Nutrient loss in cotton production: A preliminary investigation of major nutrients being transported in the irrigation tail waters

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Cotton Catchment
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Literature Review

Thesis

Nutrient transport in surface flows from irrigated cotton

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Abstract

This review investigates the current literature on nutrient loss from agricultural production systems with a focus on cropping enterprises and the cotton industry specifically.

Factors which affect nutrient loss such as soil conditions, fertiliser application forms and nutrient cycling are also discussed as well as the environmental consequences of nutrient loss.

From the current literature the evidence that there is significant nutrient loss from agricultural production but there is limited data for the cotton industry even internationally and there is none at all from the Australian cotton industry. Of the literature that is available a significant proportion of the data is from the United States and isn't particularly relevant to Australian conditions.

This review was prepared in preparation for a study which will be undertaken on nutrient loss from Australian cotton production,

Keywords: Cotton, Nutrients, Eutrophication, Nutrient Transport, Australia

I: Introduction

Nutrient loss from cotton production in the irrigation tail waters is an important and somewhat contentious issue in today's society. It is so for a variety of reasons but the major cause for concern is the environmental impact that nutrient runoff can have, particularly when it enters waterways and ground water reserves.

There is also an economic aspect to this concern, primarily because nutrient inputs in the form of chemical fertilizers are a major cost of production for crops and particularly so for irrigated cotton production. If nutrients are lost in the tail waters (runoff), effectively part of the cost of the nutrient input is being lost, as these nutrients are no longer available for the growth of the crop.

However, this loss is somewhat neutralised in the cotton industry, primarily because in New South Wales it is recommended that tail waters are captured in tail drains and returned to storage dams and thus the water is reused.

In this review, the opportunities for surface transport of nutrients in runoff water will be examined as a basis for better management of runoff.

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II: Cotton Production

1: General Information

Cotton (*Gossypium spp.*) is one of the worlds leading fibre crops accounting for a 39% of the fibre production worldwide with the other major contributors being wool and synthetics (such as polyesters) (Townsend, 2004).

Cotton is grown in around 100 countries worldwide (ICAC, 2005), with 115 million bales (26.1 million tonnes) worth around $30 billion U.S Dollars produced worldwide in the 2004/2005 season.

Major cotton producers in this period were China, India, Pakistan, USA and brazil accounting for 75% of these figures (Cotton Australia, 2005), Australian producers contributed around 497,000 tonnes (Trewin, 2005B) (1.9% of global cotton production)(Cotton Australia, 2005).

However these global production figures can be somewhat misleading because many of the worlds major cotton producers do not export large quantities of cotton but retain them for domestic use; Australia is a significant exporter of cotton onto the global cotton market.

2: Agronomic Information

Cotton crops around the world are grown on one of two systems, either dryland (or upland cotton) or irrigated cotton. Within these two systems there is considerable variation in the agronomic conditions under which the crop is grown. However, in Australian, cotton production most of the crop is grown under irrigated conditions (81% for the 2003-2004 season) (Trewin, 2005A) with high levels of various inputs into the crops.

It should also be noted that most of the cotton produced in Australia (497,000 tonnes) in the 2004-05 season was produced in New South Wales (53%) and Queensland (46%), (Trewin, 2005B), the major production areas in NSW are the Lachlan, Macquarie, Gwydir and Namoi catchments and in Queensland the Macintyre catchment and the Darling Downs region (Stanley, 2006).

In total there was 309,000 hectares of cotton grown in the 2004-05 season (Trewin, 2005), most of irrigated which as consequence used around 1.5 million mega litres of water (equating to around 6.5 ML/Ha of cotton), this irrigation accounts for around 14% of all irrigation water used in Australian for 2004-05 (Linarce, 2004).

Figure 2.2 shows a comparison of irrigation water usages for different crops or pastures. It is important to note that in the Australian cotton industry the dominant variety that is grown is Bollgard II, which is a genetically modified (GM) variety which incorporates two genes for resistance to boll damage from Helicoverpa caterpillars. However, the use of Bollgard cotton has little effect on the nutrient inputs or the water requirement of the crop, the main difference is in the pest control regime.

