha^{-1}. These NUE values would appear very reasonable given that the harvest index for cauliflower in this trial was between 40 and 45% indicating high rates of N return in field residues. The N return in field residues was about 200-250 kg N ha^{-1} at the optimal application rates of 160-200 kg N ha^{-1}.

Data for cauliflower response to N are presented as a breakdown of the harvested head into the head and bract components, which form the harvested head. This has been done to highlight the differences or similarities in the key parameters, particularly N% and DM%. Both the N% and DM% were essentially very similar over the N application rates (Table 5.4).

5.2.2.4. Cabbage response to N

The response of head, wrapper and total fresh yield and dry matter yield in cabbage increased progressively from nil applied N up to 160-200 kg applied N ha^{-1} and then increased again with a further increase in N rate to 240 kg N ha^{-1}, but then declined slightly with a further increase in N rate to 280 kg ha^{-1} (Table 5.5). At the 160-200 kg applied N ha^{-1} rate the average marketable head size was about 3.04 kg but at the 240 kg applied N ha^{-1} rate the average marketable head size was greater at 3.54 kg. The increase in marketable product size was 16.4% for an increase in N application of 20%. Compared with broccoli and cauliflower, the larger product size is a less critical issue depending on the market being supplied. A smaller sized head can be achieved in a shorter timeframe by higher N application rates.

As for broccoli at 80 kg applied N ha^{-1}, the head quality suffered from purpling giving a lower quality head. The DM% of the heads and residues was highest at an applied N rate of 0 to 80 kg/ha and was much lower in the 120 to 280 kg applied N ha^{-1} treatments (ranging from 8.7% to 9.3% for the head and 11.7% to 12.0% for the wrapper leaves).

Total crop N uptake increased progressively with increasing N application rate to a maximum of 360 kg N ha^{-1} at an application of 240 kg N ha^{-1}. The total crop N uptake was consistently greater than the N application rate and across the treatments ranged from 62-126 kg N ha^{-1} more. At the optimal N application rate of about 240 kg N ha^{-1} the removal of N in the marketable head was about 173 kg N ha^{-1}. In the nil applied N treatment, 83 kg N ha^{-1} was taken up by the whole crop suggesting high efficiency of N uptake and consistent with the other brassicas, broccoli and cauliflower. On a whole crop basis, the NUE was consistently high decreasing progressively from 333% at 40 kg applied N ha^{-1} to 122% at 280 kg applied N ha^{-1}. The decrease in efficiency with increasing N application highlights that regardless of N treatment, about 60 to 130 kg N ha^{-1} was taken up in excess of the application rate. On a harvested head basis, the NUE decreased with increasing N application rate, but overall the NUEs when expressed on the harvested head basis were high. At the optimal application rate of about 200-240 kg N ha^{-1} the NUE on a harvested head basis was 70%. Across the higher end of the range in N application rates (120-280 kg ha^{-1}), the harvest index was about 60% indicating lower residue returns compared with broccoli and cauliflower.

5.2.2.5. Cos and Iceberg lettuce responses to N

The trend in data for yield responses in Cos and Iceberg lettuce were essentially the same with only slight differences in the actual values and data are presented in Tables 5.6 and 5.7, respectively. Maximum head fresh yield and dry matter yield was obtained at an N application rate of 120 kg N ha^{-1}, and further increases in N application did not improve yield. Hence the size of the lettuce frame was not increased by higher N. The same pattern for fresh and dry matter yields was observed for the wrapper and total crop components. As for the previous crops, the DM% in both the head and wrapper components was highest in the nil applied N treatment and progressively declined up to the optimum rate of application (about 80-120 kg N ha^{-1}); with further increases in N application, DM% essentially did not change. In contrast, the N% in the head and wrapper leaves increased from the lowest value at nil applied N up to 160 kg applied N ha^{-1} above which N% in the plant tissue did not further increase.

At the optimal rate of N application (120 kg N ha^{-1}), the total crop N uptake was 104 kg N ha^{-1}. Total crop N uptake increased up to 160 kg applied N ha^{-1} but further increase in N rate essentially did not increase crop N uptake since yield had plateaued. In the nil applied N treatment, the total crop N uptake was 61 kg N ha^{-1}. The uptake of N was greater than the application rate up to 80 kg applied N ha^{-1}, equivalent at 120 kg applied N ha^{-1} and above 120 kg applied N ha^{-1} the rate of application greatly exceeded crop N uptake. Subsequently the NUE's on a whole crop basis were greater than 100% up to an application rate of 120 kg N ha^{-1} but NUE on a whole crop basis declined substantially at higher application rates to a minimum at 280 kg applied N ha^{-1} (52% for Cos and 57% for Iceberg).

5.2.3. General Discussion

A comparison of total biomass yield and yield of the marketable product for Cos and Iceberg lettuce (Fig. 5.1) highlighted the responses over N rate were the same. Similarly for celery, the difference between total fresh yield and yield of the marketable product remained the same despite the fact that no marketable head was obtained in the 0 and 40 kg applied N ha^{-1} treatments. The total fresh yields for cauliflower and cabbage were similar over the range of N rates and the response in broccoli was similar over N rate but at each rate total fresh yield was lower. The response of marketable head yield in cabbage tended to match the total crop response over N rate. However, for both cauliflower and broccoli, the responses between marketable head yield and total crop fresh yield differed over N rate. As N rate increased the total crop fresh yield increased to a much greater extent than did the marketable head yield. This indicated that the plant responded to N application by growing a greater volume of foliage. For cauliflower this could be a major constraint as it could favour the development of foliar diseases such as black rot and Alternaria.

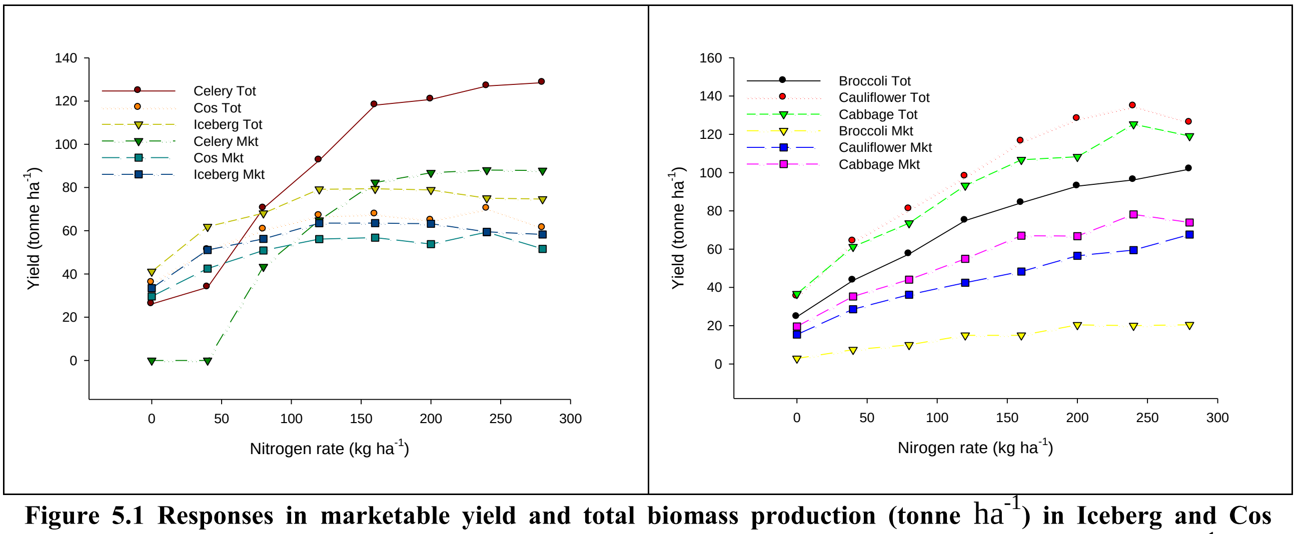

Figure 5.1 Responses in marketable yield and total biomass production (tonne ha^{-1}) in Iceberg and Cos lettuce and celery (left) and broccoli, cauliflower and cabbage (right) over N rates from 0-280 kg ha^{-1} in a trial at Qld DAFF Gatton Research Station.

The data presented in Tables 5.6 and 5.7 highlighted that the optimal N rate for Cos and Iceberg lettuce was about 120 kg N ha^{-1} whereas the average application by lettuce growers, as presented in Chapter 3, is about 87 kg N ha^{-1}. In general, the range of N application in lettuce is estimated at around 70-120 kg N ha^{-1}. This suggests that, overall, the application rate of N by lettuce growers is marginal unless soil mineral N prior to fertiliser application is sufficient to supplement crop nutrient needs (Fig. 5.2). In cabbage, cauliflower, broccoli and celery the typical application rates by growers are up to about 110 kg N ha^{-1} and generally in the range of about 70-120 kg N ha^{-1}. At this rate of application the standard grower practice is also below the critical crop requirement unless mineral N supply from the soil is sufficient to meet crop requirements.

Table 5.2 Mean fresh yield (FY), dry matter content (DM%), dry matter yield (DMYld), nitrogen concentration (%) and crop nitrogen uptake for harvested components and residues for celery grown at a range of nitrogen application rates at the Queensland DAFF Gatton Research Facility in 2011.

Celery	Rate of N application (kg ha^{-1})									
	0	40	80	120	160	200	240	280	F test prob.	LSD*
Harvested Head										
FY (tonne ha^{-1})	0.0	0.0	43.3	64.8	82.3	86.8	88.1	87.8	<0.001	12.8
DM%			8.6	8.0	7.5	7.4	6.9	7.7	<0.001	0.8
DMYld (tonne ha^{-1})	0.0	0.0	3.6	5.2	6.2	6.4	6.1	6.8	<0.001	1.0
N (%)			1.2	1.3	1.5	1.9	2.0	2.1	<0.001	0.2
N Removal (kg ha^{-1})			43	67	94	122	120	141	<0.001	20
Total Field Residues (sum field residues and trimmed leaf)										
FY	26.1	33.9	27.1	27.8	35.8	33.9	38.9	40.7	.007	8.18
DMYld	3.37	3.91	3.01	2.74	3.37	3.27	3.49	3.68	.104	
N content (kg ha^{-1})	37.8	47.2	40.4	46.5	72.8	82	95.9	108	<0.001	16.82
Field Residues										
FY	26.1	33.9	22.6	21.4	27.6	25.4	29.4	29.9	0.075	8.0
DM%	13.0	11.5	9.6	8.7	8.2	8.3	7.8	7.8	<0.001	0.8
DMYld	3.4	3.9	2.2	1.9	2.3	2.1	2.3	2.3	<0.001	0.7
N%	1.1	1.2	1.1	1.4	1.8	2.1	2.5	2.7	<0.001	0.2
N content(kg ha^{-1})	38	47	23	25	42	45	57	63	<0.001	16
Trimmed Leaf Residues										
FY (tonne ha^{-1})	0.0	0.0	5.6	6.3	8.2	8.6	9.5	10.8	<0.001	1.5
DM%			14.8	14.0	13.2	13.3	12.3	12.4	0.015	1.4
DMYld (tonne ha^{-1})	0	0	0.8	0.9	1.1	1.1	1.2	1.3	<0.001	0.2
N%			2.2	2.4	2.8	3.2	3.3	3.4	<0.001	0.3
N content(kg ha^{-1})	0	0	18	21	31	37	39	45	<0.001	7
Yield and N uptake efficiency										
Total FY (tonne ha^{-1})	26.1	33.9	70.4	92.6	118.1	120.8	126.9	128.5	<0.001	17.2
Total Crop N uptake (kg ha^{-1})	38	47	83	113	167	204	216	249	<0.001	25
N rate - Total Crop N (kg ha^{-1})	-38	-7	-3	7	-7	-4	24	31	<0.001	25
N rate - N Removal (kg ha^{-1})	0	40	37	53	66	78	120	139	<0.001	20
NUE-Total Crop (%)		118	104	94	104	102	90	89	0.038	18
NUE- Harvested Head (%)		0	54	56	59	61	50	50	<0.001	12

*Treatments are significantly different from each other when the difference between the values is greater than the LSD (least significant difference) value.

Table 5.3 Mean Fresh yield (FY), dry matter content (DM%), dry matter yield (DMYld), nitrogen concentration (%) and crop nitrogen uptake for head and field residues of broccoli grown at a range of nitrogen application rates at the Queensland DAFF Gatton Research Facility in 2011.

Broccoli	Rate of N application (kg ha^{-1})								F test prob.	LSD*
	0	40	80	120	160	200	240	280		
Head										
FY (tonne ha^{-1})	2.9	7.4	10.0	15.0	15.0	20.4	20.0	20.5	<0.001	3.4
DM%	11.5	11.2	11.5	10.7	10.3	10.2	10.1	10.0	0.010	0.9
DMYld (tonne ha^{-1})	0.3	0.8	1.1	1.6	1.5	2.1	2.0	2.0	<0.001	0.3
N%	3.9	3.4	4.3	4.0	4.4	4.3	4.6	4.7	<0.001	0.4
N Removal (kg ha^{-1})	12	29	47	63	68	89	93	96	<0.001	15
Field Residue										
FY (tonne ha^{-1})	21.8	36.2	47.4	59.9	69.2	72.5	76.2	81.3	<0.001	12.8
DM%	15.1	13.2	12.6	10.8	10.5	10.2	10.0	9.7	<0.001	1.3
DMYld (tonne ha^{-1})	3.3	4.7	5.9	6.5	7.3	7.4	7.7	7.9	<0.001	1.2
N%	1.5	2.0	1.7	2.3	2.4	2.7	2.5	3.4	0.001	0.8
N in field Residues (kg ha^{-1})	49	92	101	143	172	198	200	266	<0.001	59
Yield and N uptake efficiency										
Total FY (tonne ha^{-1})	24.7	43.7	57.4	74.9	84.2	92.9	96.2	101.8	<0.001	15.0
Crop DM% (calculated)	14.6	12.9	12.4	10.8	10.5	10.2	10.0	9.8	<0.001	1.2
Total Crop N uptake (kg ha^{-1})	61	121	148	206	240	287	293	362	<0.001	68
N rate - Total Crop N (kg ha^{-1})	-61	-81	-68	-86	-80	-87	-53	-82	0.952	
N rate - N Removal (kg ha^{-1})	-12	11	33	57	92	111	147	184	<0.001	15
NUE-Total Crop N (%)		301	185	172	150	143	122	129	<0.001	64
NUE- Harvested Head N (%)		72	59	53	42	44	39	34	0.010	19

*Treatments are significantly different from each other when the difference between the values is greater than the LSD (least significant difference) value.

Table 5.4 Mean fresh yield (FY), dry matter content (DM%), dry matter yield (DMYld), nitrogen concentration (%) and crop nitrogen uptake for head (curd and bract) and field residues of cauliflower grown at a range of nitrogen application rates at the Queensland DAFF Gatton Research Facility in 2011.

Cauliflower	Rate of N application (kg ha^{-1})								F test prob.	LSD*
	0	40	80	120	160	200	240	280		
Harvested Head (combined head and bract)										
FY (tonne ha^{-1})	15.4	28.6	36.2	42.4	48.3	56.5	59.5	67.6	<0.001	12.9
DMYld (tonne ha^{-1})	1.5	2.6	3.2	3.4	3.8	4.3	4.4	5.1	<0.001	1.0
N Removal (kg ha^{-1})	31	56	71	89	101	125	148	151	<0.001	38
Field Residue										
FY (tonne ha^{-1})	19.9	35.5	44.7	55.6	68.1	71.6	75.1	58.5	<0.001	18.0
DM%	14.5	13.2	12.9	11.4	10.8	10.9	10.9	10.9	<0.001	0.9
DMYld (tonne ha^{-1})	2.9	4.7	5.7	6.3	7.3	7.8	8.1	6.2	<0.001	1.9
N%	1.9	2.0	2.0	2.4	2.7	3.2	3.4	3.1	<0.001	0.5
N in field Residues (kg ha^{-1})	55	91	114	157	201	247	277	194	<0.001	78
Total Yield and N uptake efficiency										
Total FY (tonne ha^{-1})	35.3	64.1	80.9	98.0	116.3	128.1	134.6	126.1	<0.001	21.1
Total Crop N uptake (kg ha^{-1})	86	147	185	246	302	372	425	346	<0.001	89
N rate - Total Crop N (kg ha^{-1})	-86	-107	-105	-126	-142	-172	-185	-66	0.130	89
N rate - N Removal (kg ha^{-1})	-31	-16	9	31	59	75	92	129	<0.001	38
NUE-Total Crop (%)		368	231	205	189	186	177	123	<0.001	63
NUE- Harvested Head (%)		139	88	74	63	62	62	54	<0.001	22
Curd										
FY (tonne ha^{-1})	10.1	20.3	25.8	31.5	34.5	42.0	42.7	46.5	<0.001	7.7
DM%	9.1	8.9	8.8	8.0	7.8	7.6	7.5	7.5	<0.001	0.6
DMYld (tonne ha^{-1})	0.9	1.8	2.2	2.5	2.7	3.2	3.2	3.5	<0.001	0.6
N%	2.3	2.3	2.4	2.6	2.7	2.9	3.4	3.0	0.002	0.5
N Removal (kg ha^{-1})	21	40	54	67	73	93	109	104	<0.001	24
Bract										
FY (tonne ha^{-1})	5.3	8.3	10.4	10.9	13.7	14.6	16.8	21.2	0.002	6.5
DM%	10.3	9.8	9.6	8.7	7.7	7.7	7.2	7.4	<0.001	0.8
DMYld (tonne ha^{-1})	0.5	0.8	1.0	0.9	1.1	1.1	1.2	1.6	0.031	0.5
N%	1.7	1.9	1.7	2.4	2.7	2.8	3.2	2.9	<0.001	0.5
N Removal (kg ha^{-1})	10	15	17	22	28	32	39	48	0.002	17

*Treatments are significantly different from each other when the difference between the values is greater than the LSD (least significant difference) value.

Table 5.5 Mean Fresh yield (FY), dry matter content (DM%), dry matter yield (DMYld), nitrogen concentration (%) and crop nitrogen uptake for marketed head and field residues (wrapper leaves) of cabbage grown at a range of nitrogen application rates at the Queensland DAFF Gatton Research Facility in 2011.

Cabbage	Rate of N application (kg ha^{-1})								F test prob.	LSD*
	0	40	80	120	160	200	240	280		
Head										
FY (tonne ha^{-1})	19.6	35.3	44.1	54.9	67.0	66.8	78.1	73.9	<0.001	9.5
DM%	11.7	10.5	10.1	9.3	9.1	9.2	8.9	8.7	<0.001	0.5
DMYld (tonne ha^{-1})	2.3	3.7	4.4	5.1	6.1	6.2	7.0	6.5	<0.001	1.0
N%	1.6	1.7	1.8	2.2	2.4	2.3	2.5	2.5	<0.001	0.3
N Removal (kg ha^{-1})	36	62	79	109	143	140	173	162	<0.001	23
Wrapper										
FY (tonne ha^{-1})	17.0	25.9	29.5	38.3	39.6	41.5	47.1	45.2	<0.001	7.3
DM%	13.6	12.9	13.0	11.9	11.9	12.0	11.8	11.7	<0.001	0.6
DMYld (tonne ha^{-1})	2.3	3.3	3.8	4.6	4.7	5.0	5.5	5.3	<0.001	0.9
N%	2.1	2.1	2.2	2.9	3.1	3.0	3.4	3.4	<0.001	0.2
N in field Residues (kg ha^{-1})	48	71	83	130	144	149	188	180	<0.001	25
Total Yield and N uptake efficiency										
Total FY (tonne ha^{-1})	36.6	61.2	73.6	93.2	106.7	108.2	125.3	119.1	<0.001	15.4
Total DMYld	4.6	7.1	8.3	9.7	10.8	11.2	12.5	11.8	<0.001	1.7
Total Crop N uptake (kg ha^{-1})	83	133	162	239	286	289	360	342	<0.001	44
N rate - Total Crop N (kg ha^{-1})	-83	-93	-82	-119	-126	-89	-120	-62	0.065	
N rate – N Removal (kg ha^{-1})	-36	-22	1	11	17	60	67	118	<0.001	23
NUE-Total Crop N (%)		333	203	200	179	145	150	122	<0.001	37
NUE- Harvested Head N (%)		155	99	91	89	70	72	58	<0.001	14

*Treatments are significantly different from each other when the difference between the values is greater than the LSD (least significant difference) value.

Table 5.6 Mean Fresh yield (FY), dry matter content (DM%), dry matter yield (DMYld), nitrogen concentration (%) and crop nitrogen uptake for marketed head and field residues (wrapper leaves) of Cos lettuce grown at a range of nitrogen application rates at the Queensland DAFF Gatton Research Facility in 2011.

Cos Lettuce	Rate of N application (kg ha^{-1})								F test prob.	LSD*
	0	40	80	120	160	200	240	280		
Head										
FY (tonne ha^{-1})	29.6	42.5	50.9	56.1	56.8	53.8	59.4	51.6	<0.001	5.6
DM%	7.1	6.1	5.8	5.6	5.8	5.9	5.7	6.3	<0.001	0.4
DMYld (tonne ha^{-1})	2.1	2.6	3.0	3.1	3.3	3.2	3.4	3.2	<0.001	0.3
N%	2.5	2.7	3.1	3.4	3.7	3.8	3.9	3.9	<0.001	0.2
N Removal (kg ha^{-1})	52	69	94	106	122	120	130	126	<0.001	14
Wrapper										
FY (tonne ha^{-1})	6.4	8.7	9.8	10.8	10.8	10.9	10.9	9.7	<0.001	1.7
DM%	6.4	5.9	5.5	5.2	5.3	5.3	5.4	5.5	<0.001	0.3
DMYld (tonne ha^{-1})	0.4	0.5	0.5	0.6	0.6	0.6	0.6	0.5	0.005	0.1
N%	2.1	2.3	2.7	3.1	3.4	3.7	3.8	3.7	<0.001	0.2
N Removal (kg ha^{-1})	9	12	15	18	20	21	22	20	<0.001	3
Total Yield and N uptake efficiency										
Total FY (tonne ha^{-1})	36.0	51.2	60.6	66.9	67.6	64.8	70.3	61.3	<0.001	6.4
Total DMYld	2.5	3.1	3.5	3.7	3.8	3.7	4.0	3.8	<0.001	0.3
Total Crop N uptake (kg ha^{-1})	61	81	108	124	142	141	153	146	<0.001	15
N rate - Total Crop N (kg ha^{-1})	-61	-41	-28	-4	18	59	87	134	<0.001	15
N rate - N Removal (kg ha^{-1})	-52	-29	-14	14	38	80	110	154	<0.001	14
NUE-Total Crop N (%)		202	135	103	89	71	64	52	<0.001	21
NUE- Harvested Head N (%)		173	117	88	76	60	54	45	<0.001	20

*Treatments are significantly different from each other when the difference between the values is greater than the LSD (least significant difference) value.

Table 5.7 Mean fresh yield (FY), dry matter content (DM%), dry matter yield (DMYld), nitrogen concentration (%) and crop nitrogen uptake for marketed head and field residues (wrapper leaves) of Iceberg lettuce grown at a range of nitrogen application rates at the Queensland DAFF Gatton Research Facility in 2011.