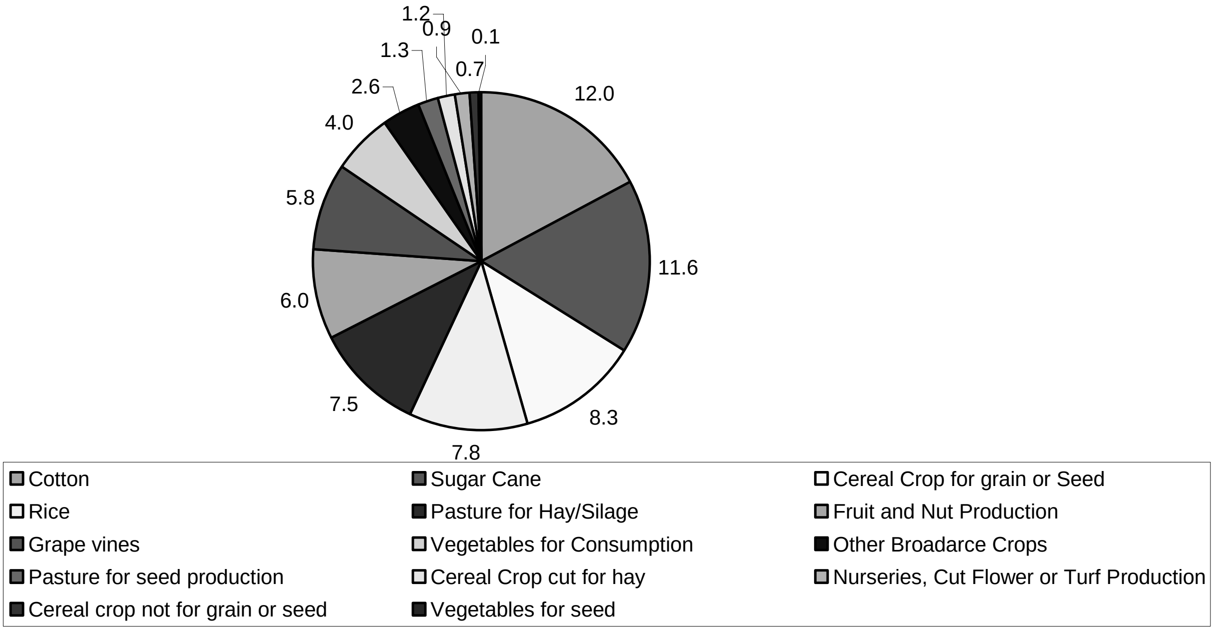

Figure 2.2 – Irrigation application per enterprise as a Percentage of total irrigation application

On the typical Australian furrow irrigated cotton farm (which as noted in part 2 above make up a significant proportion of the cotton industry) the property is setup in manner similar to that show in figure 2.3 below

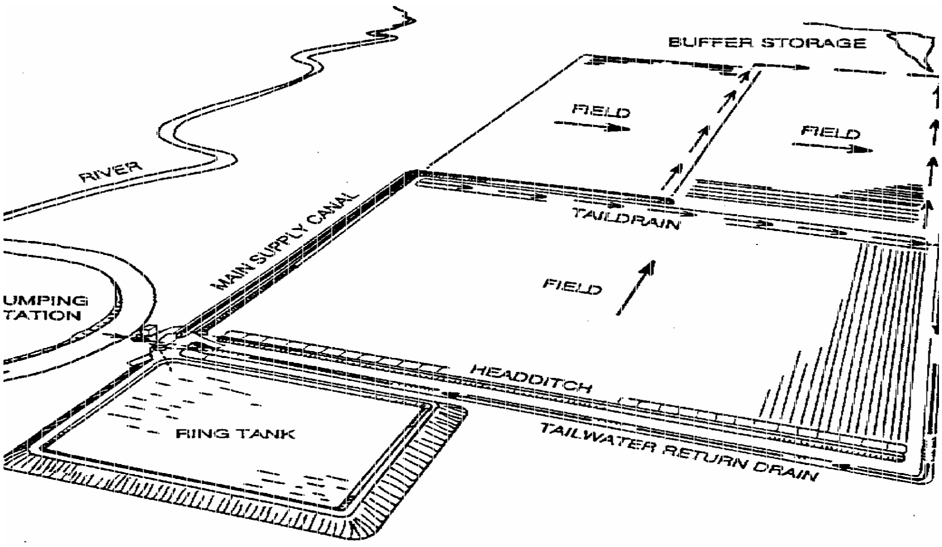

*Figure 2.3 – Stylised layout of a typical irrigated cotton property – (*Stanley*, 2004)*

Water is initially supplied to the property via a pumping station which is usually located on a river however on some properties the water source is ground water obtained via a bore.

This water is then either directly applied to the field or stored in the ring tank before use. The water to be applied is transported along a head ditch at the top end of each (laser levelled such that the gradient is around 1/1000, i.e. a drop of 1 metre for every 1000 metres of length) the field. The water is then applied to the field from the head ditch using a variety of methods (the most common being through syphons).

This irrigation water then slowly flows down the field in the furrows; the time will vary, depending on the length of the field, but on average takes about 8 hours. Runoff is generally under 10% of the application which then collects in the tail drain. The runoff then enters the return system, or, more commonly, the head ditch on the next field.

Once the water is in the return system it flows back towards the ring tank for storage; in most cases the water is pumped from the return system into the ring tank.

4: Nutrient Application to Cotton

Of major significance for nutrient runoff from irrigated cotton is the level of nutrient inputs into the production system.

Stanley (2004) recommends that nitrogen for cotton production be applied at rates of 120-180 kg per ha. It also recommended is 10-40 kg of phosphorus and 500 grams of zinc per hectare of cotton be applied. Multiplied over the whole area of cotton production, this equates to between 37,000 and 55,600 tonnes of nitrogen, 3,090 and 12,360 tonnes of phosphorus and 154 tonnes of zinc being applied to cotton in Australia per year

Of the 120-180kg of N applied per year only 110-120 kg per ha is estimated to be utilized by the growing cotton crop each year (Cotton Production Guide, 2004). Nitrogen is being applied each season, leading to an assumption of between 10 and 70 kg of N is being lost from the production system each year. However, there is no substantial evidence of where this nitrogen (and possibly other nutrients) is being lost to from Australian cotton industry.

It is assumed that nitrogen is lost by either leaching, or in the surface runoff. However, another loss pathway maybe through denitrification under anaerobic conditions in the presence of organic carbon (Kennedy, 1992)

III: Nutrients and Soils

The understanding of nutrients and soil and the interaction between these substances are the most significant factors which influence nutrient loss; this section will deal with these two topics (nutrients and soils) as well as how they interact and how this can lead to nutrient loss in surface runoff.

1: Cotton Nutrition

In cotton production and agriculture in general, significant amounts of nutrients are applied for crop growth. This is particularly so for irrigated crops such as cotton as grown in Australia. Constable, Rochester and Dowlings (2006) outlined the key nutritional uptakes for Bollgard cotton (varieties Sicot 289BR and 189RR) grown under irrigated conditions at Narrabri in north-western New South Wales, for a crop which produced 8-13 bales of lint per ha.

In this study it was found that between 194-248 kg per ha of N was taken up by the plants as well as between 19-29 kg per ha of P and K uptake had a range of 184-234 kg per ha. These uptake levels indicate the amount of nutrients that the crop needs to produce the lint yields, as well as giving an indication of the level of fertilizer input needed.

A older study undertaken by Hake, Cassman and Ebelhar (1991) found that a growing cotton crop requires 10 – 11 kg/ha N, 1.7 kg of P and 9.2 kg of K, at first glace these results seem very different however when the Rochester Et al (2005) results are converted to the same units (kg of nutrient per ha per bale of lint) as the Hake et al (1991) study the results are 21 kg of N, 2.2 kg of P and 19.9 kg of K, however even after this conversion the values are very different, with different varieties or growing conditions possibly influencing the results.

2: Nutrient Forms in Applied Fertilizers

In the cotton industry a wide range of fertilizers are applied to the growing crops and almost all of these are manufactured chemical fertilizers and contain the plant essential elements (nutrients) in varied of different forms often as ions, form of element that is applied can have a significant effect on final fate of the nutrient in the production system.

Common fertilizers used in agricultural industries include urea, anhydrous ammonia, superphosphate, ammonium nitrate, potassium chloride, monoammonium phosphate (MAP), diammonium phosphate (DAP) and ammonium sulphate.

A: Nitrogen Fertilizers

Nitrogen is an important plant nutrient needed in relatively large amounts. Large amounts of nitrogen fertilizers are applied so with cotton.

That the major nitrogen fertilizers used for Australian cotton production are anhydrous ammonia (86% N, chemical formula NH_3) and urea (46% N, chemical formula $CO(NH_2)_2$),(Tisdale, Nelson and Beaton, 1985), how ever small amounts of N are applied to the crops in the starter fertilizer which is generally DAP or MAP fertilizers (Cotton Nutripak, 2001).

Applied urea is quickly hydrolysed to ammonium (a cation) which is fairly immobile in the soil solution.

Anhydrous ammonia is also relatively immobile if correctly applied (Cotton Nutripak, 2001), however the N does not stay in this form and is rapidly converted to other forms, to be discussed in the next part on nutrient cycling.

B: Phosphorus Fertilizers

Phosphorus is an essential nutrient for the growth of the crop, but it is not needed in large quantities (Rochester et al., 2006; Hake et al., 1991); in most soils on which cotton is grown in Australia there is no need for P application.

However most starter fertilizers (that is fertilizer that is applied at sowing) contain a small amount P, as the starter is often MAP or DAP (Nutripak, 2001).

The P in these fertilisers is the form of phosphate that is HPO_4^{-2} or $H_2PO_4^{-2}$ and often binds to the soil particles

C: Potassium Fertilisers Australian spelling

Potassium is an important nutrient for cotton. However it is not often applied as a fertiliser to the crop primarily because Australian soils are not generally low in K (Nutripak, 2001). When K^+ is needed it is usually applied as potassium chloride (KCl, commonly known as potash) and infrequently as potassium nitrate (KNO_3) or potassium sulphate (K_2SO_4).

In all of these fertilizer treatments the K is released as an potassium ion and often binds to clays and part of the cation exchange capacity (CEC) of the soil (Nutripak, 2006).

3: Nutrient Cycling

It is important to note that when nutrients are applied to soil they do not necessarily stay in the form that they applied, often the nutrients under go a cycle, a series of chemical reactions often changing from one ionic form to another.

The most significant nutrient cycle is that of nitrogen however there are also cycles for the other major nutrients such as potassium and phosphorus.