Iceberg Lettuce	Rate of N application (kg ha^{-1})								F test prob.	LSD*
	0	40	80	120	160	200	240	280		
Head										
FY (tonne ha^{-1})	38.6	61.7	65.7	72.9	73.3	73.8	68.0	69.1	<0.001	8.9
DM%	5.7	5.1	4.7	4.5	4.5	4.7	4.7	4.8	<0.001	0.3
DMYld (tonne ha^{-1})	2.2	3.1	3.1	3.3	3.3	3.5	3.2	3.4	0.001	0.5
N%	2.0	2.1	2.5	2.9	3.1	3.4	3.5	3.4	<0.001	0.2
N Removal (kg ha^{-1})	44	66	78	96	104	120	110	115	<0.001	19
Wrapper										
FY (tonne ha^{-1})	7.0	10.2	11.5	15.2	14.7	15.6	14.3	16.1	<0.001	3.5
DM%	6.8	6.5	6.3	6.2	6.1	5.8	6.8	6.7	0.458	1.1
DMYld (tonne ha^{-1})	0.5	0.7	0.7	0.9	0.9	0.9	1.0	1.1	0.005	0.3
N%	2.1	2.3	3.0	3.3	3.7	4.3	4.3	4.2	<0.001	0.3
N Removal (kg ha^{-1})	10	15	21	31	33	39	43	45	<0.001	11
Total Yield and N uptake efficiency										
Total FY (tonne ha^{-1})	45.6	71.9	77.2	88.1	88.0	89.3	82.3	85.2	<0.001	10.3
Total DMYld	2.7	3.8	3.8	4.2	4.2	4.4	4.2	4.4	<0.001	0.7
Total Crop N uptake (kg ha^{-1})	54	81	99	127	137	159	153	160	<0.001	24
N rate - Total Crop N (kg ha^{-1})	-54	-41	-19	-7	23	41	87	120	<0.001	24
N rate - N Removal (kg ha^{-1})	-44	-26	2	24	56	80	130	165	<0.001	19
NUE-Total Crop N (%)		203	124	106	85	80	64	57	<0.001	16
NUE- Harvested Head N (%)		165	97	80	65	60	46	41	<0.001	12

*Treatments are significantly different from each other when the difference between the values is greater than the LSD (least significant difference) value.

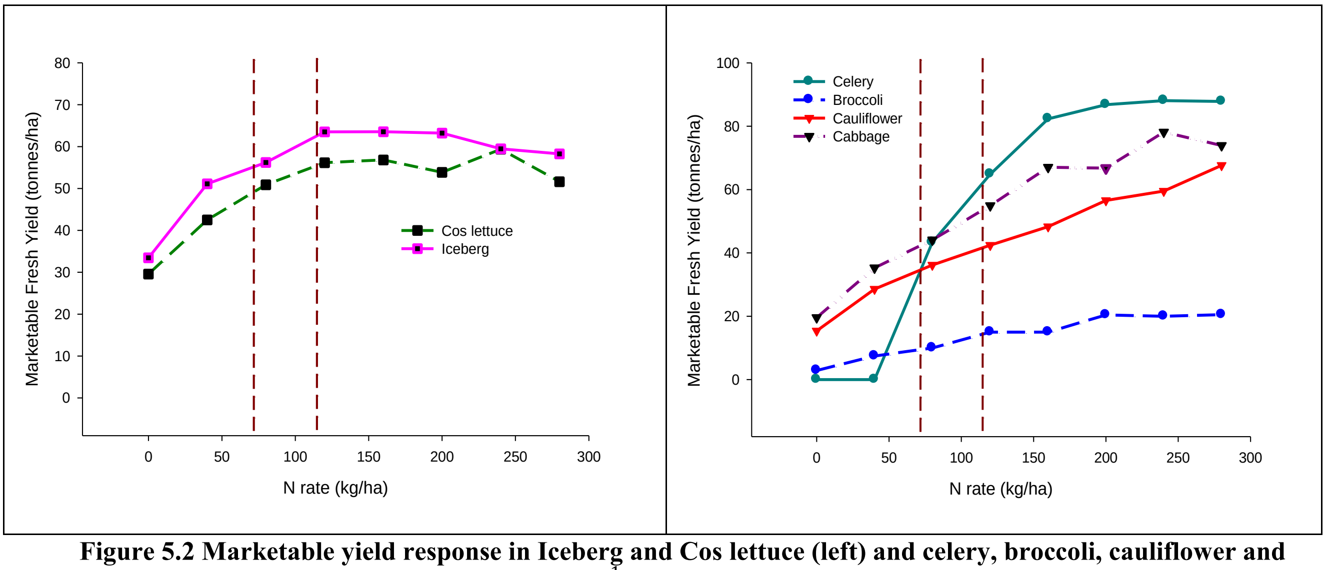

Figure 5.2 Marketable yield response in Iceberg and Cos lettuce (left) and celery, broccoli, cauliflower and cabbage (right) over N rates from 0-280 kg ha^{-1}. The dashed vertical lines indicate the general range of N applied by vegetable growers in the Lockyer Valley.

The response profile for each of the crops at each N application rate was plotted over time to establish which N rates gave optimal crop growth (Fig. 5.3). The data presented were for whole plant biomass yield. The plots for Iceberg lettuce show a distinct deviation in the deficient and marginal rates of 0-80 kg N ha^{-1} at about 40 days after transplanting, indicating that crop limitations commenced at the mid-growth stage. A similar response was observed for Cos lettuce but the deviation was most noticeable in the 0 and 40 kg N ha^{-1} treatments. The crop growth responses in broccoli, cabbage, celery and cauliflower all showed substantial deviation in responses to N rates from about 40 days after planting. In contrast to the lettuce there was clear separation in yield responses between the 0, 40, 80, 120 and 160 kg ha^{-1} N treatments and the 200-280 kg ha^{-1} N treatments (Fig. 5.3). For the non-flowering heading crops celery and cabbage the figure highlights the point at which maturity is achieved at 100 kg N ha^{-1}, the rate typically used by growers in the Lockyer region. When the final yield is translated to the equivalent yield in the higher applied N treatments, the crop is estimated to potentially reach maturity earlier (Fig. 5.3).

5.2.3.1. Nitrous Oxide Emissions from Cabbage Production

Relatively high N_2O emissions (5-15 g N/ha/d) were recorded immediately before and several days after the fourth N fertiliser application for all the fertilised treatments (Fig. 5.4). Nitrous oxide emissions from the fertilised soil were not significantly different between different N application rates, but were consistently higher than those from the nil fertiliser control. This suggested that mineral N content was not a major driving factor for N_2O production in this cropping system when it exceeded ~20 mg/kg in the 0-20 cm layer. N_2O emissions diminished gradually with time to <1 g N/ha/d approximately three weeks after the fourth N application, in spite of high mineral N content detected about two weeks after fertilisation. The decline might be due to a reduction in nitrification (which also causes N_2O emissions), which would have slowed down with time as the substrate (NH_4^+) concentration decreased.

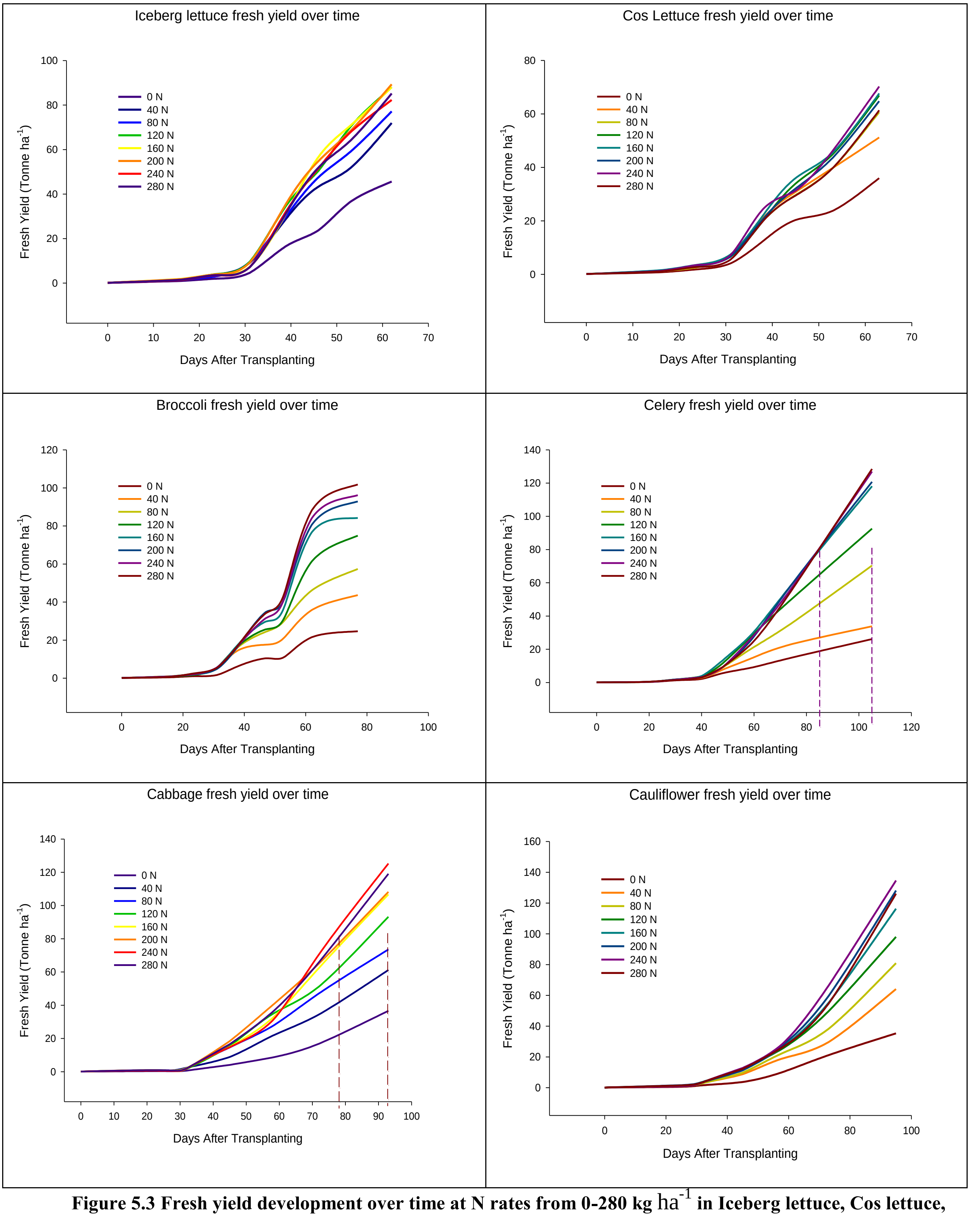

Figure 5.3 Fresh yield development over time at N rates from 0-280 kg ha^{-1} in Iceberg lettuce, Cos lettuce, broccoli, celery, cabbage and cauliflower. The dashed vertical lines in the celery and cabbage graphs indicate the difference in time to develop the same yield between the higher N rates (160-280 kg ha^{-1}) and the N rate of 100 kg ha^{-1}, typically applied by vegetable growers in the Lockyer Valley.

Overall, N_2O emissions from this vegetable cropping system appeared to be low (<15 g N/ha/d), compared to those (25-60 g N/ha/d) observed on a similar soil in a cereal cropping system at Warwick, Queensland during the summer seasons from 2006 to 2009 (Wang *et al.* 2011). The relatively low emissions might be attributable to the low temperature during the winter season and the moderate irrigation rate (generally ≤20 mm) reducing the risk of prolonged soil saturation. It appeared that N_2O emissions were insensitive to the rate of N application in this cropping system during the winter season. This indicated that other regulating factors such as temperature and soil moisture content limited N_2O production in the soil. Extended periods of measurement including the wet and warm summer season are recommended in future studies. In the peak emission period after fertiliser application the N_2O flux was on average about 8-10 g N ha^{-1} per day giving net emission of about 48-60 g of N over a 6 day period. For this single application the loss represented about 0.05% in the 120 N treatment and over 3 applications in the season is in the order of only about 0.15% and emission losses were not a major loss pathway in this study.

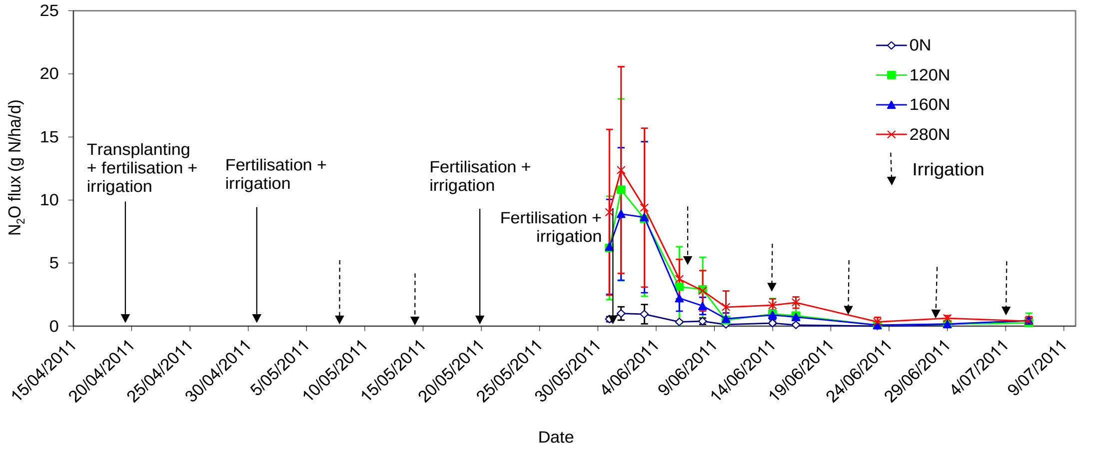

Figure 5.4. N_2O emissions (mean±SD) from different N fertilisation treatments in the second half of the cabbage cropping season at Gatton.

5.3. *Experiment 2 - Relationship between N application rate and plant density*

5.3.1. Introduction

Limited survey work shows the average plant density for broccoli in the Lockyer Valley is about 40,000 plants ha^{-1} with a maximum of 58,700 plants ha^{-1}. However, the average N application rate is only 113 kg N ha^{-1} and unlikely to meet the needs of a high demand crop. This is the same situation for other brassica crops where plant populations and N application rates are low. This experiment evaluated whether the combination of higher plant dnsities with higher N application rates would increase broccoli crop yields.

5.3.2. Materials and Methods

A field experiment was established in the winter production season in the Lockyer Valley to identify whether production (yield) of broccoli can be increased by increasing N application with higher plant density. The N rates imposed consisted of 100 (N100), 200 (N200) and 300 (N300) kg N ha^{-1} and plant populations of 40 400 (P40), 60 600 (P60) and 80 800 (P80) plants ha^{-1} were imposed in factorial combination. The experimental design was a split-plot where N treatments were main plots with the plant density treatments as sub-plots. The treatments were replicated four times. Broccoli (cv. Bravo) was planted on 9 May 2012.

Prior to planting, the trial site was planted to forage sorghum in September 2011 and the forage sorghum was bailed and removed from the site to minimise the soil residual nitrate levels and to ensure the site was uniform with respect to mineral N status. The dimensions of the main plots were 18 m by 4.5 m and sub plots were 6 m by 4.5m. A minimum buffer between N treatments of 1.5 m was imposed to prevent cross contamination between treatments. The N treatments were applied as urea as per Table 5.8 and applied with overhead solid-set sprinkler irrigation. At planting, 80 kg K ha^{-1} was applied as sulphate of potash. The trial was harvested commencing on 9 August 2012 by selecting marketable sized heads and then sequentially until all plants were harvested or when the florets began opening (for small heads). In the first harvest, six whole plants were harvested and partitioned into the marketable component and the field residue component. In subsequent harvests, only the heads were harvested. The fresh weights of the components were determined and the samples dehydrated at 72^{o}C, weighed and stored for analysis as required.

Table 5.8 Timing of nitrogen fertiliser applications and amounts in an experiment that evaluated effects of nitrogen rate (kg ha^{-1}) and plant density on growth of broccoli at the Qld DAFF Gatton Research Station in 2012.

	Date of application	Days after planting	Nitrogen rate kg ha^{-1}		
			100	200	300
Planting date	9-May-12				
1st application	15-May-12	6	50	50	50
2nd application	4-Jun-12	26	0	50	80
3rd application	19-Jun-12	41	50	50	80
4th application	1-Jul-12	53	0	50	90

5.3.3. Results and Discussion

The main effects (averaged across factors) were significant for most parameters (Table 5.9). The interaction between N rate and plant population were mostly not significant with the exception of the important parameters of marketable head number and yield.

5.3.3.1. Plant population

The P80 treatment gave the highest total head yield but this did not translate into a significant improvement in marketable head yield for which this treatment had the lowest yield (Table 5.9). The fresh yield of residues was greatest in the P80 treatment but the dry matter yield was not different from that in the P60 treatment indicating the biomass return to soil was not increased with increasing plant population. The total crop N uptake was the same in the P60 and P80 treatments indicating that the higher plant density did not result in greater N recovery and the NUE values were the same for both treatments. The number of marketable heads was only 53% in the P80 treatment indicating that about only 42,000 heads ha^{-1} were harvested compared with a 95.6% harvest in the P40 treatment. Hence head recovery was similar between the P40 (the standard farmer practice) and P80 treatments but the head size in the P80 was smaller. At an average N application rate of 200 kg N ha^{-1} (averaged over the N100, N200 and N300) the N recovery was greater than 100% and greatest in the P60 and P80 treatments.

5.3.3.2. Nitrogen application rates

The total and marketable head yields were highest in the N300 treatment and substantially reduced in the N100 where marketable yield was about 50% of that in the N300 treatment (Table 5.9). As for all crops in the 2011 rate response experiment, the higher N application gave lower head and plant residue dry matter content. The N content of the head increased with progressive increases in N rate. The percentage marketable heads was greatest in the N300 treatment (87.1%) and substantially reduced in the N100 treatment (59.6%). Furthermore, the fresh yield and dry matter yield of crop residues was increased with progressive increases in N application from 100 kg N ha^{-1} to 300 kg N ha^{-1}.

5.3.3.3. General effects

The interaction between N application rate and plant population was significant for the marketable head number and marketable head yield (Table 5.10). The marketable head yields at N300 were similar for the P60 and P80 treatments (16.9 and 16.5 tonne ha^{-1}, respectively) and substantially greater than that in the P40 treatment (14.0 tonne ha^{-1}). Nitrogen deficits in combination with higher plant populations reduced head yield as evidenced particularly in the P80 treatments at N100 and N200. The marketable head percentage in the P60 N300 treatment was 93.6% (about 56,200 heads ha^{-1}) and though the marketable head percentage in the P80 N300 treatment was only 71.3%, a similar total of about 57,000 heads ha^{-1} was harvested.

Increasing the N rate from 100 to 300 kg N ha^{-1} also consistently increased the uptake of P in the head and field residues as well as the head and residue tissue P concentrations (Table 5.11).

Table 5.9 Mean fresh yield (FY), dry matter content (DM%), dry matter yield (DMYld), nitrogen concentration (%) and crop nitrogen uptake for head and field residues of broccoli grown at plant populations 40,000 plants ha^{-1} (P40), 60,000 plants ha^{-1} (P60), and 80,000 plants ha^{-1} (P80) and nitrogen rates (100, 200 and 300 kg ha^{-1}) at the Queensland DAFF Gatton Research Facility in 2012.

	Plant population ('000 plants ha^{-1})			F test prob.	LSD*	Nitrogen application rate (kg ha^{-1})			F test prob.	LSD*
	40	60	80			100	200	300		
Head										
Total Head FY (tonne ha^{-1})	12.8	15.2	16.4	<.001	0.8	11.9	15.4	17.1	<.001	1.2
Marketable FY (tonne ha^{-1})	12.4	13.2	11.2	0.003	1.0	7.7	13.4	15.8	<.001	2.1
Unmarketable FY (tonne ha^{-1})	0.4	2.0	5.1	<.001	0.7	4.2	2.0	1.3	0.003	1.2
DM%	9.8	10.0	10.1	0.055		10.4	9.9	9.5	0.031	0.4
Total DMYld (tonne ha^{-1})	1.1	1.5	1.6	<.001	0.2	1.2	1.4	1.6	0.026	0.3
Marketable DMYld (tonne ha^{-1})	1.1	1.3	1.1	0.103	0.2	0.8	1.2	1.5	0.003	0.3
N%	4.8	4.8	4.7	0.733		4.0	4.9	5.4	<.001	0.3
Number of marketable heads (%)	95.6	79.3	53.1	<.001	6.8	59.6	81.2	87.1	0.002	10.5
Total Head N uptake (kg ha^{-1})	55	73	78	<.001	10	49	69	87	<.001	13
Marketable N Removal (kg ha^{-1})	53	64	55	0.099		32	60	81	<.001	15
Field Residue										
FY (tonne ha^{-1})	57.9	66.3	69.3	<.001	4.3	51.7	66.7	75.0	<.001	6.4
DM%	10.4	10.0	9.6	0.014	0.5	10.9	9.9	9.3	0.046	0.9
DMYld (tonne ha^{-1})	6.0	6.6	6.6	0.037	0.5	5.6	6.6	7.0	0.005	0.6
Field Residue N%	2.5	2.5	2.4	0.502		1.7	2.5	3.2	<.001	0.4
N in field Residues (kg ha^{-1})	152	164	160	0.306		96	162	219	<.001	17
Total Yield and N uptake efficiency										
Total Crop N uptake (kg ha^{-1})	207	237	239	0.009	21	144	231	306	<.001	23
N application rate - N Removal (kg ha^{-1})	53	64	55	0.099		32	60	81	<.001	15
NUE-Total Crop N (%)	110	127	126	0.007	11.0	144	116	102	0.002	16.36
NUE- Harvested Head N (%)	29	33	26	0.108		32	30	27	0.614	

*Treatments are significantly different from each other when the difference between the values is greater than the LSD (least significant difference) value.

Table 5.10 Effect of nitrogen rate and plant density on marketable head percentage and marketable head yield (MktHeadYld) of broccoli grown at the Queensland DAFF Gatton Research Facility in 2012.

Broccoli crop parameter	N rate (kg ha^{-1})	Plant population ('000 plants ha^{-1})			F test prob.	LSD*
		40	60	80		
Marketable Head %	100	93.8	55.5	29.6		
	200	96.4	88.9	58.4	<.001	13.12
	300	96.5	93.6	71.3		
MktHeadYld (tonne ha^{-1})	100	10.0	7.9	5.2		
	200	13.2	14.8	12.1	<.001	1.773
	300	14.0	16.9	16.5		

*Treatments are significantly different from each other when the difference between the values is greater than the LSD (least significant difference) value.

Table 5.11 Effect of nitrogen rate of application on P uptake in broccoli grown at a range of nitrogen application rates at the Queensland DAFF Gatton Research Facility in 2012.

Crop parameter	Nitrogen application rate (kg ha^{-1})			F test prob.	LSD*
	100	200	300		
Total crop P uptake (kg ha^{-1})	29.6	38.4	44.1	<.001	2.3
Marketable P Removal (kg ha^{-1})	5.1	8.5	11.0	0.001	2.0
Total Head P uptake (kg ha^{-1})	7.9	9.9	11.9	0.003	1.7
P in field Residues (kg ha^{-1})	21.6	28.5	32.2	<.001	1.5
Head P%	0.64	0.70	0.73	<.001	0.03
Field Residue P%	0.39	0.44	0.47	0.013	0.04

*Treatments are significantly different from each other when the difference between the values is greater than the LSD (least significant difference) value.

Overall, increasing N application rates to about 200 kg N ha^{-1} with a plant density of about 60,000 plants ha^{-1} gave maximum broccoli yield compared with the standard grower practice of about 40,000 plants ha^{-1} and 100-120 kg N ha^{-1}.