A: Nitrogen Cycle

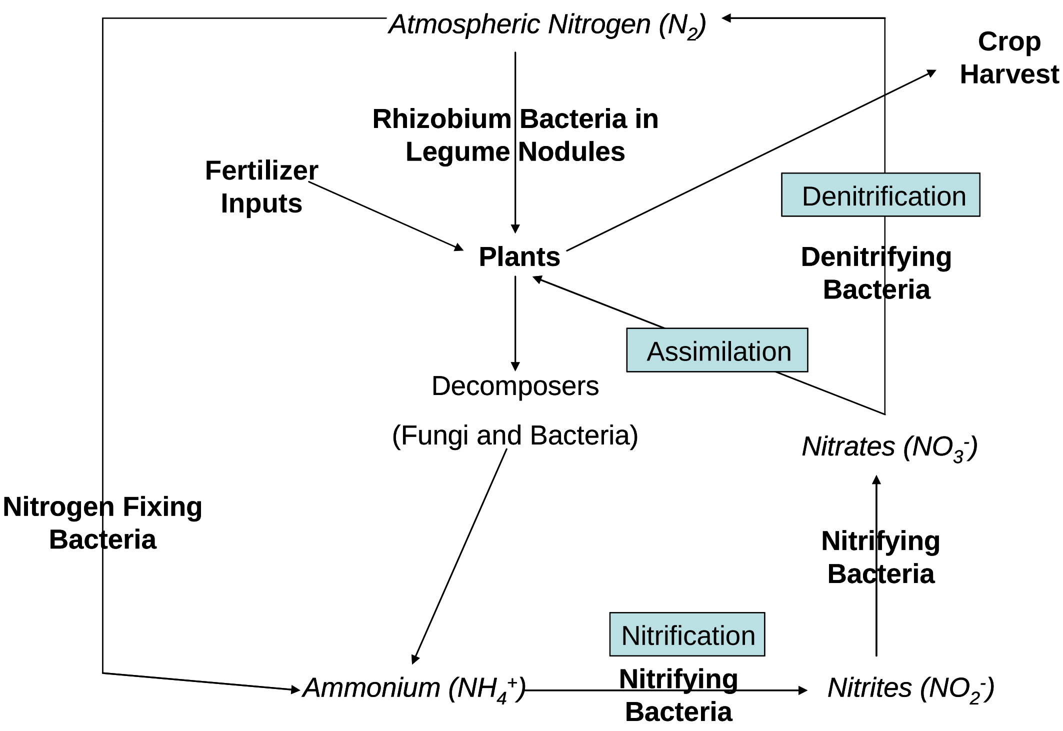

Figure 3.1: The Nitrogen Cycle (adapted from Kennedy, (1992))

From Figure 3.1 it can be seen that the nitrogen cycle is a diverse system with almost all of the process driven by microbial activity particularly bacteria. However it is important to note that nitrite as a component of the cycle is relatively unimportant in nutrient loss as it is rapidly becomes nitrified to nitrate and usually at low concentrations.

It is also significant to note from Figure 3.1 the different charges on the chemical forms of nitrogen as these charges have direct effect on the ability of the nitrogen species to be retained or lost from the soil solution. This shall be further discussed in part 4 of this section of the review.

Denitrification is another significant process in the nitrogen cycle. This is the process by which nitrate is converted to gaseous dinitrogen or nitrous oxide by microbial organisms under anaerobic conditions when carbon substrates are available.

Denitrification has often been found to occur where nitrate based fertilizers have been applied (Addiscott, 2005). Another significant component of the nitrogen cycle is the conversion of ammonium to ammonia via chemical equilibria, which occurs at pHs above 9.2 (Stumm and Morgan, 1996)

B: Phosphorus Cycle

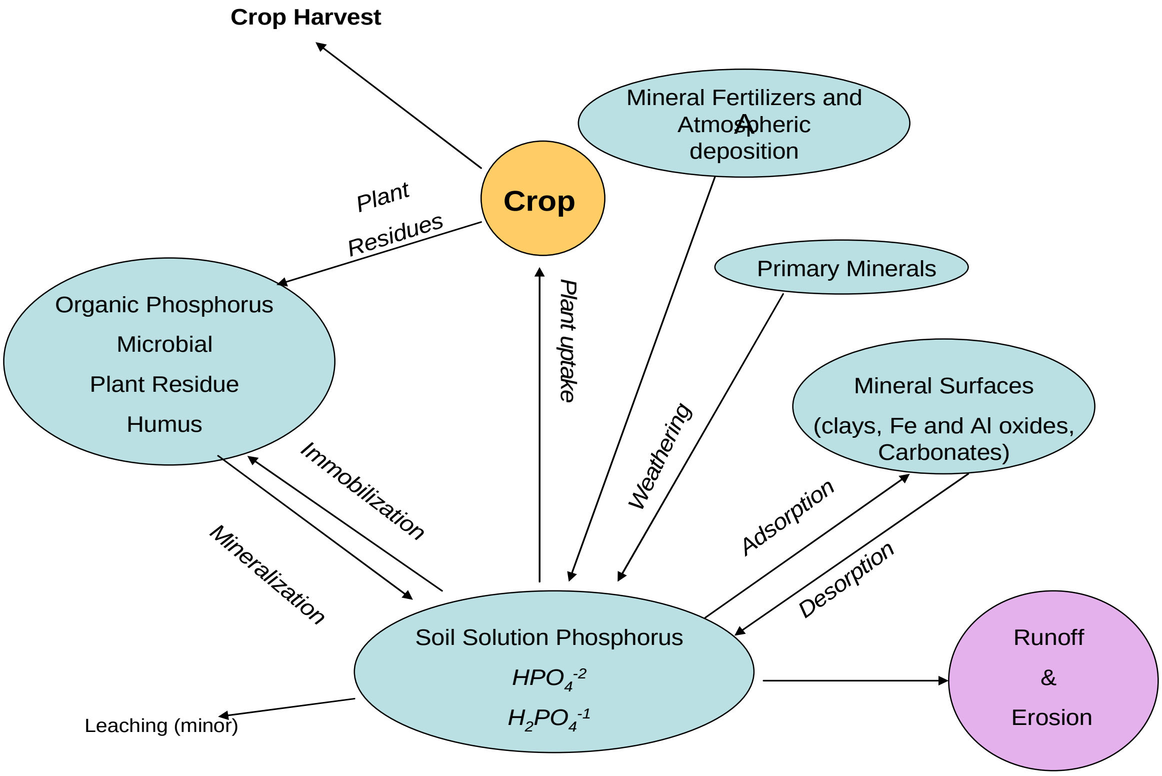

Figure 3.2: The phosphorus cycle (adapted from Pierzynski et al, 2005)

The phosphorus cycle has several notable differences from that of the nitrogen cycle discussed above; most notable is the lack of microbial organisms involved in the cycle. Nor is there any change in the oxidation state where the main changes in the cycle are between where the P is found in the soil as inorganic complexes.