5.4. Experiment 3 - Vegetable crop response to timing of N application

5.4.1. Introduction

A field experiment was established in the winter production season in the Lockyer Valley 2012 (Queensland Government DAFF Gatton Research Facility) to identify whether split applications of fertiliser can improve lettuce and broccoli crop growth and nitrogen recovery.

5.4.2. Materials and methods

An experiment was conducted to evaluate the effects of fertiliser timing of application on the growth of broccoli and lettuce. The rate of N application was 200 kg N ha^{-1} for the broccoli and 100 kg N ha^{-1} for the lettuce, both applied as urea. Nitrogen treatments were added as urea and irrigated via overhead solid set irrigation. The experimental design was a randomised complete block replicated 4 times. The preparation and planting and harvest details were as reported in the plant density experiment. Including a basal fertiliser application, the treatments consisted of 2, 3, 4 and 5 timings (treatments T2, T3, T4 and T5) as per Table 5.12.

Table 5.12 Timing of nitrogen fertiliser applications and amounts in an experiment that evaluated effects of timing (Treatments T2, T3, T4 and T5) on growth of lettuce and broccoli at the Qld DAFF Gatton Research Station in 2012.

Application date		10-May-12	25-May-12	4-Jun-12	19-Jun-12	2-Jul-12
Days after planting		1	16	26	41	48
Application number		1st	2nd	3rd	4th	5th
		Lettuce N rate 100 kg (ha^{-1})				
100	T2	50	0	50	0	0
100	T3	30	0	35	35	0
100	T4	25	10	25	40	0
100	T5	20	10	15	30	25
		Broccoli - N rate 200 kg (ha^{-1})				
200	T2	80	0	120	0	0
200	T3	66	0	67	67	0
200	T4	50	20	50	80	0
200	T5	40	25	40	60	35

5.4.3. Results and discussion

5.4.3.1. Nitrogen timing experiment

In the broccoli experiment, the head and residue fresh and dry matter yields were greatest in the T5 treatment and greater than those in T2, T3 and T4 (Table 5.13) indicating splitting applications of N to broccoli may increase crop yield and N recovery. In contrast, the effect of timing of N application on lettuce growth was not significant (data not presented).

Table 5.13 Fresh yield (FY), dry matter content (DM%), dry matter yield (DMYld) for head and field residues of broccoli grown under 200 kg N ha^{-1} at 4 timings of application (T2, T3, T4 and T5) at the Queensland DAFF Gatton Research Facility in 2012.

Broccoli	Treatment (Number of fertiliser applications)				F test prob.	LSD*
	T2	T3	T4	T5		
Total Crop FY (tonne ha^{-1})	76.4	78.9	81.5	88.3	0.005	5.67
Head						
FY (tonne ha^{-1})	12.2	12.3	12.5	14.6	0.006	1.31
DM%	9.98	9.88	9.79	9.57	0.034	0.2667
DMYld (tonne ha^{-1})	1.21	1.21	1.22	1.40	0.016	0.1215
Field Residue						
FY (tonne ha^{-1})	68.2	70.7	73.1	78.5	0.008	5.146
DM%	9.86	9.88	9.23	9.61	0.117	
DMYld (tonne ha^{-1})	6.73	6.99	6.76	7.56	0.177	

*Treatments are significantly different from each other when the difference between the values is greater than the LSD (least significant difference) value.

5.5. General Discussion

The results of the N rate trials show that the optimum application rate of N to lettuce (Cos and Iceberg) is in the order of about 80-120 kg N ha^{-1} and consistent with the application rates that are applied by Lockyer Valley lettuce farmers (about 90 kg ha^{-1}, Chapter 4). At this application rate the removal of the N in the harvested heads is equivalent to the applied N. The yield of broccoli, cabbage and cauliflower increased with increasing N rate to an optimal over the range of 160-200 kg N ha^{-1} and the application of N by growers (about 90-110 kg N ha^{-1}) is well below the total crop requirement. The N uptake in the nil applied N treatment in each of the brassica crops was relatively high (about 60-90 kg N ha^{-1}) highlighting the significance of soil mineralisation in meeting brassica crop N needs. For celery, the total crop N uptake closely matched crop N application except at the highest N application rates where uptake was about 25-30 kg N ha^{-1} less than application. The N uptake in the nil applied N treatment was about 38 kg N ha^{-1} and the difference between total crop uptake and the soil mineralised N uptake (derived from uptake in the nil applied N treatment) suggested that celery was inefficient in N uptake. This was in strong contrast to the brassica crops where total N uptake (360-425 kg N ha^{-1}) was far in excess of application in the 240-280 kg N ha^{-1} treatments suggesting that the individual crop species exerted an effect on soil N mineralisation or there were differences in the capacity of the crops to extract N from the soil; this requires further study. Data on crop development over time showed that the optimisation of N application gave more rapid crop development.

Importantly, the data developed in this experiment in conjunction with the grower crop budgeting data (Chapter 4) highlight that vegetable growers, at least in the Lockyer Valley, efficiently manage N, and budgets for N range from neutral to strongly negative. In operating negative N budgets, growers need to carefully consider the impacts of crop rotations on subsequent crop N requirements and application. For example, crops that result in high rates of N removal (eg. grain crops such as sorghum) will severely deplete soil N meaning that N application to subsequent vegetable crops may need to be increased. The research on effects of crop residues highlighted that crop residues with high C:N ratios (>35) (eg. sorghum, eggplant and sweetcorn) resulted in nitrate immobilisation. Hence not only do crops such as sorghum have high N extraction, the residues also result in N drawdown (immobilisation). This highlights that fine-tuning N management to reduce losses to the environment requires a whole of farm system approach. This would include the use of monitoring for pre-plant soil nitrate and the development of the potentially mineralisable N method.

6. Technology Transfer

A range of methods were used for technology transfer as part of this project. In Watsons Creek one of the most important methods was direct discussions with a number of growers who have experienced conflicts related to environmental issues and sensitive waterways. This strategy was also used widely in the Lockyer Valley and Bowen. In the Lockyer Valley about 14 businesses or growers were surveyed in completing the nutrient budget survey, which represented about one third of the vegetable growers in the region and comprise about 60-70% of production by volume. In general, the results have been presented widely in the key focal areas for the project work of Bowen/Ayr, Lockyer Valley and Watsons Creek (Table 6.1).

Table 6.1 Dates, activities and locations for presentations associated with project VG09041 'Environmental effects of vegetable production on sensitive waterways'.

Date	Activity
April 28 and 29 2010	Presentations to Bowen and Ayr growers and industry on the project as part of a joint soil health project presentation.
Nov 26 2010	Presentation of project nutrient budget survey results and nutrient management research to vegetable industry as part of Ausveg Enviroveg presentations UQ-Gatton Campus
Feb 8 and 9 2011	Presentation of Nutricalc nutrient budgeting calculator with field representatives from three key fertiliser sales companies servicing the Lockyer and Fassifern Valleys and Eastern Darling Downs.
Nov 2011	Sarah Limpus presented a paper at the Australasia Pacific extension network meeting at UNE.
Nov 8 2011	Presentation of project nutrient budget survey and Gatton Research Station trial results to Lockyer Valley Growers and industry – Tenthill Hotel
Feb 29 2012	Presentation to Watsons Creek Steering Committee on behalf of the vegetable growers (by Robert Premier) about the aims of this project and findings to date.
April 2012	Soil and crop health seminars at Bowen and Ayr including capsicum nutrient management. Presentation of Nutricalc nutrient budgeting calculator.
Apr 16 2012	Project leader Stephen Harper and Project officer John Bagshaw met with Robert Premier (Project leader Victoria) and key grower collaborators at Watsons Creek to discuss the project and to develop the GAP for sensitive waterways.
May 2012	Presentations on improved soil and nutrient management in Lockyer and Fassifern Valleys. Presentation of Nutricalc nutrient

	budgeting calculator.
May 16 2012	Presentation of project nutrient research results to Stanthorpe vegetable Growers and industry (including the Young Growers Group) Stanthorpe.
Oct 2012	Formal presentations on the data have been made at grower forums in Ayr, Bowen and Fassifern Valley
Feb 2013	Presentation and review of the good agricultural practice guide "Clean streams, sustainable vegetable farms" at Victorian Vegetable Grower group meeting.
June 2013	Presentation and review of the good agricultural practice guide "Clean streams, sustainable vegetable farms" with Bowen vegetable growers.

Publications

Good agricultural practices guide for sensitive waterways. A good agricultural practice guide has been developed titled "Clean streams, sustainable vegetable farms". A copy of the guide is shown in Appendix 6. The guide provides a stepwise process that allows issues associated with sensitive waterways to be addressed.

Dr Robert Premier has conducted workshops in the Watsons Creek region and reviewed the Sensitive Waterways GAP guide with vegetable growers there. The project results were presented at a VGA meeting on the 15th of January 2013; at that meeting a new group of growers that could benefit from this work was identified. These are growers with farms along creeks and rivers that empty in the environmentally sensitive Gippsland Lakes area. These farmers from East Gippsland are mostly leafy vegetable farmers and have been involved in discussions related to the nutrient leaching into the great Gippsland Lakes. A further presentation and review was conducted with Bowen vegetable growers.

The guide was also presented to EnviroVeg and FreshCare environmental for possible inclusion in the programs. Positive discussions have been held with the FreshCare environmental coordinator. However, EnviroVeg is currently undergoing a review to evaluate how it can remain relevant to the vegetable industry and how it will operate. This consultation phase will need to be completed and a coordinator appointed before the GAP can be included in the EnviroVeg program. The GAP is published in a generic format such that it can be readily adopted by interested parties wanting to use it as a guiding document under due acknowledgement.

Working with communities

Through collaboration and with funding from the project a guide has been prepared by Mornington Peninsula and Western Port Biosphere Reserve Foundation Ltd as a manual detailing a process for vegetable growers to engage with the community on sensitive waterways issues. The manual is based on the Watsons Creek Model - a process in use by the Foundation on its Watsons Creek Integrated Management Project. The Watsons Creek Integrated Catchment

Management (ICM) Project –is being used as the model to base the development of a manual for the sustainable and collaborative management of land, including agricultural land, near sensitive waterway areas. The guide is included as an attached document.

Nutrient Budgeting

The vegetable nutrient removal calculator ("Nutricalc") has been further developed and is available on the web as an Excel based tool. This tool enables growers and consultants to calculate the amount of nutrient used by their crop and that removed in harvested product and to calculate the efficiency of their fertiliser application program. The principals of nutrient budgeting were discussed individually with several agribusiness groups (particularly fertiliser resellers) and with individual farmers in presentations at grower forums. The tool has been presented to industry and growers and was reviewed to improve the ease with which it can be used and to identify any gaps in its format and content. The nutrient budgeting technique has been extended to growers in the Watsons Creek region and has allowed them to assess and review their fertiliser use efficiency.

The nutrient budgeting tool is available at:-

(http://www.healthywaterways.org/HealthyCountry/Resources/SustainableLandManagementResources.aspx)

Calculator tool user guidelines are also available at the website. The guidelines for nutrient management and budgeting have also been made available on its website and includes two fertiliser use fact sheets including:-

Fertiliser use efficiency - Matching fertiliser inputs to vegetable crop removal

Optimising nitrogen fertiliser use efficiency in vegetables

Following the significant flooding in the Lockyer Valley in 2011 and 2013, Stephen Harper specifically evaluated nutrient management issues with vegetable farmers in affected areas. This was conducted on a one-to-one basis and evaluated their flood remediation nutrition programs.

Other general publications

Annual HAL Vegetable Industry Annual Reports for VG09041: Environmental effects of vegetable production on sensitive waterways were published in Aug 2010, Aug 2011, Aug 2012 and Aug 2013.

Article published in the SEQ Hort Report (July 2010) reporting nutrient removal rates for Lockyer Valley Vegetable crops.

An article was published in the joint newsletter for VG09038 and VG09041 VegPASH news issue 6 October 2010 and circulated to growers across Australia.

A further article published in the VegPASH news issue 8 December 2012 (VG09038 and VG09041) - Nutrient budgeting as a guide for efficient fertiliser use. This newsletter is circulated directly across Australia to growers.

Peer Presentations

Sarah Limpus presented the project findings at the APEN (Australasia Pacific extension network) meeting November 2011 at UNE. The title of this paper was:-

Working with horticultural producers to promote practices contributing to sustainable vegetable production and environmental health in Bowen, Queensland. Sarah Limpus, Stephen Harper, Tony Pattison and Sue Heisswolf.

Developing SafeGauge for vegetable production in sensitive waterways.

SafeGauge for Nutrients is a decision support tool that is useful for raising awareness of differences between blocks/soil type in the relative importance of different nutrient loss pathways. SafeGauge for Nutrients qualitatively assesses the potential risk of off-site movement of nitrogen (N) by runoff/sediment to surface water, by drainage to groundwater, and by denitrification to the atmosphere. A version of SafeGauge was specifically developed to assist nutrient management in seasonal horticultural crops such as rockmelon; a more sophisticated web-based version is available for sugarcane. SafeGauge uses site-specific soil and long-term rainfall data to assess risk of off-site nutrient movement resulting from N inputs as fertilisers. The user can adjust fertiliser rate, application method and time of application to assess the effects of these changes on the risk of nutrient loss for that particular block.

A series of scenarios (evaluating soil, irrigation/rainfall and nutrient application) were run through the SafeGauge software package. The scenarios highlight that the software has potential to be used in vegetable production to identify the potential risks for nutrient loss by assessing the current farmer management practices and how, if these are modified, the impacts can be reduced. The software interfaces with climatic and soil mapping data making it unique to the farmers' own properties (Fig. 6.1), and even to identify variability within their property through accurate soil mapping. Interpretations of the scenarios highlighted that the effects of soil type, rainfall and rate of application can be assessed using SafeGuage. As an example, the software accurately identifies the presence of N in the soil in the tropics as representing a low risk of loss in the dry season, but the risk is high in the wet season (Fig. 6.2). Similarly, differences in N loss can be demonstrated for different soil types in the Bundaberg region (Fig. 6.3). SafeGauge enables the user to assess, at farm block scale, the effects of changing management practices on the potential risk to water bodies (and the atmosphere as a greenhouse gas) from off-farm movement of N. It integrates the major factors involved in determining off-site N loss and produces an easy-to-understand assessment of the potential risk.

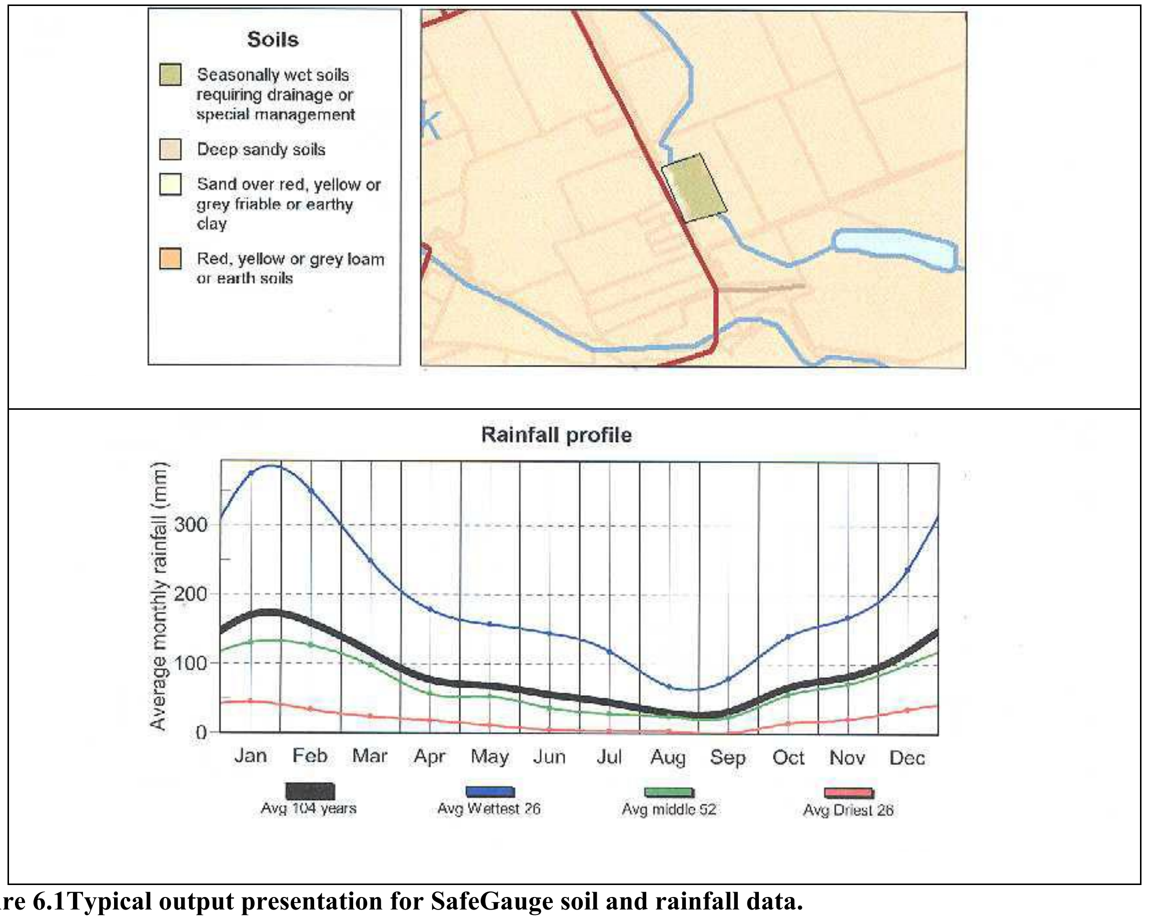

Figure 6.1Typical output presentation for SafeGauge soil and rainfall data.

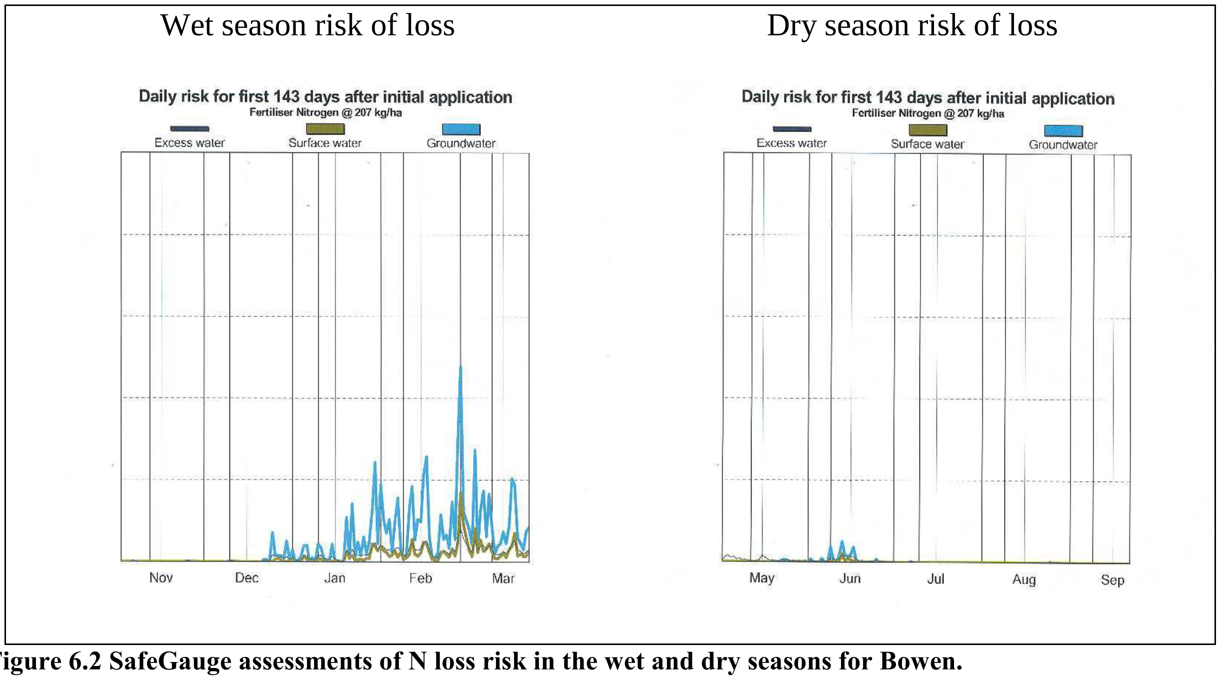

Figure 6.2 SafeGauge assessments of N loss risk in the wet and dry seasons for Bowen.

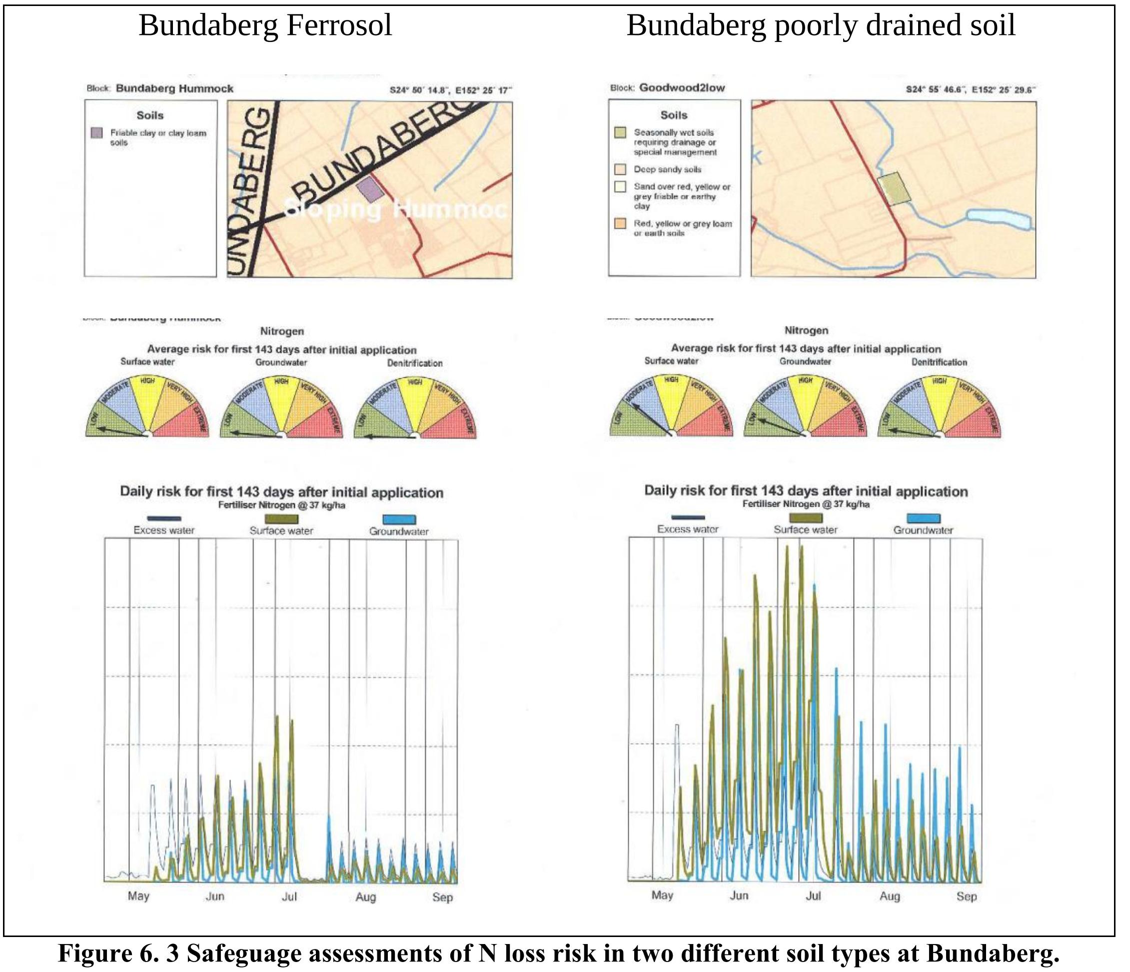

Figure 6. 3 Safeguage assessments of N loss risk in two different soil types at Bundaberg.

SafeGauge highlighted the different dominant nutrient loss pathways in soils of different permeability/drainage characteristics. Permeability is related to soil texture and structure; drainage is related to position of the soil in the landscape. The risk of N loss increased with increasing rate of application and was exacerbated by once-off applications compared with fertigation. Maximising irrigation efficiency (i.e. minimising drainage below the root zone and/or period of soil saturation) minimised the risk of N loss by drainage and denitrification.

SafeGauge for Nutrients is a decision support tool that is useful for raising awareness of differences between blocks/soil type in the relative importance of different nutrient loss pathways. SafeGauge provides guidance on management strategies for minimising losses by the different pathways, and could therefore be a component of a farm nutrient management plan. Because SafeGauge is based on look-up tables, it can be continuously updated with data/findings on nutrient and water movement as they become available. Enhancements could be made to SafeGauge for options to cover different irrigation methods and scheduling, the use of controlled release fertilisers, and seasonal forecasts.

Future actions

The vegetable nutrient removal calculator has been developed ("Nutricalc") and has been trialled and reviewed with fertiliser resellers in the Lockyer Valley who believe it is a good tool for consultants to use with growers. The tool will now be expanded to be a full budgeting tool to incorporate residue inputs and soil mineral N reserves.

It is anticipated that the information gathered within this project can be presented as a Vege-Note to the vegetable industry. The results of this project will be used to further strengthen environmental programs such as EnviroVeg and Freshcare.

It is intended that the research and survey components of the project will be evaluated to identify what can be published in scientific journals.

7. Recommendations - Scientific and Industry

The project identified and published strategies, processes and tools that can identify and address community issues and conflicts that relate to sensitive waterways. These strategies are broadly applicable to any region where general waterway concerns are held. The process includes the identification of key interested parties in waterway management from a local level to a broad regional level, simple surveying of general community concerns, application of grower surveys to identify the potential for losses (partial nutrient budgets) and, as necessary, more intensive soil, plant and water analyses to further validate farmer practices.

Critical in this process is nutrient budgeting which is a useful tool in identifying whole crop nutrient uptake, nutrient removed in harvested product and the identification of over- or under-application of nutrients. The nutrient budget surveys and longer term case studies indicate that growers in the Lockyer Valley mostly operate on near neutral budgets for N and P. Hence the expectation that nitrate losses occur is low in a normal winter production season when the amounts of rainfall are also low. The soils in the Lockyer region are relatively heavy textured which does not favour leaching processes and have high water holding capacity that reduces irrigation frequency and amounts which also reduces the potential for losses. As such, the ability to operate on neutral N and P budgets appears effective in the Lockyer region.

In contrast to this, in the Watsons Creek and Bowen districts, nutrient budgeting for a limited number of farms highlighted over-application of N. In Watsons Creek this problem was mostly because of relatively high rates of chicken manure application in relation to crop nutrient requirements. The use of nutrient budgeting in this region allowed these collaborators to greatly reduce N inputs and therefore reduce loss potential.

Since the project only operated in a very limited number of regions, the survey findings might not, indeed are unlikely to, be representative of the Australian vegetable industry. Furthermore, within the focal areas, only a small number of sites were selected for monitoring over time which also might not be representative of the region's average. A more intensive monitoring within and across regions is required if the vegetable industry wishes to develop a strong, broadly based and representative position statement on nutrient management.

However, the principles developed in the project can be easily applied to not only evaluate the potential for farming systems to lose nutrients, but to identify overall crop nutrient requirements and longer term budgets, including negative budgets as was demonstrated for K. This budgeting approach was very well received by growers and they could understand the value of the process. The more widespread adoption of the nutrient budgeting using the Nutricalc tool developed in the project would facilitate this adoption. However, a concerted extension effort is required to promote this concept.

Furthermore, the calculator needs to be expanded to include other important components including residual soil mineral N (nitrate and ammonium) at planting. An evaluation of the role of soil mineral N at planting in meeting crop uptake over the duration of cropping is important as the residual soil N in the current grower assessments played a major role in meeting the total crop N uptake particularly when growers under-applied N and in crops where nutrient demand was high.

The research trials at the QDAFF Gatton Research Station in the Lockyer Valley identified that optimal rates of N application are higher than the industry standard in brassica (broccoli, cabbage and cauliflower) and celery crops. Indeed the research trial and nutrient budget survey evidence highlighted in the Lockyer Valley that N was applied at a rate marginal in meeting crop requirements and this can result in product quality defects. In contrast to the brassicas and celery, the application of N to lettuce (Cos and Iceberg) in the Lockyer Valley region provides exceptional N use efficiency at close to 100%.

The nutrient budget survey on the one hand highlighted that growers do not tend to greatly modify nutrient input rates for different crops whilst the research trials and nutrient budgeting showed very large differences between crops for their nutrient uptake. A better understanding by growers of vegetable crop nutrient requirements and management is important to identify specific crop nutrient inputs that maximise crop productivity and quality. The development of critical N input rates would allow optimisation of crop productivity.

The project has developed a sound knowledge of crop nutrient requirements and tools that can address issues related to impacts on sensitive waterways. This can be broken down into some key points including:

- The identification of key and active waterway stakeholders (context analysis)
- Surveying community perceptions and expectations to identify perceived problems or contributing parties.
- The publishing of a guide to working with communities in sensitive waterways to allow better resolution of issues.
- The development of a Good Agricultural Practices Guide for Sensitive Waterways that can be used to improve nutrient and soil management.
- The development of Nutricalc to assist with nutrient budgeting and assessing fertiliser use efficiency associated with the publishing of the key documents: Fertiliser use efficiency - Matching fertiliser inputs to vegetable crop removal and Optimising nitrogen fertiliser use efficiency in vegetables.

The further development of the various tools from this project into a more structured grower friendly package as a module that underpins an environmental quality assurance system would be extremely useful. Based on this, more intensive training sessions on the good agricultural practices to reduce nutrient leaching into sensitive waterways would be required.

A better understanding of where sensitive waterways are located in relation to key vegetable production areas is important. At the start of this project, three areas were identified (Watsons Creek in Victoria and the Great Barrier Reef and Moreton Bay in Queensland) and this project was tailored to address issues at these sites. The Victorian project team has identified other areas where vegetable farming near sensitive waterways may be an issue. These are vegetable farmers along the mouth of the Murray River in South Australia, vegetable farmers in Gippsland farming near the Gippsland lakes, vegetable growers in the Hawkesbury River, and vegetable growers along the Murray River basin. Future work should concentrate on other sites for both educating growers and monitoring farms for nutrient leaching and preferably take into account the potential for losses to occur.

In this regard there is a strong potential to modify the SafeGauge nutrient management software to meet the needs of the vegetable industry across Australia. The scenarios evaluated in this project indicate SafeGauge can be an effective tool for evaluating the likely potential (risk) for soil and nutrient losses. The software has been successfully used in the Queensland sugar industry to identify the risk of nutrient and sediment loss, and identify the pathways of loss using soil mapping, fertiliser inputs and timing, irrigation management and expected rainfall.

An opportunity exists to conduct a regional nutrient budget using the method developed by Harper and Menzies (2009) that was applied to the Lockyer Valley. This consists of validating ABS data for production, identifying nutrient removal in the marketed product and matching this to regional vegetable fertiliser inputs based on hard data collected at a local level. From this, strong statements can be made at a regional level about vegetable industry nutrient use.

Finally, in the Lockyer Valley survey and monitoring, the project has identified that depletion of nutrients other than N and P is a serious issue. This is particularly the case for potassium where crop uptake of K is high and essentially the same quantum as for N. However, the replacement of K is only about 25% of that removed in harvested product. Growers need to more carefully consider the potential for K limitations to impact on crop growth and productivity. Soil nutrient depletion and nutrient under-application are serious issues affecting the long-term viability of intensive vegetable production and a better understanding is required of other nutrient dynamics and the potential future impacts of depletion.

8. Acknowledgements

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10. Appendices

Appendix 1 - Context analysis information for Lockyer Valley, Bundaberg Bowen and Watsons Creek

Context analysis data that includes details of groups involved in waterway management in the key project areas of the Lockyer Valley, Burnett-Mary (Bundaberg), Bowen Gumlu and Watsons Creek. The first table includes Queensland organisations with a statewide responsibility.

Table 1. Queensland organisations with State-wide responsibility

Group	Groups major State-wide focus/activity	Web address
Growcom	Private company. Growcom is the Queensland horticulture industry's strongest advocate and provides industry services, support and products.	www.growcom.com.au
Qld Department of Agriculture Forestry and Fisheries	State Government Department. An economic development agency providing agricultural research development and extension across Queensland	www.daff.qld.gov.au/about-us/default.htm
Qld Department of Environment and Resource Management (DERM)	State Government Department. Addresses issues of environment and sustainability including conserving the state's natural and cultural heritage.	www.derm.qld.gov.au

Growcom has developed a series of Farm Management System modules. These include water use efficiency, nutrient management and water quality modules. These modules consist of a series of questions that vegetable producers can work through to assess the environmental risks associated with different aspects of their production system. There are links to further information that growers can then access to minimise any risks. These modules are available to interested fruit and vegetable producers in Queensland. Growcom's Land & water group is active in delivering Reef Rescue-funded activities in the Horticulture industry in Queensland. The Reef Rescue funds are managed through regional NRM groups. Growcom's Reef Rescue program aims to help horticultural growers toward best management practice with a focus on reducing sediment, nutrient and pesticide movement from farms into waterways and the Great Barrier Reef. Their modus operandi is to conduct risk assessments with growers to jointly determine areas of improvement, and then to offer incentive money to qualifying growers to enable these improvements. Training is offered to these growers and to all growers in aspects of horticulture production management that will have the greatest impact on reducing farm-based pollutants affecting the Great Barrier Reef. Growcom also conducts field days to showcase growers involved in the program, and to promote best management practice.

Department of Agriculture Forestry and Fisheries (DAFF - Queensland Government) has research and extension officers operating in all of the vegetable regions of Queensland. See individual region reports for their regional activities.

Sustainable Agriculture officers operate in the Lockyer Valley, Caboolture region and at Gympie, encouraging fruit and vegetable practices that protect sensitive waterways, in particular efficient water and fertiliser use, reduced tillage and controlled traffic farming. This group have developed an ABCD Framework of practices for fruit and vegetables consistent with the Reef Rescue initiative. This framework identifies and benchmarks different standards of practice based on potential environmental impact. A=aspirational (or cutting edge) best practice, B=current industry best practice, C=compliant practice (meets legal requirements) and D=degrading practice (degrades environmental values). Similar frameworks have been developed for other agricultural industries that operate in the Great Barrier Reef catchments.

The horticulture ABCD Framework document (along with other resources) can be found here:

http://www.healthywaterways.org/HealthyCountry/Resources/SustainableLandManagementResources.aspx

The Department of Environment and Resource Management acts in a regulatory role. It regulates the taking of groundwater and the compliance with creek works and inspection of this. They are involved in a number of water monitoring initiatives, including regular groundwater monitoring, and surface water monitoring related to two main initiatives: The healthy waterways initiative in South East Queensland and the Reef Loads Program (Great Barrier Reef Initiative 5) in the GBR catchments from Bundaberg north.

Lockyer Valley Context analysis

Table 2. Key groups involved in waterway management issues in the Lockyer Valley.

Group	Groups major focus/activity	Web address
Community groups		
Lockyer Water users forum	Irrigation water management	
Lockyer Landcare`	Landcare group	
Atkinsons Buaraba Landcare Group	Landcare group	http://www.ourshopfront.com/landcare/
West Moreton Landcare Group	Landcare group	
Helidon Hills-Murphy's Creek Landcare Group	Landcare group	http://www.hhmclandcare.org.au/
Industry and resource management groups		
SEQ water	Bulk water supply including domestic and irrigation.	http://www.seqwater.com.au/public/home

Group	Groups major focus/activity	Web address
SEQ Catchments	Peak NRM group for SEQ responsible for planning and implementation	www.seqcatchments.com.au/index.html
SEQ Healthy Waterways Partnership	A not-for-profit organisation that works collaboratively with government, industry, researchers and the community to protect and improve the waterways of South East Queensland.	www.healthywaterways.org/Home.aspx
Growcom Sunwater	See Section 1 for details	www.growcom.com.au
Government		
Lockyer Valley Regional Council	A regional council that represents most of the Lockyer Valley	www.lockyervalley.qld.gov.au/
Somerset Regional Council	A regional council that represents the lower Lockyer Valley.	www.somerset.qld.gov.au/
Department of Environment and Resource Management (DERM)	See Section 1 for details	www.derm.qld.gov.au/
Department of Agriculture Fisheries and Forestry (DAFF)	See Section 1 for general State-wide details.	www.daff.qld.gov.au/about-us/default.htm
Powerlink	A government-owned corporation that owns, develops, operates and maintains the high-voltage electricity transmission network.	www.powerlink.com.au/asp/index.asp
Universities		
Griffith University	Education and Research	www.griffith.edu.au/
Queensland University of	Education and Research	www.qut.edu.au/

Group	Groups major focus/activity	Web address
Technology		
The University of Queensland	Education and Research	www.uq.edu.au/
University of Southern Queensland	Education and Research	www.usq.edu.au/

Community Groups

The Atkinsons Buaraba landcare group operates in the northern part of the Lockyer Catchment. This area is not a major vegetable producing region and is relatively remote from the key vegetable producing areas in the Lockyer Valley. The group currently does not have any major activities in relation to nutrient and sediment management. However, it completed a project that evaluated water use and soil moisture monitoring across three farming systems including turf, tree crops (avocadoes) and forage. The chairman Greg Banff is currently implementing a land and water management plan on his own turf production property.

The West Moreton Landcare Group operates in the eastern part of the Lockyer Valley Catchment. There is essentially no vegetable production in this sub-catchment and it is remotely located from the key vegetable production areas of the Lockyer Valley. This group has had a major focus on the management of salinity in a key tributary Black Snake Ck. The group has managed a 3 year project that was federally funded which conducted a scientific and on-ground evaluation of salinity in Black Snake Ck. A comprehensive report on this work was published. The group does not conduct activities directly related to vegetable production.

The Lockyer Landcare group operates in the western part of the Lockyer Valley catchment. Vegetable production in this region is important but it is not a substantial production area. The major focus of this group is the control of environmental weeds, mostly privet, and replacement with native vegetation in the Upper Flagstone Ck catchment. They currently have a funding submission with Toowoomba Regional Council to support this activity. Past activities have included the battering of creek banks and revegetation to stabilise alluvium and reduce sediment loss.

Helidon Hills-Murphy's Creek Landcare Group operates in the area to the north of Helidon and covers an area with around 34,000ha of very high nature conservation significance and one of the largest pieces of mostly continuous bushland left in South East Queensland. There is essentially no vegetable production in this area but there are small pockets of orchard crops.

The Lockyer Water Users Forum is a peak irrigator body in the Lockyer Valley. Their primary focus has been on the management of water resources in the region and the negotiation of secure irrigation resources principally as recycled water from Brisbane city. Currently the Queensland Government through CSIRO is conducting a major project that is reviewing engineering issues and distribution to evaluate feasibility.

Industry and resource management groups

SEQ catchments is a peak body representing community needs for NRM. They run a program that evaluates water quality across catchments in South East Queensland (SEQ). The program monitors and reports stream water quality and operates at two levels in achieving this. The first element of the program is a monitoring program that operates through volunteers collecting and submitting samples for analysis. Measurements of dissolved oxygen, turbidity, temperature pH and salinity are taken. The second element monitors water quality from major flow events and involves the Healthy Waterways partnership. In the Lockyer region the event monitoring site for this is in Deep Gully near Ropely. This monitoring is undertaken under the EHMP program. This sub-catchment essentially does not produce vegetables and it is not linked with areas of vegetable production. Hence any monitoring from this site can't be related to vegetable production impacts. There is a further waterwatch program which no longer operates that monitored water quality in the upper Lockyer Creek above where vegetables are produced and in Alice Creek to the north of the catchment where there is no vegetable production.

SEQ Catchments works with landholders to reduce sediment delivery to waterways through gully and creek bank stabilization projects, delivering grazing management packages and assisting in the development of Land and Water Management Plans and Property Management Plans that consider economic, social and environmental aspects of managing a property, including drainage and sediment movement off property.

SEQ Catchments is a partner in the Queensland Government funded Healthy Country Program. This program is a partnership between DAFF - Queensland, SEQ Catchments, SEQ Healthy Waterways Partnership and SEQ Traditional Owners Alliance. Under the Healthy Country program a 'focal' area has been identified in the Black Fellow Creek region to evaluate the potential impact of improved land management on stream water quality. An SEQ Catchments project officer has been employed until June 2011 to specifically work in this 'focal' area. Their role in this 'focal' area is to engage with the local community and undertake relevant and appropriate landscape restoration activities that will contribute to reduced rural diffuse sediment loads in the waterway. This 'focal' area is a significant area for vegetable production and is upstream of the most intensive vegetable production area in the Lockyer Valley, namely Tenthill. In-stream monitoring of rainfall events has not been initiated because of the intensity of flood events and the high probability of equipment loss in such events. Lidar mapping 2009 and 2011 of this area clearly indicates sediment movement across the landscape, waterway connectivity and erosion and deposition areas in the channel itself.

SEQ Healthy Waterways Partnership is also a partner of the Healthy Country program. Their role in this program is the co-ordination of the Griffith University contribution including the development and implementation of the monitoring and evaluation program. They have funded research conducted by DAFF - Queensland and The University of Queensland that has conducted a broad regional nutrient budget for horticultural production in the Lockyer Valley and conducted limited on-farm nutrient budgeting.

Government

The Department Agriculture Fisheries and Forestry (DAFF - Queensland) is also a partner in the Queensland Government funded Healthy Country program. An Extension Officer has been employed until June 2011 through this program to work with vegetable producers in both the Black Fellow Creek ‘focal’ area as well as across the broader Lockyer Valley catchment. The primary role of this officer is to engage and work with vegetable producers to promote and support the implementation of improved soil and nutrient management practices that reduce the risk of sediment and nutrient movement off-farm. Key management practices include optimising nutrient management (fertiliser program decisions, method and timing of application), cover cropping (role in reducing soil loss and soil quality benefits) and controlled traffic farming and minimum tillage (economic and soil quality benefits). As part of this extension program various case studies and factsheets have been produced, numerous trial and demonstration sites established and several field days and field walks held to promote these practices. As part of this program an Agricultural Economist has also undertaken economic analyses of some of these management practices to highlight the cost:benefits of implementation to producers.

DAFF - Queensland has conducted considerable research and extension into the efficient use of irrigation resources and improved practices of irrigation to reduce nutrient leaching. It currently conducts programs that are developing improved vegetable crop genetics for nutrient use efficiency. DAFF - Queensland currently has a major project funded by Brisbane City Council that evaluates the beneficial reuse of composted green waste into vegetable production in the Lockyer Valley including soil improvement.

Powerlink is the government-owned corporation that owns, develops, operates and maintains the high-voltage electricity transmission network. They currently conduct a joint project with SEQ Catchments and The University of Queensland that aims to stabilise soil and landscape under its high voltage transmission lines that link the Middle Ridge substation in Toowoomba with the Greenbank substation between Brisbane and Ipswich. The project site is immediately west of Grandchester and south of Laidley and approximately 30minutes from Ipswich.

The topography is described as rising undulating to moderate range country. The vegetation on the easement was a mixture of predominantly spotted gum, narrow leafed ironbark, blue gum and other smaller endemic species on a dispersive duplex soil. They have funded the Dispersive Soils Project (DSP) project which aims to reduce the movement of sodic clay sediment wash from this site and enhance the water quality entering the local creek system.

The project assesses soil properties relevant to erosion, monitors erosion, and provides recommendation for improved land management options on easements.

Universities

Griffith University has also been contracted to the Healthy Country program for the reduction of rural diffuse pollutants within the Lockyer Valley. Their primary role has been the modelling of sediment and nutrient sources to prioritise activities within the catchment. They have also been involved in the development and delivery of the monitoring and evaluation component of the Healthy Country program.

The University of Southern Queensland with National Centre for Engineering in Agriculture and Growcom have developed a Nutrient Balance and reporting Tool funded by the Queensland Government. This is an online tool (calculator) that will assist growers and industry to record fertilizer applications, determine seasonal nutrient balances and identify corrective actions.

The University of Queensland (UQ) has worked with DAFF - Queensland, the Healthy Waterways Partnership, DERM, Powerlink and SEQ Catchments over a breadth of projects. Of specific interest to vegetable production they jointly worked on regional nutrient budgeting in the Lockyer Valley and catchments of the Great Barrier Reef Lagoon. In conjunction with DAFF - Queensland they have several postgraduate students researching improved nutrient management in vegetable production including the beneficial reuse of greenwaste and germplasm nutrient use efficiency.

Burnett-Mary (Bundaberg) region context analysis

Table 3. Key groups involved in waterway management issues in the Burnett Mary region.

Group	Groups major focus/activity	Web address
Community groups		
Burnett Catchment Care Association	Central Burnett Catchment group – mainly grazing	www.burnettcatchment.org www.betterburnett.com
Mary River Catchment Coordinating Committee	Mary River catchment group – coordinates activities in the region from Maleny to near Hervey Bay	www.mrccc.org.au
Tiaro & District Landcare Group	Landcare in Mary River valley	
Friends of the Burrum River System.	A local catchment group	www.burrumriver.qld.au
Industry and Resource Management groups		
Bundaberg Fruit & Vegetable Growers Inc	Fruit & vegetable industry representative organization	www.bfvg.com.au
Growcom	See Table 1 for details	www.growcom.com.au
Burnett Mary Regional Group	Peak NRM group for the Burnett Mary region responsible for NRM planning	www.bmrg.org.au
Sunwater	Manages a regional network of bulk water supply infrastructure including Paradise Dam, the main water supply for irrigated agriculture in the region.	www.sunwater.com.au
Government		
Bundaberg Regional Council	A regional council that represents the Lower Burnett region including most of the horticultural production area	bundaberg.qld.gov.au
North Burnett Regional Council	A regional council that represents the north Burnett region - not much vegetable production in the region	www.northburnett.qld.gov.au
South Burnett Regional Council	A regional council that represents the south Burnett region - some vegetable production in the region	www.southburnett.qld.gov.au
Gympie Regional Council	A regional council that represents the Gympie region - some vegetable production in the region	www.gympie.qld.gov.au

Department of Energy &Resource Management (DERM)	See Table 1 for general State-wide details details	www.derm.qld.gov.au
Department of Agriculture Fisheries and Forestry (DAFF - Queensland)	See Table 1 for general State-wide details	www.daff.qld.gov.au/about-us/default.htm
Universities		
Central Queensland University	Rockhampton based with various regional campuses including Bundaberg.	www.cqu.edu.au

Community Groups

The Burnett Catchment Care Association is most active in the central Burnett catchment where grazing is the main land-use. They do regular water monitoring in that region. The Mary River Catchment Coordinating Committee acts as an umbrella organization for other Landcare and catchment groups operating in the Mary River Catchment. Land use in the catchment is varied and includes vegetable production mainly in the Gympie region. There are no active catchment or Landcare groups operating in the main vegetable production areas around Bundaberg.