Most phosphorus found dissolved in the soil solution is in the form of the phosphate ions.

From the cycle in can be seen that phosphorus in the soil comes from a variety of sources including the weathering of primary minerals (such as apatites), from the mineral surfaces (clays, secondary P minerals (labile P) (Pierzynski et al., 2005)). Organic sources in the soil and fertilizer inputs also play a role in phosphorus inputs into the soil solution.

C: Potassium Cycle

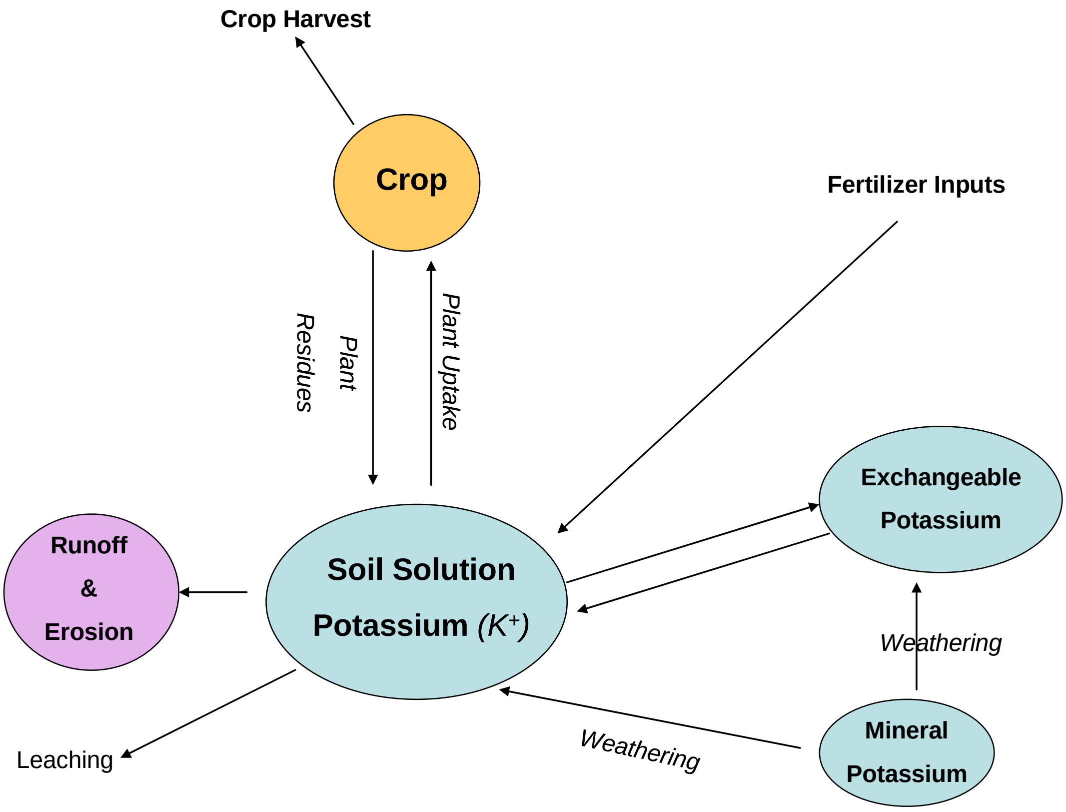

Figure 3.3: The Potassium Cycle

Figure 3.3 shows the potassium cycle once again with potassium there is little microbial involvement with cycle beyond the decomposition of organic material in the soil, for the most part potassium is found bound the negatively charged soil colloids and forms part of the cation exchange capacity of the soil (exchangeable potassium). the mineral potassium refers to the potassium contained within primary minerals such as feldspars and micas and secondary minerals such as illites which is released in the soil solution or the exchangeable potassium by weathering (Tisdale, Nelson and Beaton, 1985).

3: Soil Characteristics that Affect Nutrient Retention in the Soil Solution and Nutrient Movement Pathways

The characteristics of the soil itself can have a large impact on the ability of nutrients to be removed by the actions of water. Thus it is important to consider the soil properties in any review of nutrient movement by water.

One of the major influences on nutrient retention in the soil is the clay content of the soil. This is particularly so for positively charged cations, such as potassium and ammonium, because these cations bind to the negatively charged clay colloids in the soil. Thus clay more colloids and consequently more surface area for the cations to bind to.

However ammonium in the soil quickly under goes nitrification to form nitrite and as a result the effect of the clay colloids only briefly retains nitrogen as NH_4^+. This binding process plays no role for nutrient anions such as nitrate, phosphate and nitrite.

It should be noted that of these anions nitrate is not held in the soil by any method and is actively repelled by the clay (Kennedy, 1992) and is completely mobile in soil water (Tisdale *et al*, 1985).

For phosphorus in the form of phosphate, the most significant soil characteristics influence on its retention in the soil solution are pH, clay mineral content and types, the amount of organic matter and the amount P in the parent materials of the soil (Laegreid *et al*, (1999), Davis *et al*, (2005)

The movement of these nutrients in water is affected by the soil characteristics which define their retention. This also defines by which method a nutrient is transported such as leaching, surface flows, subsurface flows.

Nutrients such as potassium and phosphate tend to move with the sediment as they are bound to the soil colloids (Laegreid, Bockman and Karastad, 1999);(Sims and

Sharpley, 2005). K is transported almost exclusively in surface flows attached to sediment but P transport is slightly different as it is slightly soluble in water, such that limited amounts are transported dissolved. This means that some P can be transported by sub-surface flows and leaching however the majority of P is transported with sediment in surface flows (runoff) (Laegreid, Bockman and Karastad, 1999) and (Tisdale, Nelson and Beaton, 1985).