Industry and Resource Management groups

Burnett Mary Regional Group (BMRG) is the peak coordinating body for natural resource management in the Burnett and Mary river catchments. A Landcare Coordinator linked with BMRG has been appointed until 2013 to promote connectivity and integration between NRM and Landcare groups operating in the Wide Bay region. The planned outcome for the role is to promote improved knowledge, skills and practices in natural resource management with landholders in the region through existing NRM and Landcare groups.

The Burnett Mary Reef Partnership is a loose affiliation of regional organisations made up of: Growcom, Queensland Dairy Organisation, Isis and Maryborough Canegrowers, Bundaberg Sugar Services, Burnett Catchment Care Association, Mary River Catchment Coordinating Committee, Agforce, Bundaberg Fruit and Vegetable Growers, and Burnett Mary Regional Group.

Horticulture industry groups

Bundaberg Fruit & Vegetable Growers is an organization representing fruit and vegetable growers in the Wide Bay and Gympie regions. The group employs several staff that manage day-to-day operations, and has a Board comprising horticulture growers, DAFF - Queensland and Bundaberg Regional Council.

Growcom is the Queensland horticulture industry's strongest advocate and provides industry services, support and products. Their Land & water group is active in rolling out Reef Rescue-funded activities in the Horticulture industry in Queensland. The Reef Rescue funds are managed through regional NRM groups, BMRG being the group responsible for the Burnett and Mary river catchments.

Growcom's Reef Rescue program aims to help horticultural growers toward best management practice with a focus on reducing sediment, nutrient and pesticide movement from farms into waterways and the Great Barrier Reef. Their modus operandi is to conduct risk assessments with growers to jointly determine areas of improvement, and then to offer incentive money to qualifying growers to enable these improvements. Training is offered to these growers and to all growers in aspects of horticulture production management that will have the greatest impact on reducing farm-based pollutants affecting the Great Barrier Reef. Growcom also conducts field days to showcase growers involved in the program, and to promote best management practice.

Sun Water manages a regional network of bulk water supply infrastructure including Paradise Dam, the main water supply for irrigated agriculture in the region.

Government

Bundaberg Regional Council (BRC) encompasses most of the vegetable growing area in the Burnett Mary region. BRC has identified a number of water quality projects in order to satisfy aims and objectives of the Reef Guardian Council Program. This includes a water monitoring program in and around their sewage treatment plants to identify potential point source pollution, incorporating water sensitive urban design into council infrastructure and gardens, developing a stormwater management plan, and providing support for schools and community-based monitoring programs. BRC also works with BMRG and other community organisations and supports the actions of the QLD Water Quality Alliance.

The Stormwater Smart project was initiated by BMRG and Bundaberg City Council and involved five other former local governments including Burnett, Kolan, Isis, Biggenden and Miriam Vale. Over the past 3 to 4 years a Water Quality Monitoring Plan has been produced by Central Queensland University. Bundaberg Regional Council and BMRG have completed two rounds of stormwater quality monitoring at 28 sites throughout the localities/regions mentioned above. A final round of monitoring was conducted during the summer of 2010-11.

The State Government recently approved the State Planning Policy 4/10 Healthy Waters (SPP Healthy Waters). This will require Council to assess development applications and condition the works to meet the policy. This will be applicable to a variety of development activities such as residential and industrial estates, requiring them to meet modern Water Sensitivity Urban Design principals.

The Department of Environment and Resource Management has a range of water monitoring activities in the Burnett region. They have about 800 monitoring bores for checking groundwater levels and in 50 to 80 of these they check water quality once a year where water quality is an issue, particularly along the coastal strip to check for salinity due to saline ingress from the ocean. They regularly monitor streams for flow levels and surface water quality at selected monitoring sites at a sub-catchment level.

The Department of Employment, Economic Development & Innovation has a vegetable R&D team based at Bundaberg Research facility. Projects relevant to water quality protection include a Reef Rescue-funded research project looking at the impact of management practices on productivity and off-site water quality in sugarcane and intensive vegetable rotations.

The primary aim of this project is to quantify the effects of different sugarcane-vegetable rotations on offsite water quality. However it is also investigating soil health and nutrition with these different systems. The selected vegetable rotation treatments compare conventional tropical vegetable production (cultivation and use of drip irrigation and plastic mulch) with some newer practices such as minimum tillage, planting into a trash blanket, using an interrow green mulch (millet), and improved nutrient management. The crop sequence in the horticulture phase between cane crops is spring capsicum followed by autumn zucchini.

Measurements will include crop yield and quality, soil health, crop nutrient uptake and nutrients in leached and runoff water.

Universities

Central Queensland University has a campus at Bundaberg which includes a Professor of Horticulture who is 50% funded by DAFF - Queensland and is closely involved in vegetable research with DAFF - Queensland in the Burnett region.

Bowen-Gumlu District context analysis

Table 4. Key groups involved in waterway management issues in the Bowen – Gumlu districts.

Group	Groups major focus/activity	Contact	Web address
Community Groups			
Industry and Resource management groups			
NQ Dry Tropics	The peak NRM group for the Dry Tropics region of North Queensland, including the Bowen and Gumlu regions.	Brett King (Project Officer) 07 4724 3577 brett.king@nqdrytopics.com.au	www.burdekindrytropics.org.au/
Burdekin Bowen Integrated Floodplain Management Advisory Committee	Formed by representatives nominated by the Lower Burdekin Landcare Association from a range of bodies within the Sub-region. The area covered by the committee is the floodplains in the Bowen and Burdekin Shires, embracing the lower catchments of the Bogie, Don, Elliot, Burdekin and Haughton Rivers.	Brooke Corrie (Project Officer) 07 4783 4344 brooke@bbifmac.org.au	www.bbifmac.org.au/default.htm
Bowen Gumlu District Growers Association	Represents fruit and vegetable growers in the Bowen and Gumlu regions.	Denise Kreymborg Industry Development Officer bdgainc@bigpond.com	www.bdgainc.com.au/index.html
Growcom	See Table 1 for details		www.growcom.com.au
Government			
Whitsunday Regional Council	Regional Council representing the Bowen and Gumlu districts. They don't do any water monitoring in the region.		www.whitsunday.qld.gov.au
Department of	See Table 1 for general State-wide		www.derm.qld.gov

Energy &Resource Management (DERM)	details details		.au
Department of Agriculture Fisheries and forestry (DAFF - Queensland)	See Table 1 for general State-wide details		www.daff.qld.gov.au/about-us/default.htm
Universities (including units and departments)			
Australian Centre for Tropical Freshwater Research	Part of the James Cook University based in Townsville.	07 4781 4262 actfr@jcu.edu.au Lab: 07 4781 5209 actfr.labratory@jcu.edu.au	www-public.jcu.edu.au/actfr/index.htm
Catchment Reef Research Group (CRRG)	Part of the James Cook University based in Townsville. A sub-group of ACTFR.	Mr Jon Brodie Group Leader 07 4781 6435 Jon.brodie@jcu.edu.au	www-public.jcu.edu.au/actfr/JCUPRD_056494

Industry and Resource management groups

North Queensland Dry Tropics (NQDT) is the peak NRM group for the Dry Tropics region responsible for NRM planning. They have developed the Burdekin Water Quality Improvement Plan to reduce sediment and agricultural chemicals from entering waterways. They also administer funding for Reef Rescue and Healthy Habitat projects in the region.

The Burdekin Bowen Integrated Floodplain Management Advisory Committee (BBIFMAC) has developed WQ Pixel, an on-farm water quality monitoring support program for growers in the Lower Burdekin, it is funded by NQDT. BBIFMAC also promotes macro-invertebrate and waterway health at local schools.

The Bowen Gumlu District Growers Association represents fruit and vegetable growers in the Bowen and Gumlu regions. They advocate on behalf of Bowen and Gumlu growers and provide support for research and development, water issues, Reef Rescue, industrial relations, Codes of Practice and Award issues, and the Carbon Pollution Reduction Scheme.

Government

The Whitsunday Regional Council has adopted strategies to construct water treatment plants, and new and upgraded sewerage treatment plants at Bowen.

Universities (including units and departments)

The Australian Centre for Tropical Freshwater Research (ACTFR) conducts freshwater research and operates a commercial analysis laboratory. They are instrumental in delivering the Burdekin Community Water Quality Event Monitoring Project for NQDT.

The Catchment to Reef Research Group (CRRG) is a sub-group of ACTFR that conducts research into the “catchment to reef continuum”, from the headwaters of the Great Barrier Reef catchments to the outer reef including tracing the source, transport and levels of pollutants and sediment in the catchment in relation to land uses.

Watsons Creek Context analysis

The aim of this analysis is to identify all stake holders in the region that have an interest relate to water quality monitoring and the engagement of community/catchment for addressing diffuse pollutant losses from vegetable production systems to sensitive waterways. It identifies existing and key past activities that relate to the management of sensitive waterways in the region and links the project into related regional activities and external support, building on established relationships with key players in the wider community.

A list of groups and individuals was formulated and expanded following broad discussions across the community of parties interested in waterway management. In the Watsons Creek area the key identified groups are presented in Table 5.

Table 5. Key groups involved in waterway management issues in Watsons Creek.

Group	Groups major focus/activity	Web address
Community groups		
Water watch Victoria	Waterwatch Victoria is a successful community engagement program connecting local communities with river health and sustainable water issues and management.	http://www.berg.org.au/our-work/waterwatch http://www.vic.waterwatch.org.au/
Healthy waterways	Healthy Waterways Program is supported by Melbourne Water, the Department of Sustainability and Environment and councils in the Port Phillip and Westernport catchment area.	http://www.waterwatchmelbourne.org.au/content/about_waterwatch/about_waterwatch.asp
Biosphere	International conservation and education group	http://www.biosphere.org.au/projects/watsoncreek/watsonckreport2008.pdf
Peninsula link	Road construction project that will transverse Watsons creek draining areas, it has monitoring activities.	http://peninsulalink.com.au/Resources/infodocs/Waterways-UPDATE-scr.pdf
Vicwaterdata	Landcare group, data and monitoring group	http://www.vicwaterdata.net/vicwaterdata/home.aspx
Melbourne water	Bulk water supply including domestic and irrigation	http://www.melbournewater.com.au/content/rivers_and_creeks/river_health/measuring_environmental_condition_of_rivers/index_of_river_condition.asp
Southern Peninsula flora and fauna association	Ecological sustainability group	http://www.spiffa.org/friends.html

Watsons Creek catchment Landcare group	Lancare group interested in improving environmental issues related to Watsons Creek.	http://www.healthywaterways.org/Home.aspx
Mornington peninsula shire	Local Government committed to a sustainable peninsula and environmental restoration	http://www.mornpen.vic.gov.au/Page/Page.asp?Page_Id=130&p=1
Victorian Vegetable Growers association	The Victorian VGA is the peak vegetable growers association in Victoria and provides industry services, support to growers including environmental programs like EnviroVeg.	http://www.vgavic.org.au/
Department of Sustainability and Environment	Leads the Victorian Government's efforts to sustainably manage water resources and catchments, climate change, bushfires, parks and other public land, forests, biodiversity and ecosystem conservation.	http://www.dse.vic.gov.au/dse/index.htm
Southern Rural Water	Southern Rural Water is responsible for the management and licensing of groundwater and surface waters.	http://www.srw.com.au/
South East Water	South East Water is the water and sewerage authority for the Mornington Peninsula Shire and can provide advice on reticulated water and sewers, and if they are available to your property.	http://www.sewl.com.au/Pages/HomePage.aspx

Government and semi Government groups:

Melbourne Water operates across most of Melbourne catchment area and has the responsibility to monitor water quality. Watsons Creek strictly speaking does not form part of what we may think of as typical of Melbourne catchment as it does not empty into a lake or reservoir nor does it contribute to Melbourne drinking water, it has however pumping licenses for a number of operations including vegetable growing. Melbourne Water hence has the charter to monitor water quality. Most of the allegations that vegetable farming is a major contributor to the problems at Watsons Creek originated from work done 20 years ago by Melbourne Water. Melbourne Water runs the healthy water ways project and is carrying out monitoring activities of water quality on a regular basis.

The Department of Sustainability and Environment plays a significant role in coastal care and coastal environmental issues, this is directly related to what is happening in Watsons Creek as it empties into a marine National park of international significance. It also manages environmental sustainability issues related to water ways and biodiversity strategies.

Mornington Peninsula shire is responsible for local planning and local issues, it has an active initiative in a sustainable peninsula concept. As part of this it has a commitment to increase the quality of water and other parts of the environment. It primarily supports community groups in meeting this aim.

Southern Rural water and South East Water are semi Government bodies that are responsible for the management of ground water and surface water and drinking water and sewage disposal respectively. They play a part in monitoring aspects of the quality of the water in Watsons Creek.

Victorian water data is a joint initiative between a number of Government Departments and together they run the "Victorian Water Resources Data Warehouse" is a site dedicated to disseminating up-to-date information on Victoria's water resources through the World Wide Web. The site gives access to both raw and summary data on both water quality and quantity throughout Victoria, and is a central repository for published documents produced from this data.

Community Groups

Watsons Creek catchment Landcare group, this group has the main aim to improve the environment around the Watsons Creek catchment area, remove weeds and replant native vegetation along the creek. It has not been very active in the past two years but it is still involved as part of other programs.

Southern Peninsula flora and fauna association, (SPIFFA) has a focus on locally threatened species and threatened ecosystems. They actively promote and support the preservation of existing habitat and the systematic restoration of diminished environmental values, habitat and biodiversity on both public and private lands, they have a small interest in the Watsons Creek catchment area due to the vastness of the catchment region and the fact that it empties into an area of environmental significance.

Cross Regional Industry and resource management groups

The Waterwatch Program was set up by the Australian Government in 1993, and is supported by the Government's Natural Heritage Trust. Waterwatch provides standardised methods and equipment for local groups to monitor water quality in their rivers, streams and lakes. Under Waterwatch, nearly 3000 groups across the country are monitoring water quality at over 7000 sites throughout 200 catchments. Test results are collated in the Waterwatch Victoria database, which allows community data to be pooled, analysed and interpreted at the catchment level and beyond. The information collected provides a basis for action to tackle problems and improve waterway health.

Peninsula Link is a large road building project that transverses a number of creeks and waterways including Watsons creek. The project team for Peninsula Link is committed to improving the environmental health of our waterways and will be undertaking landscaping and revegetation as part of the construction program. Monitoring of water quality may also play a part on their overall monitoring activities. Victorian Vegetable Growers Association is an industry peak body that has a large interest in vegetable farming and supporting vegetable growers including growers that farm close to Watsons creek. Western Port Biosphere, is a non-profit Foundation and works with the community and UNESCO to create a better future for Western Port—environmentally, socially and economically. They do this through research, education, community engagement, partnerships and on-ground conservation efforts. They are involved in monitoring water quality in Watsons creek.

Appendix 2 – Nutrient budgeting survey data for key crops

Plant population, dry matter content (DM%), Fresh Yield (tonne ha^{-1}), Dry Matter Yield (DMYld) (tonne ha^{-1}), nutrient concentration (%) and crop nutrient uptake (kg ha^{-1}) for brassica crops surveyed from farms in the Lockyer Valley 2010. (The number of samples collected is included in brackets next to the crop type and the range of values is included where the sample number is 3 or more).

		Plant population ('000 plants ha^{-1})	DM%	Fresh Yield	DMYld	Nutrient Composition (%)			Nutrient Uptake (kg ha^{-1})		
						N	K	P	N	K	P
Broccoli (5)											
Field residue	mean	41.1	9.9	53.5	5.3	3.17	3.37	0.43	159.4	172.7	22.8
	range	25.0 – 58.7	8.4-10.7	42.8-74.8	4.22-8.06	1.68-4.84	2.41-3.94	0.38-0.46	96-222	141-194	17.9-36.5
Curd	mean		10.1	13.5	1.37	3.43	3.53	0.71	44.3	47.3	9.6
	range		8.9-11.3	10.1-18.5	1.03-2.10	2.09-5.15	3.02-4.03	0.66-0.76	28.6-58.9	37.3-63.6	7.94-13.9
Drumhead Cabbage (3)											
Field residue	mean	30.1	11.6	37.6	4.3	2.41	2.41	0.25	106.1	102.7	11.0
	range	26.2-35.2	10.5-12.8	33.7-43.8	4.0-4.6	1.07-3.12	1.66-3.52	0.18-0.29	43.0-139.	72.0-141.	7.4-12.9
Head	mean		8.6	84.3	7.3	2.30	2.1	0.3	173.4	148.8	23.3
	range		8.1-9.3	73.9-100.	5.97-8.60	1.99-2.84	1.58-2.48	0.28-0.34	118.-244.	130.-179.	19.9-25.0
Other Cabbage-Field residue											
Purple Cabbage (1)		35.3	10.4	37.4	3.9	1.59	1.43	0.21	61.8	55.4	8.3
Sugar Loaf Cabbage (2)	mean	40.8	9.1	22.6	2.1	2.74	2.47	0.28	55.3	50.4	5.8
Wombok (2)	mean	39.1	6.1	37.3	2.3	3.24	4.29	0.48	73.1	96.8	11.2
Other Cabbage-Head											
Purple Cabbage (1)			8.7	85.8	7.5	2.16	2.36	0.35	162.0	176.7	26.5
SugarLoaf Cabbage 2)	mean		7.9	57.0	4.5	3.09	2.64	0.41	139.4	119.0	18.4
Wombok (2)	mean		5.3	128.5	6.9	3.66	3.17	0.69	247.5	211.7	47.8
Cauliflower (6)											
Field residue	mean	28.0	9.5	55.2	5.2	3.10	2.37	0.54	162.9	125.0	27.9
	range	25.0-30.2	8.9-10.5	34.2-78.0	3.59-7.14	1.03-4.03	1.27-2.85	0.48-0.58	52.8-272.	60.8-203.	20.0-37.6
Head – Curd	mean		7.7	29.0	2.2	2.90	3.00	0.49	65.7	67.0	11.0
	range		7.5-7.9	25.9-36.6	2.06-2.75	2.22-3.37	2.24-4.00	0.45-0.51	46.9-92.8	46.4-86.4	9.47-13.4
Head – Bract	mean		8.1	11.9	0.97	3.46	2.85	0.53	33.9	27.4	5.2
	range		6.6-10.5	8.43-14.3	0.81-1.28	2.69-4.03	2.12-3.55	0.50-0.55	23.9-49.3	18.1-32.4	4.06-7.00
Marketable Head (Curd & Bract)	mean		7.8	40.9	2.2	3.28	2.91	0.52	66.2	100.9	38.3
	range		7.3-8.4	35.1-48.3	2.06-2.75	2.80-3.70	2.18-3.41	0.49-0.53	47.5-93.3	70.3-127.	29.5-43.9

Plant population, dry matter content (DM%), Fresh Yield (tonne ha^{-1}), Dry Matter Yield (DMYld) (tonne ha^{-1}), nutrient concentration (%) and crop nutrient uptake (kg ha^{-1}) for lettuce celery and carrot crops surveyed from farms in the Lockyer and Fassifern Valleys 2010. (The number of samples collected is included in brackets next to the crop type and the range of values is included where the sample number is 3 or more).

		Plant population ('000 plts ha^{-1})	DM%	Fresh Yield	DMYld	Nutrient Composition (%)			Nutrient Uptake (kg ha^{-1})		
						N	K	P	N	K	P
Lettuce (11)											
Field residue	mean	52.1	5.2	17.0	0.9	3.20	4.78	0.37	28.0	44.8	3.3
	range	40.0-59.3	4.62-6.23	11.5-22.7	0.64-1.30	2.12-4.05	2.66-7.24	0.20-0.68	22.3-45.1	19.1-92.7	1.4-4.9
Heart	mean		4.5	66.0	3.0	2.99	3.35	0.53	87.0	99.0	15.5
	range		3.65-5.04	54.2-84.7	2.15-3.82	1.33-4.62	2.79-4.42	0.41-0.69	40.3-141.	72.9-151.	12.3-22.3
Cos Lettuce (1)											
Field residue		49.0	5.3	9.1	0.5	2.56	3.60	0.28	12.2	17.2	1.3
Heart			4.9	54.8	2.7	4.37	5.91	0.62	117.8	159.3	16.7
Celery (2)											
Field residue	mean	61.5	6.9	36.4	2.5	2.34	4.86	0.38	58	128	9
Trimmings	mean		11.5	12.8	1.5	2.32	2.61	0.39	34	37	6
Head	mean		5.7	82.8	4.7	1.80	4.10	0.46	86	186	22
Carrot (4)											
Field residues	mean	757	19.1	14.3	2.7	1.93	2.50	0.16	52.3	66.0	4.3
	range	593-955	17.1-20.6	8.68-17.0	1.79-3.35	1.75-2.06	1.72-3.20	0.15-0.16	30.9-62.9	42.2-91.3	2.98-5.44
Roots	mean		11.2	74.6	8.4	1.35	2.04	0.21	111.3	170.2	18.0
	range		10.3-11.6	70.5-76.9	7.76-8.78	0.78-2.22	1.83-2.14	0.19-0.22	68.6-180.	148-186	15.2-19.5

Total biomass Fresh Yield (Tonne ha^{-1}), Harvest index (%), crop nutrient partitioning and applied fertiliser for brassica, lettuce, celery and carrot crops surveyed from farms in the Lockyer and Fassifern Valleys 2010. (The number of samples collected is included in brackets next to the crop type and the range of values is included where the sample is 3 or more).

Crop		Total biomass FY (t ha^{-1})	Harvest Index (%)	Total nutrient uptake in above ground biomass (kg ha^{-1})			Nutrient removal in harvested product (kg ha^{-1})			Fertiliser nutrient applied (kg nutrient ha^{-1})		
				N	K	P	N	K	P	N	K	P
Broccoli (5)	mean	66.9	20.1	203.7	219.9	32.4	44.3	47.3	9.6	113.3	63.0	34.7
	range	53.5-93.3	18.3-21.0	132-281	185-258	26.6-50.6	28.6-58.9	37.3-63.6	7.94-13.9	84.2-147	33.2-99.3	13-74.3
Drumhead Cabbage (3)	mean	121.8	68.9	279.5	251.5	34.3	173.4	148.8	23.3	93.7	28.2	37.1
	range	113-134	62.7-74.8	199-380	208-321	32.4-37.7	118-244	130-179	19.9-25.0	48.4-122	16-35.2	13-74.3
Purple Cabbage (1)		123.2	69.6	223.8	232.0	34.8	162.0	176.7	26.5	110.6	33.3	74.4
SugarLoaf Cabbage (2)		79.6	71.8	194.7	169.4	24.3	139.4	119.0	18.4	102.5	50.2	13.0
Wombok (2)		165.8	77.6	320.6	308.5	59.0	247.5	211.7	47.8	85.0	45.8	16.9
Cauliflower (6)	mean	96.1	43.3	262.5	219.4	44.1	99.6	94.4	16.1	98.6	57.0	31.6
	range	69.3-126	38.2-50.6	140-405	134-320	34.4-56.7	76.1-133	73.6-116	14.0-19.0	43.9-147	33.2-99.3	0-74.3
Lettuce (11)	mean	83.0	79.3	115.0	143.8	18.8	87.0	99.0	15.5	87.7	56.4	27.27
	range	65.8-99.9	72.5-84.7	67.4-172	104-179	13.7-27.3	40.3-141	72.9-151	12.3-22.3	31.6-136	33.2-89.0	0-74.3
Cos Lettuce (1)		63.9	85.8	130.0	176.5	18.1	117.8	159.3	16.7	91.2	89.0	20.0
Celery (2)	mean	132.0	72.4	177.5	350.6	36.9	86	186	22	111.7	72.2	21.1
Carrot (4)	mean	88.9	84.1	163.6	236.2	22.3	111.3	170.2	18.0	97.5	129.4	34.3
	range	79.2-92.4	81.5-89.0	126-210	190-278	20.7-23.9	68.6-180	148-186	15.2-19.5	51.3-177	70.5-186	25.2-51.3

Appendix 3 Detailed data from grower case studies

Cropping details for Lockyer Valley Grower A's property for vegetable crops sown between 2011 and 2013.

Crop	Planting date	Harvest date	Crop density (plants ha^{-1})	Fertiliser	Rate (kg ha^{-1})	Analysis	Date of application
Lettuce	19/05/11	12/08/2011	59,800	Fertica®	400	(N-11.7%, P-6.5%, K-14.1%, S-13.2%)	12/05/2011
				Nitrabor	250	(N-15.4% Ca-18.3% B-0.3%)	20/06/2011
Sugarloaf Cabbage	2/04/2012	5/06/2012	37,000	Rustica®	492	(N-12%, P-5.2%, K-14%, S-8.3%)	28/03/2012
				Nitrabor	283	(N-15.4% Ca-18.3% B-0.3%)	26/04/2012
				Nitrabor	185	(N-15.4% Ca-18.3% B-0.3%)	16/05/2012
Cauliflower	2/04/2012	4/07/2012	36,600	Rustica®	200	(N-12%, P-5.2%, K-14%, S-8.3%)	28/03/2012
				Nitrabor	115	(N-15.4% Ca-18.3% B-0.3%)	26/04/2012
				Nitrabor	75	(N-15.4% Ca-18.3% B-0.3%)	16/05/2012
Butternut Pumpkin	30/07/2012	19/12/2012	---	Rustica®	246	(N-12%, P-5.2%, K-14%, S-8.3%)	25/07/2012
Cauliflower	14/03/2013	18/06/2013	33,100	Rustica®	492	(N-12%, P-5.2%, K-14%, S-8.3%)	9/03/2013
				Nitrabor	381	(N-15.4% Ca-18.3% B-0.3%)	
				Urea	197	(N-46%)	30/04/2013
				Potassium Nitrate	98	(N-13.0%, K-38.3%)	10/05/2013
				Potassium Nitrate	184	(N-13.0%, K-38.3%)	31/05/2013

Mean fresh yield, dry matter content (DM%), dry matter yield (DMYld), nutrient composition and nutrient uptake for Lockyer Valley Grower A's property for vegetable crops sown between 2011 and 2013.

Crop and component	Fresh Yield ($t\ ha^{-1}$)	DM%	DMYld ($t\ ha^{-1}$)	Nutrient concentration N%	P%	K%	Nutrient uptake ($kg\ ha^{-1}$) N	P	K
Lettuce 2011									
Head	64.2	4.9	3.1	2.99	0.5	4.41	93.9	15.6	138.4
se	±1.4	±0.05	±0.04	±0.03	±0.01	±0.1	±1.8	±0.4	±4.2
Wrapper	19.4	5.7	1.1	3.64	0.34	7.25	40.5	3.8	81.1
se	±1.2	±0.11	±0.07	±0.02	±0.01	±0.21	±2.2	±0.3	±7.7
Whole Plant	83.6	5.1	4.3	3.14	0.46	5.08	134.4	19.4	219.5
se	±0.4	±0.05	±0.03	±0.02	±0.01	±0.1	±0.8	±0.3	±6.3
Cauliflower 2012									
Residues	94.8	9.2	8.7	3.07	0.58	2.25	268	50.7	195
se	±25.2	±0.8	±3.1	±0.29	±0.1	±0.34	±98.8	±20.9	±48.3
Curd	46.2	7.4	3.4	3.2	0.49	3.15	109.3	16.6	107.3
se	±7.5	±1	±1	±0.41	±0.04	±0.34	±23.4	±3.9	±19.9
Bract	18.4	6.1	1.1	3.51	0.59	3.41	39.5	6.7	38.4
se	±3.9	±0.5	±0.2	±0.32	±0.05	±0.44	±8.2	±1.6	±7.1
Market Head (Curd&Bract)	64.6	7.1	4.6	3.28	0.51	3.21	148.8	23.3	145.7
se	±10	±0.8	±1.1	±0.39	±0.04	±0.36	±30.2	±5	±22.2
Whole Plant	159.4	8.5	13.3	3.14	0.56	2.58	416.8	74	340.6
se	±34.6	±0.7	±4	±0.31	±0.08	±0.32	±123.6	±25	±63.7
Cabbage 2012									
Head	70.7	7	5	3.2	0.43	2.68	158.9	21.1	133.1
se	±9	±0.3	±0.6	±0.18	±0.01	±0.21	±16	±2.7	±23.1
Wrapper	24.8	9	2.2	3.69	0.31	1.97	82.1	6.9	43.6
se	±5.7	±0.2	±0.5	±0.19	±0.01	±0.16	±20.9	±1.6	±7.5
Whole Plant	95.5	7.6	7.2	3.35	0.39	2.46	241	28	176.8
se	±2.1	±0.1	±0.1	±0.05	±0	±0.05	±4.9	±0.4	±5.2
Pumpkin 2012									
Fruit	23.7	14.9	3.5	1.46	0.38	2.34	51.5	13.4	82.5
Vines	20.3	16.2	3.3	1.88	0.37	1.72	61.7	12.1	56.5
Whole Plant	44.0	31.1	6.8				113.2	25.4	139.0
Cauliflower 2013									
Residues	58.7	9.3	5.4	2.62	0.61	2.93	141.9	33.2	158.5
se	±6.9	±1.5	±0.7	±0.48	±0.08	±0.62	±23.6	±6.1	±28.8
Curd	37.2	6.5	2.4	3.14	0.53	3.64	75.8	12.9	88.5
se	±11.9	±0.6	±0.7	±0.31	±0.02	±0.19	±17.2	±3.9	±29
Bract	17.6	7.4	1.3	3.13	0.59	3.98	40.4	7.6	51.7
se	±4.7	±0.8	±0.4	±0.2	±0.07	±0.48	±10.5	±1.5	±16.8
Market Head (Curd&Bract)	54.8	6.8	3.7	3.13	0.55	3.76	116.3	20.4	140.1
se	±15	±0.6	±1	±0.27	±0.01	±0.1	±25	±4.9	±37.2
Whole Plant	113.5	8.3	9.1	2.83	0.59	3.27	258.1	53.7	298.6
se	±19.7	±1.2	±1.6	±0.34	±0.05	±0.41	±17.6	±8	±52.8

se denotes Standard Error

Changes in mean soil nitrate (mg kg^{-1}) and standard errors (SE) from 0-100 cm in the soil sampled for Lockyer Valley Grower A's property for vegetable cropping sequences between 2011 and 2013.

Date	0-10cm	SE	10-20cm	SE	20-40cm	SE	40-60cm	SE	60-80cm	SE	80-100cm	SE
22/02/2011	10	1.1	9	0.5								
1/03/2011	15	1.4	24	2.1								
8/03/2011	24	2.0	41	4.3								
15/03/2011	35	1.3	43	1.9								
22/03/2011	8	0.4	19	1.9								
28/03/2011	15	0.9	21	2.0								
18/04/2011	24	2.7	24	2.6	6	0.8	2	0.0	3	0.2	2	0.2
24/05/2011	32	5.5	52	6.7	31	4.2	9	0.9	5	0.8	5	1.1
21/06/2011	82	8.8	53	5.6	38	4.0	12	3.0	5	0.9	5	1.0
12/07/2011	33	7.0	23	4.6	23	1.6	9	1.2	4	0.4	5	0.4
19/08/2011	13	1.9	4	0.3	4	0.6	3	0.3	4	0.3	4	0.3
6/02/2012	8	0.7	18	2.0	17	1.5	14	1.0	11	1.7	9	1.7
2/04/2012	34	7.3	31	1.2	18	1.4	15	0.9	15	1.7	12	2.1
8/05/2012	4	0.0	11	1.3	18	0.8	17	1.2	15	0.7	12	1.2
28/05/2012	3	0.6	3	0.0	2	0.3	5	0.9	8	0.9	10	1.8
16/07/2012	4	0.5	2	0.3	2	0.0	2	0.0	2	0.0	2	0.0
18/09/2012	32	7.3	31	8.3	8	1.3	3	0.6	3	0.3	3	0.3
8/03/2013	4	0.0	4	0.3	4	0.3	4	0.7	4	0.0	4	0.3
26/03/2013	18	1.9	14	2.0	7	0.7	6	0.6	7	0.3	6	0.5
22/04/2013	7	1.2	8	2.2	4	0.4	5	0.3	5	0.5	5	0.5
10/05/2013	4	0.3	5	1.9	3	0.3	3	0.4	4	0.8	4	0.9
4/07/2013	5	0.5	4	0.5	2	0.0	2	0.0	2	0.0	2	0.0

Uptake and plant tissue concentrations of other nutrients (Ca, Mg, S, B, Cu, Fe, Mn, Na and Zn) in a lettuce crop for Lockyer Valley Grower A's property sown in 2011.

Lettuce Crop Uptake									
Part	Ca	Mg	S	B	Cu	Fe	Mn	Na	Zn
	kg ha^{-1}	kg ha^{-1}	kg ha^{-1}	g ha^{-1}	g ha^{-1}	g ha^{-1}	g ha^{-1}	kg ha^{-1}	g ha^{-1}
Total	39.0	24.5	8.4	96.3	83.5	2982.7	333.3	32.1	272.9
Se	0.9	0.7	0.1	2.8	7.0	850.5	18.8	2.1	12.7
Head	19.8	12.7	5.7	61.2	20.9	577.3	138.5	18.3	142.7
Se	0.7	0.6	0.2	1.1	2.2	240.4	9.4	1.1	6.3
Wrapper	19.2	11.8	2.7	35.2	62.5	2405.4	194.8	13.8	130.2
Se	1.2	0.8	0.2	3.2	8.7	904.6	21.4	1.5	14.9

Lettuce Concentration data									
	Ca	Mg	S	B	Cu	Fe	Mn	Na	Zn
	%	%	%	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}	%	mg kg^{-1}
Total	0.9	0.6	0.2	22.3	18.1	631.6	74.4	0.7	62.1
se	0.0	0.0	0.0	0.5	1.3	160.9	3.6	0.0	2.3
Head	0.6	0.4	0.2	19.5	6.7	181.8	44.1	0.6	45.4
se	0.0	0.0	0.0	0.3	0.6	73.6	2.4	0.0	1.6
Wrapper	1.7	1.1	0.2	31.5	55.8	2208.3	176.0	1.2	116.0
se	0.1	0.0	0.0	1.0	6.5	845.2	18.4	0.1	5.8

Uptake and plant tissue concentrations of other nutrients (Ca, Mg, S, B, Cu, Fe, Mn, Na and Zn) in a cauliflower and cabbage crops for Lockyer Valley Grower A's property sown in 2012.

Crop Uptake										
	Part	Ca %	Mg %	S %	B mg kg^{-1}	Cu mg kg^{-1}	Fe mg kg^{-1}	Mn mg kg^{-1}	Na %	Zn mg kg^{-1}
Cauliflower	residues	229	75	80	301	197	1501	292	112	198
	se	26.4	8.5	6.7	25.0	22.0	254.6	35.1	10.7	10.8
	Curd &Bract	19	11	30	77	18	384	73	23	212
	se	1.2	0.8	2.0	4.4	1.3	37.5	3.4	2.3	39.6
	total	247	86	109	378	214	1885	365	135	410
	se	27.3	9.0	7.6	27.7	22.9	289.1	37.6	12.8	41.0
Sugarloaf Cabbage	Heart	41	18	33	112	115	532	102	24	131
	se	1.2	0.5	1.0	3.1	21.1	93.3	2.2	0.9	6.1
	wrapper	99	34	32	71	352	1216	122	21	46
	se	6.9	2.4	2.0	4.7	46.2	427.5	11.4	1.2	3.8
	Total	140	52	65	183	466	1748	224	45	177
	se	7.7	2.8	1.8	5.4	58.3	506.5	9.7	0.9	8.0

Plant tissue nutrient concentration										
Plant type	Part	Ca %	Mg %	S %	B mg kg^{-1}	Cu mg kg^{-1}	Fe mg kg^{-1}	Mn mg kg^{-1}	Na %	Zn mg kg^{-1}
Cauliflower	Residues	2.6	0.9	0.9	34.6	22.9	169.8	33.4	1.3	22.9
	se	0.5	0.2	0.1	4.9	12.4	65.4	7.6	0.2	5.1
	Curd	0.3	0.2	0.6	15.3	3.7	77.1	15.6	0.4	29.8
	se	0.0	0.0	0.1	0.6	0.8	17.9	1.6	0.1	7.9
	Bract	0.9	0.4	0.8	22.1	4.3	104.4	17.2	0.8	98.3
	se	0.1	0.0	0.0	0.7	0.5	28.3	1.6	0.2	138.9
	Curd& Bract	0.4	0.2	0.6	17.0	3.8	84.0	16.0	0.5	46.2
	se	0.0	0.0	0.1	0.5	0.7	19.9	1.4	0.1	27.9
Sugarloaf Cabbage	Heart	0.8	0.4	0.7	22.6	22.9	108.5	20.5	0.5	26.6
	se	0.1	0.0	0.0	2.2	14.2	81.7	2.0	0.1	6.9
	wrapper	4.4	1.5	1.4	31.9	157.3	534.0	54.7	0.9	20.6
	se	0.4	0.2	0.1	2.1	65.6	697.7	13.5	0.1	4.4

Cropping details for Lockyer Valley Grower B's property for vegetable crops sown between 2011 and 2013.

Crop	Planting date	Harvest date	Crop density (plants ha^{-1})	Fertiliser	Rate (kg ha^{-1})	Analysis	Date of application
Drumhead Cabbage	07/02/11	27/04/2011	28,900	Fertica	200	(N-11.7%, P-6.5%, K-14.1%, S-13.2%)	6/02/2011
				Urea	100	(N-46%)	11/03/2011
Lettuce	9/07/2012	14/09/2012	55,740	Fertica	250	(N-11.7%, P-6.5%, K-14.1%, S-13.2%)	2/07/2013
				Nitrabor	100	(N-15.4% Ca-18.3% B-0.3%)	23/08/2012
Cauliflower	13/04/2013	15/07/2013	30,200	Fertica	300	(N-11.7%, P-6.5%, K-14.1%, S-13.2%)	6/04/2013
				Urea	150	(N-46%)	22/05/2013

Mean fresh yield, dry matter content (DM%), dry matter yield (DMYld), nutrient composition and nutrient uptake for Lockyer Valley Grower B's property for vegetable crops sown between 2011 and 2013.

Crop and component	Fresh yield (t ha^{-1})	DM%	DMYld (t ha^{-1})	Nutrient concentration			Nutrient uptake (kg ha^{-1})		
				N%	P%	K%	N	P	K
Drumhead Cabbage 2011									
Head	95.2	7.9	7.5	1.79	0.38	2.54	133.5	28.3	188.9
se	±4.9	±0.1	±0.4	±0.05	±0.01	±0.08	±6.5	±1.3	±4.7
Wrapper	44.5	9.0	4.0	2.03	0.32	2.88	82.5	12.8	115.6
se	±2.5	±0.7	±0.4	±0.09	±0.01	±0.07	±11.0	±1.3	±10.6
Whole Plant	139.7	8.2	11.5	1.87	0.36	2.64	216.1	41.0	304.6
se	±6.9	±0.2	±0.7	±0.06	±0.00	±0.06	±17.2	±2.2	±14.2
Lettuce 2012									
Head	64.6	4.7	3.0	3.43	0.56	4.98	104.2	17.0	151.1
se	±1.6	±0.1	±0.1	±0.07	±0.02	±0.14	±4.8	±0.8	±6.8
Wrapper	23.3	6.6	1.5	3.22	0.37	7.57	48.8	5.6	115.5
se	±1.1	±0.2	±0.1	±0.26	±0.02	±0.64	±3.9	±0.2	±11.8
Whole Plant	87.9	5.3	4.6	3.36	0.50	5.84	153.0	22.6	266.6
se	±1.8	±0.2	±0.1	±0.11	±0.02	±0.17	±6.5	±0.9	±12.7
Cauliflower 2013									
Residues	79.4	8.8	7.0	3.17	0.67	3.44	222.0	47.2	240.5
se	±4.2	±0.5	±0.7	±0.07	±0.03	±0.10	±18.7	±3.9	±17.1
Curd	39.6	6.9	2.7	3.17	0.56	3.59	87.1	15.5	98.5
se	±1.2	±0.1	±0.1	±0.07	±0.01	±0.06	±3.7	±0.7	±3.0
Bract	18.1	7.0	1.3	3.23	0.63	3.92	40.8	8.0	49.5
se	±1.1	±0.2	±0.0	±0.04	±0.01	±0.07	±1.9	±0.3	±2.1
Market Head (Curd&Bract)	57.7	7.0	4.0	3.19	0.59	3.69	127.9	23.5	148.0
se	±1.8	±0.1	±0.1	±0.04	±0.01	±0.03	±4.1	±0.7	±2.9
Whole Plant	137.1	8.2	11.1	3.17	0.64	3.53	349.9	70.7	388.4
se	±4.2	±0.4	±0.7	±0.05	±0.02	±0.06	±21.6	±4.6	±19.3

se denotes Standard error

Changes in mean soil nitrate (mg kg^{-1}) and standard errors (SE) from 0-100 cm in the soil sampled for Lockyer Valley Grower B's property for vegetable cropping sequences between 2011 and 2013.

Date	0-10cm	SE	10-20cm	SE	20-40cm	SE	40-60cm	SE	60-80cm	SE	80-100cm	SE
3/02/2011	12	0.8	13	0.8	8	0.7	7	0.4	6	0.7	6	0.6
22/02/2011	23	2.8	23	2.2	12	1.9	8	0.4	7	0.4	7	0.8
8/03/2011	6	0.3	8	1.1	13	1.3	9	0.7	8	0.8	8	0.6
22/03/2011	25	9.4	17	5.1	6	0.4	6	0.7	5	0.8	6	0.8
9/04/2011	7	1.5	4	0.5	3	0.4	2	0.0	2	0.0	2	0.2
30/04/2011	12	4.2	5	0.7	2	0.2	2	0.0	2	0.0	3	0.3
6/02/2012	11	1.9	22	3.4	14	2.1	9	1.0	6	0.3	4	0.6
7/02/2012	14	4.5	25	6.2	31	4.0	12	2.4	7	0.4	6	0.3
28/05/2012	12	0.8	27	2.7	27	2.3	15	1.7	9	0.8	6	0.6
16/07/2012	30	1.9	28	8.7	20	2.3	16	1.3	12	1.9	9	0.9
30/07/2012	42	11.3	23	4.8	18	1.5	13	0.6	10	0.9	9	0.7
16/08/2012	34	11.9	17	3.7	17	1.2	15	1.2	13	1.8	11	1.6
18/09/2012	8	2.2	3	0.3	3	0.3	5	0.7	6	0.6	6	0.6
26/03/2013	7	0.3	7	0.7	5	0.3	6	0.5	7	1.0	6	0.7
22/04/2013	38	8.3	23	1.8	9	1.1	7	1.0	9	1.3	9	1.7
10/05/2013	31	9.0	26	5.0	11	0.7	6	0.3	6	0.5	6	0.4
23/07/2013	16	5.5	3	0.3	2	0.0	2	0.0	2	0.0	2	0.0

Uptake and plant tissue concentrations of other nutrients (Ca, Mg, S, B, Cu, Fe, Mn, Na and Zn) in a cabbage crop for Lockyer Valley Grower B's property sown in 2011.

Cabbage Crop uptake									
	Ca kg ha^{-1}	Mg kg ha^{-1}	S kg ha^{-1}	B g ha^{-1}	Cu g ha^{-1}	Fe g ha^{-1}	Mn g ha^{-1}	Na kg ha^{-1}	Zn g ha^{-1}
Head	65.4	22.5	66.6	158.1	114	566	126	25	218
se	5.2	1.3	3.2	8.3	23	111	9	1	55
Wrapper	152.0	42.7	68.9	135.8	521	1922	202	28	181
se	11.0	3.7	5.3	15.0	59	640	28	3	19
Total	217.4	65.2	135.5	293.9	635	2488	328	52	399
se	13.2	4.6	8.2	22.2	81	740	37	5	73

Cabbage Plant tissue nutrient concentration									
	Ca %	Mg %	S %	B mg kg^{-1}	Cu mg kg^{-1}	Fe mg kg^{-1}	Mn mg kg^{-1}	Na %	Zn mg kg^{-1}
Head	0.88	0.30	0.89	21	15	75	17	0.33	29
se	0.07	0.01	0.03	0.2	2.9	12.0	1.1	0.01	6.2
wrapper	3.80	1.06	1.72	34	133	453	50	0.69	45
se	0.11	0.02	0.05	1.7	21.8	104	3.1	0.05	1.9

Uptake and plant tissue concentrations of other nutrients (Ca, Mg, S, B, Cu, Fe, Mn, Na and Zn) in a lettuce crop for Lockyer Valley Grower B's property sown in 2012.

Lettuce Crop uptake									
	Ca kg ha^{-1}	Mg kg ha^{-1}	S kg ha^{-1}	B g ha^{-1}	Cu g ha^{-1}	Fe g ha^{-1}	Mn g ha^{-1}	Na kg ha^{-1}	Zn g ha^{-1}
Head	20.6	14.3	5.7	72	15.7	636	118	14.6	326
se	1.4	1.3	0.2	3	1.2	223	12	1.6	121
Wrapper	31.9	22.9	3.1	62	17.2	13372	445	16.2	115
se	0.7	0.8	0.2	3	3.4	4310	113	0.5	26
Total	52.6	37.2	8.9	134	32.9		563	30.8	441
se	1.5	1.8	0.3	3	3.0		114	1.6	116

Lettuce plant tissue nutrient concentration									
	Ca %	Mg %	S %	B mg kg^{-1}	Cu mg kg^{-1}	Fe mg kg^{-1}	Mn mg kg^{-1}	Na %	Zn mg kg^{-1}
Head	0.68	0.47	0.19	24	5.2	204	38.8	0.48	105.3
se	0.04	0.0	0.00	0.5	0.3	65	2.8	0.04	38.5
wrapper	2.10	1.51	0.21	41	11.2		288.3	1.07	74.8
se	0.07	0.0	0.01	1.6	2.1		71.2	0.07	16.4

Uptake and plant tissue concentrations of other nutrients (Ca, Mg, S, B, Cu, Fe, Mn, Na and Zn) in a cauliflower crop for Lockyer Valley Grower B's property sown in 2013.