Nitrogen transport is completely different from that of potassium and phosphorus because the nitrate ion is highly mobile in solution.

It is readily transported in solution either by leaching, subsurface flows or surface runoff.

Any of these transport pathways can cause significant losses of nitrate (and thus nitrogen) from the soil solution (Addiscott, 2005)

IV: Environmental Consequences

Nutrient movement into waterways via groundwater leaching or surface runoff can have significant consequences for the environment as well as being a possible cause of inefficiency in agricultural systems.

Major environmental consequences include eutrophication, algal blooms, water pollution (and its subsequent effect on water quality) and well as the effect of soil acidification.

Another important consideration is the source of the release of nutrients into the environment. Is the source a point source (an easily identifiable single point of release) or a non-point source (a diffuse area of release) as is often the case with agricultural runoff.

1: Eutrophication and Algal Blooms

One of the most significant environmental effects of nutrient runoff that occurs when these nutrients enter waterways is eutrophication and often, associated algal blooms.

Eutrophication is defined by the Webster dictionary as “the process by which a body of water becomes enriched in dissolved nutrients (as phosphates) that stimulate the growth of aquatic plant life usually resulting in the depletion of dissolved oxygen”.

However this definition has a major short coming mainly as phosphates are not the only cause of eutrophication; nitrogen has a significant effect on eutrophication (Laegreid, Bockman and Karastad, 1999).

Algal blooms are a phenomenon brought about as a direct result of increased nutrient loads in waterways. These allow for rapid growth and expansion of algal populations including blue green algae, (Young Et Al, 1996), some of which are able to fix N_2 (where P is available) increasing the eutrophication risk

One of the major effects of these algal blooms is a substantial drop in the biological oxygen levels in the waterways. This can be brought about through the blue-green algae being relatively unpalatatable to zoo plankton species! This under-utilised material to be broken down by decomposers using significant amounts of oxygen in the process lowering the total oxygen in the waterway.

This lowered oxygen level can have a significant detrimental effect on other aquatic organisms (Laegreid, Bockman and Karastad, 1999).

Further effects that nutrient runoff into waterways can have on water quality are the eutrophication and associated algal blooms discussed above which can make the water unusable due to toxins produced by the blue-green algae.

2: Water Pollution and the Effects on Water Quality

A further environmental concern that stems from nutrient loss in surface runoff and groundwater leaching is the effects of these nutrients on water sources and waterways in terms of water pollution as well as the effect on the water quality.

It is not just the nutrients that are of concern but also the soil erosion that is often associated with surface runoff. As mentioned earlier this is the primary means that nutrients such as phosphorus and potassium are transported. Sediment increases the turbidity of the water, which can have a detrimental effect on the aquatic ecosystem of the waterways.

Another effect on water quality contributed by runoff containing nutrients is nitrate contamination of water ways, this is a particular concern due to the poisonous nature of nitrate to humans and livestock, nitrate levels which are considered dangerous are 45 mg per L of nitrate (US EPA, 1991)

3: Soil Acidification

Soil acidification is a environmental consequence which is linked to nutrient loss but not directly caused by it. It is a process by which soil can become more acidic and often caused by excess ammonium (NH_4^+) ions in the soil which act as a protein donor to the soil solution which lowers pH making the soil more acidic (Addiscott, 2005).

This process of soil acidification can be linked with nutrient loss (such as N) as the this lost N is often needed to be replaced with fertilizer applications in agricultural systems (Kennedy, 1992)

V: Studies of Nutrient Loss

Research on nutrient loss is not a new field. There has been a significant amount of agricultural research in the field, ranging from broad scale catchment research to more intense individual crop or farming system research.

1: General Agricultural Research

As mentioned above their has been a large volume of research conducted on nutrient loss in the international literature covering everything from catchment studies right down to small plot areas, with research on almost every crop or land use possibility of combinations of land-uses, also covered under this title of general agricultural research is studies and experiments which have been done on the movement of sediments (and what effects this) as well as attempts to model the flow of nutrients and sediment on large scales.

A: General Agricultural Studies into Nutrient Loss

In the literature there is a variety of studies which investigate factors which influence nutrient runoff, these factors include field design rainfall intensity and soil types for example.

Some of these papers also give a estimate of nutrient runoff which could be expected from agricultural lands.

Monke et al. (1976) paper, reports in the effect of simulated rainfall on nutrient and soil movement in overland flow (runoff) from the interill of soil which has undergone different cultivation operations. The experiment was conducted on three soil types (loam, silt loam and silty clay) of two varieties, those which had been cultivated recently and those which had not been cultivated recently. The samples collected by the experimenters was analysed for nitrogen, phosphorus, potassium and suspended sediment, samples were filtered and as such both the filtrate collected solids where analysed for their nutrient content.

The results from the experiment concluded that the more recently cultivated soils more readily enabled nutrient loss from the soil but further conclusions where not possible to be drawn, however for suspended solids it was concluded that this was affected by the soil type, the rate of water inflow and the cultivation status.

The effects of rainfall intensity on nitrogen and phosphorus losses in surface runoff were discussed in Flanagan and Foster (1989) Their experiment was conducted in the United States, using rainfall simulators to replicate the effects of peak intensities of storm events. In terms of nutrients, the experimenters analysed for sediment bound and solution nitrogen and phosphorus levels; soil nutrient status was also determined, using both of these data sets enrichment ratios were determined which indicated the concentration of nutrients in the runoff compared with that of initial soil.