Cauliflower crop uptake									
Part	Ca kg ha^{-1}	Mg kg ha^{-1}	S kg ha^{-1}	B g ha^{-1}	Cu g ha^{-1}	Fe g ha^{-1}	Mn g ha^{-1}	Na kg ha^{-1}	Zn g ha^{-1}
Residues	183	59	64	230	380	4788	426	65	574
se	27.6	9.5	4.8	21.4	44	1295	61	9.9	185.7
Curd& Bract	20.3	11.0	28.9	70	28	1323	91	16	190
se	1.3	0.5	0.7	1.8	1.4	375	1.6	1.9	31.5
Total	203	70	93	300	408	6111	517	82	764
se	29	10	5	23	44	1084	59	11	169

Cauliflower plant tissue nutrient concentration									
	Ca %	Mg %	S %	B mg kg^{-1}	Cu mg kg^{-1}	Fe mg kg^{-1}	Mn mg kg^{-1}	Na %	Zn mg kg^{-1}
Residues	2.58	0.82	0.91	33	54	647	60	0.93	77
se	0.21	0.07	0.03	1.0	4.2	115.0	3.6	0.1	16.9
Curd	0.34	0.24	0.70	16	5	186	21	0.35	33
se	0.02	0.01	0.02	0.2	0.2	23.1	0.5	0.0	0.3
Bract	0.86	0.36	0.77	21.23	11.80	628.25	26.28	0.52	77.60
se	0.04	0.01	0.01	0.4	1.2	279.4	2.9	0.1	22.1

Appendix 4 - Effects of vegetable crop residues on soil nitrogen availability

This experiment investigated how applications of different crop residues affect mineral N supplying capacity of a vegetable soil.

Materials and methods

Crop residues

Ten different crop residues, representative of those returned in vegetable cropping systems were selected for this study. The crop residues had a wide range of C/N ratios (Table 1); this ratio is often used as a quality indicator of plant materials in terms of biodegradability and N-supplying capacity.

Table 1 Carbon and nitrogen contents of the crop residues

No.	Plant residue	TC (%)	TN (%)	C/N
1	Zucchini	30.26	3.59	8
2	Capsicum	39.50	3.70	11
3	Broccoli	38.56	3.12	12
4	Green Bean	39.14	2.74	14
5	Potato	36.72	1.98	19
6	Carrot	39.77	1.96	20
7	Lablab	43.04	1.94	22
8	Sorghum	42.29	1.22	35
9	Eggplant	44.35	0.93	48
10	Sweet corn	45.01	0.89	51

Incubation

The 0-10 cm layer of a vegetable cropping soil from the Gatton Research Station was used in the incubation study. The soil was a cracking clay (Vertosol) containing 41% clay, 24% silt and 35% sand with a pH value (1:5 soil:water) of 7.7. The initial soil mineral N (NH_4^+-N plus NO_3^- -N) content was 6.7 mg N/kg, equivalent to 8.1 kg N/ha.

An aliquot of 1.16 g of fine-ground plant material was thoroughly mixed with field moist soil (150 g dry mass). This was equivalent to a crop residue application rate of 9.2 t/ha in the 0-10 cm layer. The soil-crop residue mixture was sprayed with water before being packed into a 250 mL polypropylene jar at the field bulk density of 1.2 g/cm3. The amount of water added was just sufficient to bring the water filled pore space (WFPS) in the soil to 60%. A soil-only treatment without the addition of any crop residues was also included as a control. Each polypropylene jar was then placed into a 2 L glass jar and incubated at 25^{o}C in an incubator. The glass jar was capped with a lid that had a hole in the centre for aeration. The moisture of the soil–plant material mixture was checked by periodic weighing and replenished by adding deionised water. The experiment was completed after 28 days and soil mineral N contents were determined by extraction with 2 M KCl.

Net N mineralisation during the incubation was calculated as the difference in soil mineral N content immediately before and after the incubation. The results were expressed as kg N/ha using a soil depth of 10 cm and a bulk density of 1.2 g/cm3.

Results and discussion

The net amount of N mineralised in the control soil during 28 days amounted to 8.3 kg N/ha (Fig. 1). Application of eggplant, sorghum and sweet corn residues resulted in negative net N mineralisation, reducing the soil mineral N content from the initial value of 8.1 kg N/ha to 5.2-7.2 kg N/ha. Assuming N losses from soil were negligible during the incubation, the negative net mineralisation values were most likely due to biological immobilisation of the soil mineral N, in which soil microorganisms assimilate mineral N during the consumption of organic carbon. These three residues had the highest C:N ratios of all the residues. The results suggest that application of these crop residues during, or immediately prior to, the cropping season could reduce the amount of soil mineral N available to crops, which might lead to short-term N limitations in the absence of applied N fertiliser. Application of a sufficient amount of fertiliser N would be required to supplement this initial N-consuming effect. Alternatively, these N-immobilising crop residues would better be applied during the early fallow period to avoid the N-depleting effect on early crop growth, but which would also help retain soil N in the organic form and thus avoid losses from pathways such as nitrate leaching and denitrification during the fallow period.

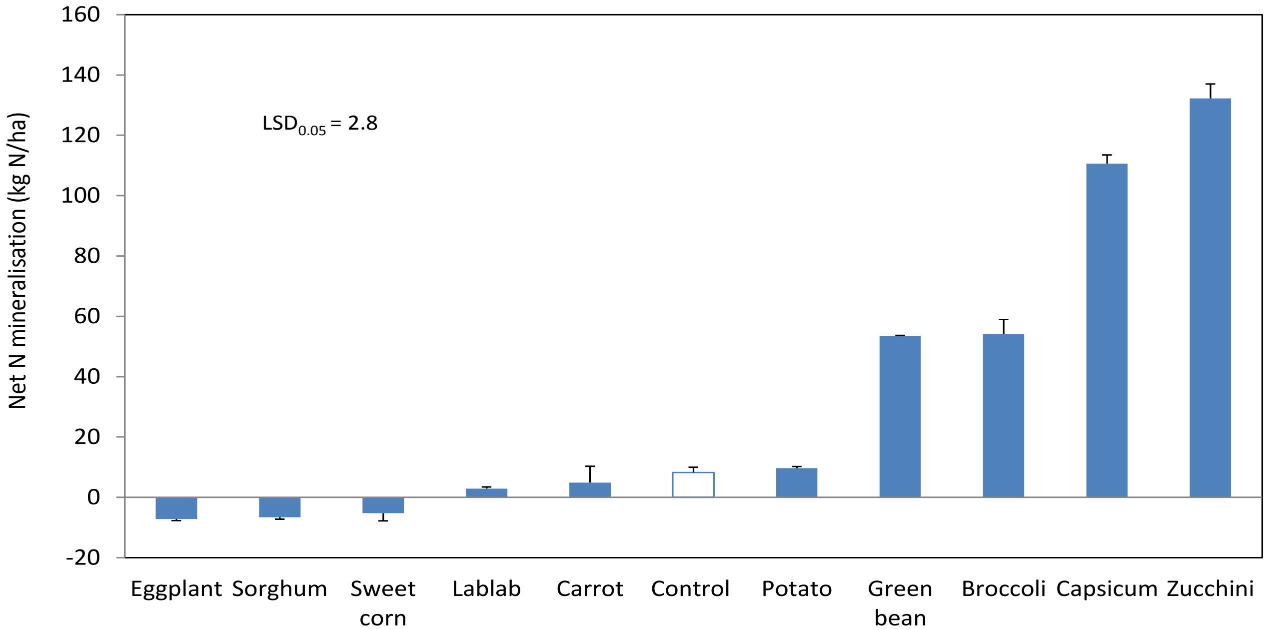

Figure 1. Net N mineralisation from soil without (control) or with addition of crop residues (9.2 t/ha) during a 28-day incubation at 25°C and 60% WFPS%. Treatments are significantly different from each other when the difference between the values is greater than the LSD (least significant difference) value.

Application of lablab, carrot and potato crop residues did not result in a reduction in soil mineral N content by the end of the incubation. However, net N mineralisation for these materials was slightly lower than the control soil, indicating that these crop residues did not have the immediate benefit of increasing N availability. With the exception of soils with high N-supplying capacity, application of fertiliser N would be needed in addition to these crop residues, at least during the early cropping season. Green bean and broccoli residues increased soil mineral N content by 45-46 kg N/ha compared with the control. Capsicum and zucchini residues supplied 102 kg N/ha and 124 kg N/ha, respectively, during the twenty-eight days. These results demonstrate the great agronomic and economic values of these crop residues as they could be used to replace significant amounts of fertiliser N in vegetable production.

The rates of net N mineralisation of different crop residues were determined by their quality. Net N mineralisation increased exponentially with the total N content in the plant materials (Fig. 2) and decreased exponentially with the C/N ratio of the crop residues (Fig. 2). Therefore, these chemical indices could be used to predict the N-supplying capacity of different crop residues.

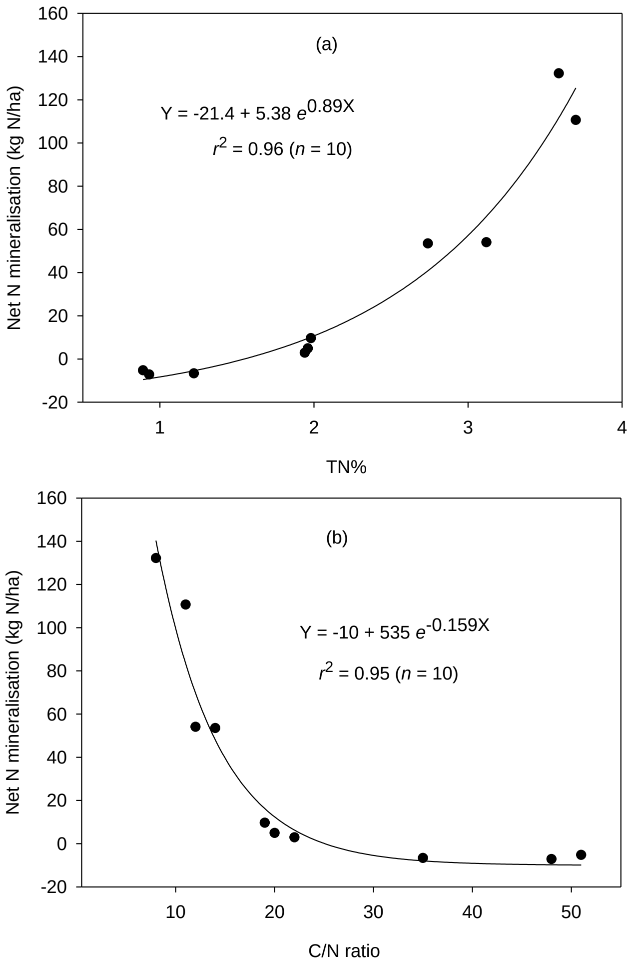

Figure 2. Relationship of net N mineralisation of crop residues to (a) their total N content and (b) C/N ratio.

Crop residues with high N contents (>2.5%) or low C/N ratios (<15) such as green bean, broccoli, capsicum and zucchini residues provide a valuable alternative source of bioavailable N in vegetable cropping systems. Cropping rotations that include these crops should consider the release of mineral N from these residues in developing subsequent crop nutrient budgets since fertiliser input rates and hence input costs may be reduced. The N-supplying capacity of different crop residues differs significantly and can be predicted from their N content and C/N ratio. The crop residues with low N contents or high C/N ratios tend to immobilise soil mineral N during the early stage after application. Therefore, these materials would be better incorporated during the early fallow period. This may help retain soil mineral N and reduce N losses from leaching and denitrification. If the low-N crop residues have to be applied at the beginning of a cropping season, fertiliser N would be required to ensure sufficient N supply. Further studies are required to examine the long-term N mineralisation dynamic of these low-N materials. This information would be useful for developing efficient N management practices for the whole cropping season.

Appendix 5 - Vegetable system nutrient dynamics monitoring

Introduction/Background

The nutrient and water dynamics of two fundamentally different vegetable farming systems (treatments) were monitored during 2013. The first treatment was a current Best Practice (BP) management system, which represented the management practices performed by the majority of Bowen-Gumlu vegetable growers using tillage and plasticulture. The second treatment was a Zone-till and organic mulch (MULCH) system where after the initial bed preparation, tillage was minimised to a zone at the centre of the bed and organic mulch was used in place of plastic films.

Methods

A summer crop of forage sorghum was broadcast-sown after each crop and slashed once before finally being slashed and sprayed with herbicide. The sorghum mulch was cultivated into the soil to breakdown before bed-forming and laying plastic mulch film and drip tape in the BP. In the Zone-till and organic mulch (MULCH) system tillage was minimised to a zone at the centre of the bed and organic mulch was used in place of plastic films. A zone 0.05 m wide to 0.25 m deep was cultivated with a wavy-disc cultivator to minimise soil disturbance but promote transplant survival and root development. A more detailed explanation is contained in the VG09038 final report. As with BP, a cover crop was planted, slashed and sprayed off, however it was retained on the surface of the bed to create an organic mulch. Three replications of the treatments were established.

A basal application of CK55 (N:P:K 13.5:15.0:12.5) was applied to the BP treatment and incorporated into beds at a rate of 52.7 kg N/ha (Table 1). The crops were fertigated throughout the growing season with soluble fertiliser through drip tape. The BP treatment was irrigated and fertigated once a week, while the MULCH system was irrigated and fertigated twice per week to maintain soil moisture. Nitrogen application was the same in each treatment. Treatments were irrigated independently to avoid moisture stress based on tensiometer readings. Tensiometers were installed using an auger, at three depths (0.15, 0.4 and 0.6 m) to monitor soil-water tension as an indicator of crop stress and water use.

Table 1. Rates of nutrient application (N, P and K) (kg/ha). in a field experiment evaluating a conventional best practice (BP) and a minimum tillage practice (MULCH) in a capsicum crop in 2013 at the Bowen Research Station.

	Best Practice			Mulch/Zone-till		
Year	N	P	K	N	P	K
2013	133	49	132	114	0	116

One set of FullStops™ was installed at 0.15 and 0.4 m depths in each replication to collect soil soulution wetting front samples as per Henderson *et al.* . Soil samples were also collected to monitor nutrient concentrations at key depths. Soil cores were taken to 0.15, 0.4, 0.6 and 0.8 m and tested for nitrogen separately. Capsicum transplants cv. Warlock were planted in double rows spaced 0.39 m apart giving a plant density of 32,050 plants/ha. Plant samples were taken at harvest, dried and tested for nutrient concentration to determine nutrient removal (in saleable fruit) and retention (in plant residue).

Results/Discussion

Yield

The marketable yield was substantially higher in the BP (35.6 t/ha) compared with the MULCH (17 t/ha). The total crop N uptake in the BP was 153 kg/ha and greater than the amount applied as fertiliser (133 kg N/ha) (Table 2) indicating that soil mineral N contributed to total crop N uptake. The total N uptake in the MULCH treatment was 89 kg/ha and less than the applied amount (114 kg N/ha). This suggests that although the N application in the MULCH was less than in the BP (about 20 kg/ha less) N was not a factor in the reduced yield in the MULCH treatment. Nitrogen uptake of marketable fruit in the BP treatment exceeded that in the MULCH treatment by 43% increasing FUE of marketable fruit by 50%. The nutrient application in the 2 treatments was not balanced for P and though soil tests indicated P was adequate this may have been a limitation particularly in the lower soil profile.

Table 2. Nitrogen uptake, removal and fertiliser use efficiency (FUE) in a field experiment evaluating a conventional best practice (BP) and a minimum tillage practice (MULCH) in a capsicum crop in 2013 at the Bowen Research Station.

Item	Unit	Best Practice	Mulch/Zone-till
Total yield	t/ha	60.2	38.3
Marketable1 yield	t/ha	35.6	17.0
Total crop N uptakeT2	kg/ha	153.3	89.0
N removalM1	kg/ha	81.0	34.9
FUE total	%	115	78
FUE marketable	%	61	31

1 Marketable fruit is ≥90 mm in length with an even block shape, no sunscald and few marks
2 Total yield is stems and leaf (residue), marketable fruit and unmarketable fruit (shed rejected fruit)

Irrigation was managed so as not to allow crop stress and is supported by the tensiometer data (data not presented) which resulted in a greater number of irrigations to the MULCH treatment than the BP. Notwithstanding, readings from the deep (0.6 m) tensiometers in the MULCH treatment indicated that soil at this depth was generally drier than the soil at 0.4 m, indicating that over irrigation was not an issue in this treatment. However, in the BP treatment the tensiometer readings at 0.6 m were consistently low at about -0.5 to about 2 KPa (data not presented). The MULCH treatment tended to maintain consistently greater moisture at 0.4 m compared with the BP at 0.4 m probably as a result of more frequent irrigation. The careful management and monitoring of irrigation can be used to mitigate the potential for nutrient loss.

Soil nitrate dynamics

The nitrate-N concentrations in samples collected from the Fullstops from the two treatments at 0.15 m tended to be variable over time (Fig. 1) with samples from the MULCH treatment generally having higher nitrate concentrations than that in the BP samples. This is likely to be due to the greater frequency and volume of irrigation applications in the MULCH treatment mobilising nitrate to a greater extent. In the 0.4 m samples the patterns for nitrate were different between the BP and MULCH treatments. In the BP the initial nitrate concentrations were greater than 100 mg/l (26 DAS) and declined to about 2 mg/l at 83 DAS. In contrast in the MULCH the initial nitrate concentrations were about 2 mg/l (26 DAS), increased to about

45 mg/l at 32 DAS then declined to about 2 mg/l at 83 DAS; the same value as in the BP treatment at this time of sampling.

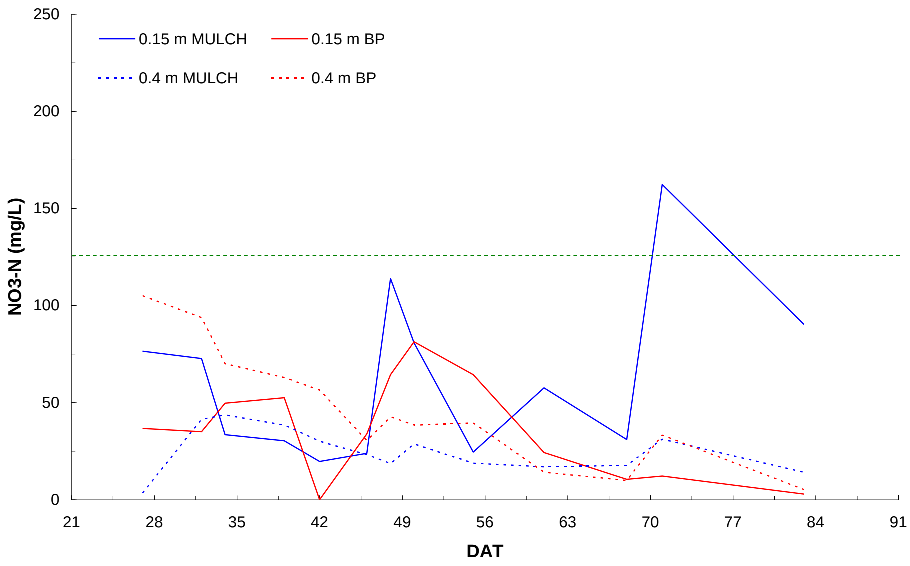

Figure 1. Changes in nitrate concentration over time in samples collected from FullStops™ 0.15 and 0.4 m in a field experiment evaluating a conventional best practice (BP) and a minimum tillage practice (MULCH) in a capsicum crop in 2013 at the Bowen Research Station. DAT denotes days after transplanting.

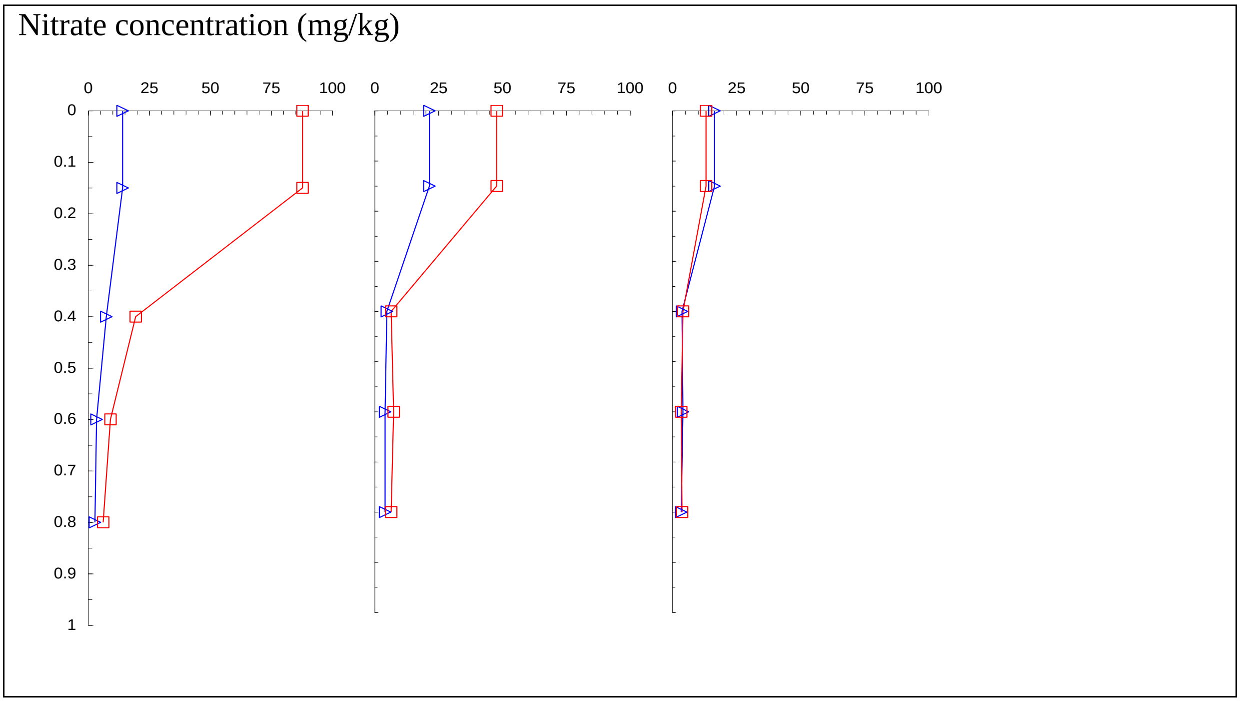

Figure 2. Changes in nitrate concentration over time (from left to right, at 12, 61 and 105 days after transplanting) in soil samples (0 to 1.0 m) collected from a field experiment evaluating a conventional best practice (BP – □ red line) and a minimum tillage practice (MULCH – ▷ blue line) in a capsicum crop in 2013 at the Bowen Research Station.

The nitrate concentration in the soil samples decreased in the 0.15 to 0.4 soil depth range over the course of cropping (Fig. 2). The concentration of nitrate in the surface soil in the MULCH treatment did not exceed 25 mg/kg which was in contrast to the BP treatment (about 85 mg/l) suggesting that N limitations may have restricted growth in the MULCH treatment. The data does not provide evidence of deep nitrate movement in either treatments.

The research identified fertiliser use inefficiencies related to irrigation and nutrient scheduling in the organic mulch, zone-tillage treatment compared with the best practice treatment. The perception that the MULCH treatment may deliver more sustainable nutrient management was not supported in the data where this treatment had lower yield and nutrient use efficiency compared with the BP treatment. To improve productivity in the MULCH system it is likely that greater N inputs are required and the potential for P to be limiting crop growth needs to be addressed. The need for increased irrigation inputs in the MULCH treatment is likely to increase the risk of nitrate leaching and hence potentially loss below the crop root zone. The effective management of soil moisture through soil moisture monitoring devices (e.g. tensiometers) can improve crop production and nutrient use efficiency by preventing over-application of irrigation and subsequently nutrient leaching. Though FullStops™ and tensiometers can be difficult and time consuming to maintain in a commercial situation they nonetheless could be utilised to monitor nutrient movement to ensure nitrate is retained at shallow soil depths. This was especially relevant in the MULCH treatment where higher rates of irrigation were required to maintain crop water availability and the potential for leaching was a concern. Other automated devices may be more appropriate for commercial situations. The data suggests that deep soil sampling gave less variable results than the FullStops™ samples suggesting it is a more reliable tool for identifying nitrate movement.

Appendix 6 Clean Streams, Sustainable Vegetable Farms - A guide to managing fertilisers for efficient use and for protecting sensitive waterways

John Bagshaw, Robert Premier and Stephen Harper

Acknowledgements

This document has been developed as part of the project VG09041 "Environmental effects of vegetable production on sensitive waterways", funded by HAL using the vegetable industry levy and matched funds from the Australian Government. State government funding for the project has been provided through the Queensland Department of Agriculture, Forestry & Fisheries.

Clean streams, sustainable vegetable farms -

A guide to managing fertilisers for efficient use and for protecting sensitive waterways

Preamble

Waterways that empty into ecological and environmentally sensitive areas such as marine parks or freshwater lakes within national parks are deemed to be sensitive waterways. Farmers that farm on catchments that empty into marine parks or national parks usually have to deal with potential overland flow or drainage into sensitive waterways. This document may benefit these growers as it deals with issues that may arise when farming near sensitive waterways. This document is best used in conjunction with an environmental code of practice such as Enviroveg or the Freshcare environmental code.

Introduction

Vegetables are an important part of Australian healthy diets, they underpin most recipes in Australian foods. The Australian vegetable industry is truly part of the food industry and like other sectors of the food industry, it has seen some major changes in recent years. The most important of these was the introduction of on farm quality assurance plans to manage food safety at the farm level.

In recent years the broader food industry in Australia has addressed other issues. Most importantly it has become more environmentally conscious and has changed many practices to reduce its foot print on the environment. Many food industries have adopted environmental certification codes.

The vegetable industry has also followed this trend and has embraced environmental codes of practice such as Enviroveg and Freshcare environmental. These codes however do not fully cover specific circumstances faced by some growers. Farming near sensitive waterways is one of these special circumstances. Sensitive waterways are always under scrutiny because of their important function. Usually they empty into marine parks or waterways within national parks of national and international significance.

Example of areas of national and international significance where sensitive waterways empty include Westernport Bay in Victoria (home of three marine parks including the Yaringa marine park) and Moreton Bay in Queensland (home of the Moreton Bay marine park), both sites have been listed as Ramsar sites by the Australian Government. The Ramsar Convention is a convention on Wetlands of international importance. It aims to stop the worldwide loss of wetlands and migratory bird habitat, and conserve those that remain through wise use and management. Another illustrative example of a marine national park is the Great Barrier Reef in Queensland. This area is listed as a World heritage Site.

These areas are scrutinised continuously by ecologists, marine scientists, community groups and other interested parties. The whole community is responsible for the environmental welfare of these important areas. Vegetable growers are also part of the community and must show adequate levels of responsibility. Growers that have farms that can potentially drain into a sensitive waterway have an added level of responsibility. They must do their best to ensure that their practices prevent entry of nutrients, chemicals, silt and other environmentally degrading matter into sensitive waterways. They will also need to be able to demonstrate this to the wider community.

Growers need to understand that they must play their role in minimising risks to the environment. They should be proactive in dealing with practices that have the potential to harm sensitive waterways. There are other reasons for growers to be proactive. Firstly, water is a key input into farms so each individual farm has a responsibility to protect water supplies for downstream water users. Secondly, farm drainage water potentially carries a number of pollutants that can be traced back to the farm. Hence running a clean farming operation often protects the business from longer term community scrutiny, or regulation, in the event pollutants are found to be a problem in sensitive waterways at a future date. Farming operations have a bad reputation (deserved or not) when it comes to polluting water supplies and are usually the first to be suspected when environmental degradation is noticed in sensitive waterways.

Vegetable growers farming in a sensitive waterway should proactively mitigate risks by firstly establishing a baseline of impact. This is done by measuring water quality upstream from their farms and downstream from their farms at regular intervals. They should be proactive when it comes to nutrient management on their farm, they should show that they are applying nutrients according to the need of the farm in order to reduce nutrient drainage into the sensitive waterway. They should understand who else is contributing to sensitive waterway pollution and engage with them in order to jointly deal with the problem. Perception is often the major problem, so above all, vegetable growers should engage with the local community and key stakeholders to communicate their good practices and demonstrate they are being proactive in dealing with this issue.

Section 1: Community approach to waterway protection

Where a waterway system empties into a sensitive environment, the whole community living within the water catchment can impact on that environment, and is its protector. Vegetable growers are usually just one part of this community and they are best able to mitigate business risks in the event of waterway pollution by engaging with all community stakeholders. By engaging and being engaged through the community approach vegetable growers gain important information regarding the catchment area they farm in. This information is critical in addressing their own farm activities.

Engaging with the community also benefits the vegetable grower by showing that they are willing to play their part in protecting the sensitive water way.

The community engagement process may be started by others or could be started by growers. How it starts is not important, what is important is playing an active role and understanding that effective community engagement must be based on three guiding principles; no blame, trust and integrity.

A booklet "Living with sensitive waterways, a guide to working with the community" was produced by the Mornington Peninsula and Westerport biosphere foundation Ltd as part of the overall project and is available to vegetable farmers.

Section 2: Keeping fertilisers on farm

In any natural system under normal weather conditions low levels of nutrients make their way into aquatic ecosystems. Indeed, they are important in maintaining healthy waterways. However in extreme weather events, in both natural and farming systems, high levels of nutrients can unavoidably be lost into waterways. This section aims to assist vegetable growers to manage nutrient inputs to meet crop requirements and to restrict environmental losses under normal weather conditions.

Evaluate the risk of fertiliser loss

It is important to understand the potential risk of losing nutrients from your farm as this will impact on the strategies you use to better manage nutrients. The risk of losing nitrogen (N) from farming systems broadly relates to the relationship between the environment, soil type and crop requirement. There are several key risk factors to consider in evaluating the potential to lose nutrients including

- Rainfall intensity & timing
- Soil type
- Irrigation amount and timing
- Rate, type and placement of fertiliser applied in relation to crop need and crop stage.

A relatively simple way to evaluate potential for N loss from your farming system is to consider both the rainfall during crop growth and type of soil on your farm. The rainfall and soil type are factors that you essentially cannot greatly control. Nitrogen (as nitrate) is easily leached hence the risk of loss is high under high-intensity rainfall, particularly in sandy or other light textured soils. For example if expected rainfall is high during the growing season then the risk of fertiliser loss is high. If rainfall is low during the growing season or distributed evenly over the year then risk of fertiliser loss is lower. To illustrate this Table 1 compares Gatton and Bowen vegetable producing districts

Table 1: Rainfall patterns for Gatton and Bowen vegetable producing districts

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Gatton													
Av monthly rain (mm)	110.9	100.3	78.3	49.4	46.2	42	37.5	27.1	35.4	65.4	79.2	100.5	771.9
Mean rain days (>0.2mm)	9.9	9.8	9.6	6.7	6.3	5.6	5.3	5.1	5.3	7.5	8.3	9.4	87.3
Bowen													
Av monthly rain (mm)	179.9	263.8	114.7	58.8	42.1	23.8	18.4	25.1	12.1	13.5	44.3	154.2	960.4
Mean rain days (>0.2mm)	11.5	12.9	9.9	8.1	5.8	4.6	3.2	2.8	2.6	3.5	6.7	9.3	76.9

From - http://www.weatherzone.com.au/climate/

For the Gatton region peak vegetable production is in autumn to early spring (March to early October). The sequential planting of crops is mostly in the months from late March to August which are the driest months. In contrast the summer vegetable crops are grown over the months starting with planting in August and final harvest in about May. Hence these crops are grown during the high rainfall summer months which presents a greater risk of nutrient loss.

In Bowen there is essentially no summer (wet season) vegetable production. Vegetables are grown over the period of about April (first planting) to October (final harvest). The rainfall during this period is extremely low and hence the risk of nutrient loss during the season is low. Though the annual rainfall for Bowen is higher than Gatton (960.4mm vs 771.9mm) the rainfall received during the peak growing period April to October is higher in Gatton than Bowen (303.0mm vs 193.8mm). On this basis the peak growing season risk of loss could be greater at Gatton.

The highly soluble forms of N (particularly nitrate but also ammonium) are the plant available forms so these are the main forms of N applied as fertiliser. High levels of soil nitrate predispose the system to losses of nitrate. Hence minimising the risk of N loss should be aimed at minimising the soil concentrations, including matching applications of fertiliser to crop needs and uptake.

Potential nitrogen loss pathways

Once nitrogen is applied to the farm there are four pathways for N loss from the soil including:

- Nitrogen in harvested product removed to market.
- Loss through surface runoff and sediment.
- Leaching through the soil profile.
- Atmospheric losses (volatilisation and denitrification).

In general the most significant loss pathways are through harvested product and leaching through the soil profile. More information about nitrogen loss pathways can be found at:

http://www.extension.umn.edu/distribution/cropsystems/dc3770.html

Evaluating crop nitrogen requirements

An important step in understanding the potential for N loss and how efficiently you apply N to your crop is to understand the N requirements of your crop. Strictly speaking, the crops' total N requirement is the amount of N per hectare contained in leaf, stem, fruit and roots. However, practically this can be achieved by calculating the amount of N contained in the harvested (marketable part) and unharvested (crop residue) components. Because measuring the amount of N in roots is difficult, an estimate of 5-10% for root system N can be added on. The crop total N requirement can then be matched with the amount of N fertiliser applied.

The first step in doing a partial nutrient budget is to calculate the amount of N taken up by your crop. This does require some data to be collected from your crop, and some specialist knowledge, so you may need to seek assistance from an agronomist. A nutrient uptake calculator, 'Veg Nutricalc', has been developed as an aid to developing a partial nutrient budget and to calculate fertiliser use efficiency. The calculator and a guide to partial nutrient budgeting can be found under the heading 'Fact Sheets' at:

http://healthywaterways.com.au/HealthyCountry/Resources/SustainableLandManagementResources.aspx

This tool is a user-friendly spreadsheet that allows the user to input data, and it does the calculations automatically.

The second step is to work out how much N was added to the crop as fertiliser. The 'Veg Nutricalc' calculator can be used to make this calculation. Since all farming and natural systems are somewhat leaky, losses of nutrient are inevitable. The amount of loss is a function of the soil properties (texture and cation exchange capacity) and applied irrigation or rainfall. The best option for measuring how much fertiliser your crop uses is to conduct a partial nutrient budget using your own crops. This involves collecting fresh yield and residue weights, and collecting and sending tissue samples of both to a reputable laboratory to determine dry matter content (%) and N content (%) of the tissues.

Alternatively, Table 2 includes data collected from a range of vegetable crop grown in Queensland. These local Queensland figures can be used to prepare a nutrient budget if you are not able to do so using your own crops. However, this data shows that the range of key parameters (dry matter % and N%) can be highly variable and so using generic values such as this might not give a realistic picture of crop nutrient uptake and removal in your crop.

The N uptake (kg/ha) column in Table 2 is calculated using fresh yield, dry matter % and N% figures. The amount of N required to grow the crop equates to N taken up by the harvested portion of a crop and by the crop residue (plant parts not removed from the field).

A range of soils references also publish crop removal figures from local and overseas research but the same limitations apply to this data as for the data in Table 2.

Table 2: Harvest indices, dry matter %, N% and nitrogen uptake for a range of crops grown in Queensland.

Crop	Plant part	Fresh Yield (tonne/ha)	Harvest Index (%)*	Dry Matter (%)	DM% range	N%	N% range	Nitrogen uptake (Kg/ha)
Broccoli	Curd	13.5	20.1	10.1	8.95-11.3	3.43	2.09-5.15	47
Broccoli	Crop residue	53.5	79.9	9.9	8.43-10.7	3.17	1.68-4.84	167
Cabbage - Drumhead	Head	84.3	69.2	8.6	-	2.30	-	167
Cabbage - Drumhead	Wrapper residue	37.6	30.8	11.6	-	2.41	-	105
Cabbage - SugarLoaf	Head	57.0	71.6	7.9	-	3.10	-	140
Cabbage - SugarLoaf	Wrapper residue	22.6	28.4	9.1	-	2.74	-	56
Cabbage - Wombok	Head	128.5	77.5	5.3	-	3.70	-	253
Cabbage - Wombok	Wrapper residue	37.3	22.5	6.1	-	3.24	-	74
Capsicum	Fruit	41.5	72.2	6.3	-	2.3	-	60
Capsicum	Plant Residue	12.7	22.1	12.7	-	2.7	-	42
Capsicum	reject fruit	3.3	5.7	6.3	-	2.5	-	5
Carrots	Carrots	77.0	84.0	11.4	10.0-12.3	1.35	0.50-2.26	116
Carrots	Plant tops	14.6	16.0	18.9	17.1-20.8	2.06	1.01-3.45	57
Cauliflower	Market Head (Curd and Bract)	40.9	42.6	7.9	7.51-7.96	3.18	2.22-3.37	103
Cauliflower	Plant residue	55.2	57.4	9.5	8.95-10.5	3.10	1.03-4.03	163
Celery	Head	82.8	72.4	5.7	-	1.80	-	85
Celery	Plant residue	36.4	17.9	6.9	-	2.34	-	59
Celery	Trimmed leaf tips	12.8	9.7	11.5	-	2.32	-	34

Lettuce	Head	66.0	79.3	4.5	3.65-5.04	2.99	1.33-4.62	88
Lettuce	Wrapper residue	17.0	20.7	5.2	4.62-6.23	3.20	2.12-4.05	29
Onion	Bulb	64.5	80.5	10.0	9.46-10.43	1.37	1.2-1.51	88
Onion	Tops	15.6	19.5	9.5	9.0-10.2	1.81	1.6-2.12	26
Rockmelon	Fruit	38.8	70.7	6.9	-	2.68	-	72
Rockmelon	Plant Residue	7.5	13.6	18.3	-	1.84	-	25
Rockmelon	reject fruit	8.7	15.8	6.9	-	2.23	-	13
Shallot	Whole top	29.4	100.0	9.2	9.1-9.4	2.91	2.53-3.11	79
Sweetcorn	Cobs	47.1	55.0	16.8	16.0-17.4	1.51	1.27-1.68	144
Sweetcorn	Leaves	10.5	12.2	25.6	23.7-29.3	2.30	2.01-2.47	59
Sweetcorn	Stem	28.1	32.8	19.4	18.2-21.1	1.23	1.26-1.74	58
Zucchini	Fruit	36.8	41.5	7	-	4.5	-	117.0
Zucchini	Plant Residue	51.9	58.5	7	-	2.3	-	81.4

* Harvest Index is expressed on a fresh whole plant basis (excluding roots with the exception of carrots)

Fertiliser use efficiency

Ideally the amount of fertiliser applied would exactly match the amount taken up by the crop which would give a 100% efficiency of application, if very little nitrate was in the soil at planting (that is, less than about 4mg/kg of nitrate N).

In the context of fertiliser application rates and crop N requirements and removal, fertiliser use efficiency is the amount of N taken up by the crop as a percentage of that applied as fertiliser.

Field surveys of vegetable crop nutrient dynamics on heavy textured soils in the Lockyer Valley, Queensland show nutrient use efficiencies of greater than 90% over a range of vegetable crops. In sandy soils it is more difficult to achieve high fertiliser use efficiency. Crop fertiliser use efficiencies greater than 100% means fertiliser applied is less than crop nutrient uptake. This indicates that the crop gets extra N from the soil N reserves to supplement fertilisers added.

Different vegetable crops appear to differ in their ability to use N for maximum yield. This in turn affects their fertiliser use efficiency. For example capsicum requires N to be applied in excess of whole crop uptake (fruit, leaf, stems, roots). A fertiliser use efficiency of about 65% might be the best achievable result for achieving maximum yield in capsicum but strategies should be applied to restrict loss of N that is excess to crop uptake.

Know how much nitrogen is returned in crop residues

In vegetable production there is a wide range of crop harvest indices. The crop harvest index refers to the amount of the whole plant biomass that is harvested (and thus removed from the paddock). For example, for broccoli the harvested head of broccoli represents only about 30% of the whole plant biomass whereas for lettuce the harvested head represents about 80% of the whole plant biomass as only the older wrapper leaves are not harvested. Crop harvest index is important because in crops with a low harvest index, substantial amounts of nutrient are returned to the soil system and are generally available for a subsequent crop.

A range of harvest indices for vegetable crops grown in Queensland is presented in Table 2.

Crop harvest indices enable us to take into account the residual N already in the soil from a previous crop, and, along with other partial nutrient budget information, forms a basis for determining the likely fertiliser N requirements for the subsequent crop

How much available N is in my soil

The availability of this crop residue N as nitrate can be confirmed by conducting a soil test immediately before planting the next crop. This is important in determining the amount of available N. Soil nitrate is usually expressed as mg per kg NO_3^-N and each 1 mg per kg increment roughly equates to 1.1 kg of N per ha (assuming a soil bulk density of 1.1 kg per litre of soil) to a depth of 10 cm and double it to a depth of 20 cm (a standard working depth in vegetable production). Taking into consideration the amount of residual soil nitrate at planting the crop nutrient requirement the theoretical total fertiliser required by the crop is as follows:

Applied N fertiliser = Whole crop requirement (harvested product + crop residue) minus residual soil nitrate.

However the applied fertiliser needs to be somewhat higher. This acknowledges the nitrogen needs of the root system (assume 5-10% of whole crop requirement) and the fact that all systems lose some nitrogen.

The aim of better managing N fertiliser is to minimise the amounts of soluble nitrate N in the soil so as to minimize the risk of N loss.

Maintaining low soil nitrate levels –fertiliser management during crop growth

Since nitrate is soluble, and hence mobile in the environment, strategies for reducing the impact of fertilisers on sensitive waterways need to focus on maintaining the lowest possible levels of nitrate in the soil. This is particularly the case in fallow periods or in probable high rainfall periods (based on long term climatic data).

During crop growth low nitrate levels can be maintained by carefully matching fertiliser application to crop growth requirement. Crop N uptake is directly proportional to crop growth hence peak demand for N by the crop is in the latter stages of growth. On light textured soils where there is a high risk of leaching smaller more frequent applications will reduce the risk of loss. In heavier textured soils higher rates can be applied less frequently provided irrigation matches crop requirements and the risk of intense rainfall is low. Where soil variability is high on a farm nitrogen should be applied to suit the lightest textured soil as it presents the highest risk for N loss.

Maintaining low soil nitrate levels – Fallow management

The presence of high residual nitrate levels after vegetable harvest can be managed by sowing cover crops to extract nitrate and reduce surface soil erosion and associated nitrate loss. Applying organic amendments that have a high carbon to nitrogen ratio can cause drawdown of nitrate through microbial immobilisation resulting in lower soil nitrate levels.

On light textured soils building nutrient and water holding capacity by adding organic matter and green manure crops in rotation can lower soluble nitrate and reduce the potential for leaching.

Organics wastes and amendments

Organic wastes and amendments present challenges in managing crop nutrients and preventing losses to sensitive waterways. This is because application rates needed are high and all of the nitrogen in them are not immediately available but rather released over a long time frame. Furthermore the N content of products varies considerably. As an example, the N content of a range of chicken wastes (including raw, composted, broiler and litter products) ranges from about 1.5%-4%. At a moderate application rate of only 20 tonne per ha, between 300 kg and 800 kg of N per ha may be added to the farming system. In total this is far in excess of most vegetable crop requirements but much of the added N is not in an immediately available form. Nonetheless, repeated annual application at such rates will result in environmental losses of nitrogen. If waste products are applied to your farm you need to know how much N is being applied and regularly monitor soil nitrate to ensure excessive levels are not consistently present. Soil nitrate test strips are a cheap and effective way of measuring this.

Section 3: Managing runoff & drainage water to reduce nutrient pollution

Nitrate fertilisers are soluble, so most nitrate is lost from farms in overland water flow or by leaching into sub-surface drainage. Phosphates are mainly insoluble and so are lost from the farm attached to eroded soil particles. Some sandy soils with a low Phosphorus Buffer Index (PBI) can lose phosphorus through leaching.

Preventing nitrate loss in overland water flow

Managing water runoff from above production areas

If your production area has rising land above it, you need to stop external water from above your paddocks flowing onto and through them, taking soil and nutrients with it. This is best achieved by making diversion banks above production areas to divert runoff into stable grassed drainage areas outside cultivated paddocks.

Managing water runoff from production areas

Water from production areas usually flows off the growing beds to the inter-row areas, then along the inter-rows to headlands. Some farms plant cereal in the inter-row soon after bed-forming, and kill it with herbicide before it seeds or before it gets in the way of other agronomic practices. The resulting dead mulch acts to slow water down along the inter-row, especially on sloping ground, and holds the soil in place during rain events. Ideally water at the headlands should be directed along vegetated drainage areas and into collection dams. Vegetated drainage areas slows water down reducing its erosiveness, and holds soil in place stopping collection dams filling up with silt.

Use dams or wetlands to hold and/or clean water on-farm before release into waterways

A dam should ideally be large enough to collect all the water off your production area from an average rainfall event. The advantage of dams is it adds to your volume of irrigation water, and may even supply some of the nitrate lost in the runoff back to the crop at the next irrigation.

Constructed wetlands are another option if putting in a dam is not feasible. A constructed wetland is really about developing a wetland or ‘swamp’ area on your farm, filled with water plants. The wetland slows water down, dropping out silt, and the plants strip the water of excess nutrients before the water flows out of the wetland and goes on it's way to streams and rivers. Local councils, landcare groups or environmental groups may be able to provide advice on what plants to use in a wetland in your area.

Before establishing dams or wetlands on your property check with your local authorities to ensure you comply with regulations concerning water and waterways.

Managing leachates

Leachates are nutrients that leach down below the root zone of your crop in irrigation water or rainfall. Once below the root zone these nutrients are no longer available to your crop and become a wasted resource (that you have paid for). Of more concern environmentally is where these nutrients finish up.

The best solution for all (farmers and the environment) is to minimise leaching of nutrients below the root zone. This is best achieved using careful irrigation scheduling monitored with soil water detectors installed near the bottom of the root zone. Tools such as tensiometers, enviroscanR or wetting front detectors will provide guidance to efficient irrigation use.

Some farms have installed drainage pipes to collect and quickly remove drainage water from paddocks. Managing nutrients leached below the root zone is more feasible in this instance as you know where they are going (to the exits of the drainage pipes). This drainage water can then be directed to dams or wetlands as above.

Where drainage pipes are not installed, it is uncertain where the leachates end up. The only option here is to minimise nutrients being leached below the root zone using efficient fertiliser and irrigation methods.

Managing riparian areas

Riparian areas are the vegetated areas along rivers and streams. These areas should be maintained with good vegetation cover. Vegetation should including a range of low ground covers, shrubs and trees. These riparian areas act to clean water running from adjacent areas in to the rivers and streams. To be an effective buffer they should be at least five metres wide. Some streams have banks that are higher than the surrounding land, meaning that surrounding water will only flow into them along particular tributaries or gullies. The same principle applies to these tributaries and gullies – keep a good riparian area along the side of them.