It was known that sediment with high clay or organic matter content than the original soils tended to be more likely to become enriched (USDA, 1980). The study was conducted over 6 randomly assigned storm patterns (intensities) on each of the plots used in the trial, each treatment was replicated three times. The conclusions of the experiment were that there was no correlation between N and P enrichment ratios also it was found that storm intensity did not significantly affect the loss of soluble N or P nor sediment bound N or P.

Expansive clays and there effects on nutrient runoff (in particular N and P) is discussed in Torbert et al (1995), this paper is directly relevant to the Australian cotton industry due to vertosols being expansive clays.

The main aims of the study were to examine the effects of tillage systems and fertilizer N on nutrient runoff, the study was conducted in the united states, using simulated rainfall as the water source. Measurements were taken for both N and P losses in both solution and sediment, further measurements were made for loss of fertilizer N. Cultivation treatments were no tillage and chisel-ploughing.

The results were found that chisel ploughing on expansive clay soils caused lower amounts of nutrient runoff than no-till systems, and this was explained by tillage causing the soil to be less likely to form a surface crust and allowing more infiltration of water into the soil profile.

A study into solute transport from low angle slopes (like those found on an laser-levelled cotton field) was reported in Walton et al (1999), this study was undertaken using field plots and repacked soil cores, with water being provided via a rainfall generator. The study did not actually study nutrient movement but tracer chemicals (such as bromide) to indicate water pathways. The experiment also involved 3 different soil surface conditions (zero-till, disk ploughing and residue cover) on land which was normally used for sugar cane production in northern Queensland.

The findings of study were that volume of solute in surface runoff varied greatly with soil type and that soil structure played an important role in how likely a solute was to runoff. To this end it was reported that the zero-till plots had greater nutrient loss than those which had been tilled. This was attributed to pore-size distrubition, the only effect noted of the slope was in the time it took for the runoff to begin to drain from the field.

Sharply *et al.* (2001) identifies that there is significantly need for management of phosphorus in modern agriculture. They discussed that P runoff loss generally occurs from small parts of the landscape in relatively few large storms.
They also identified these small areas as occurring where there was high soil P levels or P applications in mineral fertiliser or manure, coincide with high runoff erosion potential.

A further general agricultural study was that of Wickham and Wad (2002), which was a study to assess the watershed scale level of risk associated with nitrogen and phosphorus and as such used previous data from studies carried out in the US state of Maryland. The results indicated that risk of N and P export exceeding specified safe levels (7.32 and 0.83 kg/ha/year respectively) dramatically when less than 95% of the catchment was forested. The model also predicted that P was more likely to exceed if urban land was more abundant than agriculture and for N it was the reverse.

From this section it can been seen that there has been a some research into more general aspects of nutrient loss, and for the most there has been significant indication that this loss is occurring from agricultural lands.

B: Catchment Studies

Catchment level studies of nutrient loads in waterways is one of the most prolific areas of research into nutrient losses and there have been many studies encompassing a wide geographic scope (thus a large number of different land and soil types) as well as a large number of land uses ranging from land used for cropping and pastures, woodlands and forests right through to undisturbed catchments.

Table 5.2: Comparison of catchment level studies

Authors	***Year***	***Country***	***Size***	***Substances tested for***	***Findings***	***Length of Study***	***Water***
Smolen	*1981*	USA	0.05 Sq km	NH_4, NO_3, NO_2, P	Nutrient enrichment in Agricultural Runoff	3 Years	Rainfall
Hopmans, et al	*1987*	Australia	0.213 Sq km	Sediment, Na, K, Ca, Mg, Cl	Nutrient enrichment in runoff after land clearing	1.5 Years	Rainfall
McDowell, et al	*1989*	USA	0.0187 Sq km	NH_4, NO_3, TKN, Total N, Soluble P	Nutrient enrichment in Agricultural Runoff	6 Years	Rainfall
Heaney, et al	*2001*	Ireland	4450 Sq km	Sediment, NO3, P	Trivial	1 year	Rainfall
Cao, et al	*2003*	China	1.74 Sq km	NO_3, DRP	Nutrient enrichment in Agricultural Runoff	2 years	Rainfall
McKergow, et al	*2003*	Australia	5.9 Sq km	Sediment, Total N, Total P	Nutrient enrichment in Agricultural Runoff	10 years	Rainfall
Ierondiaconou, et al	*2005*	Australia	27,760 Sq km	Total N and Total P	Nutrient enrichment in Agricultural Runoff	22 Years	Rainfall

From table 5.2 it can be seen that there is significant variation between the 8 studies with significant variation in the size of the catchment investigated, the length of the study and what samples were analysed .

Within all the eight studies samples were collected after rainfall events (be they storms or showers); however, there were significant differences between the intensity of the rainfall events at which samples were taken. The most important similarity between all of the broad scale catchments studies was that all the studies concluded that there was enrichment by nutrients of surface flows from agricultural land. But as will be discussed below, there was significant variation as to the degree of enrichment.

Smolen (1981) was undertaken in the state of Virginia in the United States of America and involved 50 ha of adjacent land split into three catchments.

The aim of the study was to assess the impact of cropping activities on the nitrogen and phosphorus load in stream waters, by comparing agricultural land with a non-agricultural (control) catchment. In two of the three catchments farming activities were undertaken as normal but for the third fertiliser or tillage operations were undertaken.

The results of the study found that for total N there was 1.7% (~2kg per ha) increase from agricultural land compared with the control and for Total P 2.3% (~1kg per ha) increase.

Hopmans *et al.* (1987) studied the effects of forest clearing on the water quality and nutrient exports in south-eastern Australia (around the town of Wangaratta in northern Victoria), the study was part of the major Cropper Creek Hydrological Project.

The study consisted of around 200 ha of land of three creeks; measurements were taken for common soil quality indicates as well as ions such as K, Mg and Ca which were determined via AAS (atomic absorption spectrometry). The main aims of the study were to evaluate the effects of converting natural forest to pine forests on nutrient export into streams. The relevant results from this study (K concentration) showed that there was a 200% increase in concentration of K (around 0.2 mg per litre) as a result of the removal of the native vegetation.

McDowell *et al.* (1988) studied nitrogen and phosphorus yields on the silty soils of the Mississippi Delta in the United States. The study was conducted over 6 years with a land area of 18.7 ha, this land was under cotton production. It measured runoff from storm events and the nutrient analysis was through with nitrate N, ammonium N, and total kjeldall N (TKN) being tested for N and for P, soluble P and sediment Total P (STP) were analysed for. Results were reported for both the suspended (sediment attached) and dissolved nutrient content over the 6 years of the study.

It was found that total N export was 42.3 kg per ha, with 18.2% of N transport in solution; the average total P was 21.2 kg per ha (with 7.5% of P transported in solution).

An Irish study conducted by Heaney *et al*. (2001) was primarily focussed on the impact of agriculture on the environment in particular a large lake and its associated ecosystems; the catchment for this lake (Lough Neath) is 4450 km^2.

This study was conducted over 16 years with composite samples taken every 14 days from the 6 major rivers flowing into the lake, the emphasis of the analysis was on phosphorus because the major concern for the researchers was blue-green algal blooms in the lake. However there was analysis of nitrate levels and sediment volumes entering the lake.

The results from the study showed a mean of 0.046 mg per L of phosphorus entering the lake along with 1.68 mg per L of Nitrate and 3.69 mg per L of sediment.

However when this results are compared with results for the other studies discussed this results seem trivial in terms of the volumes of inflow. However the results were determined to be significant by authors of the paper.

Cao *et al.* (2003) studies nutrient runoff and modelling in agricultural catchments in Southeast China. The study is based on a catchment of 1.74 km^2 and is located on soils of sandy textures. Land use in the catchment consists primarily of horticultural crops and forested lands. The study was conducted over 2 years However samples were only collected at two storm events as the aim of the study was to investigate nutrient loss during stormflows.

The results of the study show that on average the N concentration in the surface flows was 1.26 mg per L and the Dissolved Reactive Phosphorus (DRP) was 0.025 mg per L.

An Australian study into nutrient export from agricultural catchments conducted by McKergow *et al*. (2003) investigated the effect of riparian management on nutrient exports in particular relation to livestock enterprises. The study catchment was located in Western Australia (near Albany) an area of about 6 km^2.

Analysis was undertaken for various nutrients in both the soil and water but the most relevant to this review being P and K as well as sediment loads in the water. The results from this study for the land affect by stock are for total N 4.114 mg per L, for total P 0.595 mg L^{-1} and for suspended sediment 54.85 mg L^{-1}.

Another Australian study conducted by O'Reagain et al (2005), researched nutrient loss and water quality resulting from extensive grazing in northern Queenslanbd, this study was undertaken on a catchment of 10 km^2 on a river which empty into the great barrier reef lagoon, and as such to the emphasis on the report was ultimately on the effect of this nutrient runoff on the Great Barrier Reef.

The study found that average nutrient flows in the waterways had 23 mg L^{-1} of suspended sediment, 270 mg L^{-1} of Total N and 29 mg L^{-1} total P.

These results are very large compared to those of other studies discussed however no explanation was given in the paper for this.

For the most part the 8 papers discussed above are of generally high quality with sound methodology and well reported results. However some of the studies lack a control build in to the experimental design instead relying on safe levels of nutrients from organisations such as U.S. Environmental Protection Agency for comparison of their results. Overall it can be seen that from all the papers that nutrient export is occurring from agricultural lands albeit in low quantities for the most part however any nutrient transport into waterways has the potential to cause significant environmental consequences for that waterway.

C: Australian Catchment Reviews

There have been two significant Australian review papers which have combined past research to demonstrate the scale of nutrient loss into waterways in Australia; both papers dealt with south eastern Australia, the first by Young et al (1996), examined looks at the Murray-Darling Basin and second Ierodiaconou *et al.* (2004) examined south western Victoria.

Young et al's study is the most comprehensive of the two studies using both the limited Australian data and overseas data (particularly from North America), to draw conclusions about nutrient loss. These conclusion are that there is significant nutrient loss from agricultural land but the actual value is very variable and depend on the conditions which are found at the study site.

The second study conducted by Ierodiaconou covered a significantly smaller area (27 000 km^2) than the Young study and was focused on the nutrient volume in flows from 3 river catchments in south western Victoria.

The main aim of this study was the production of GIS model to illustrate the effect of changing land use on nutrient export. The paper also summarised nutrient losses from different land uses, these values were taken from various previous literature.

Ierodiaconou also presents data which indicates total nitrogen and phosphorus exports from various land uses which shows the two mist significant exporters of nutrients on a kg per ha per year basis as Market gardens (7kg/ha/year P and 26 kg/ha/year N) followed by irrigated dairy pasture (5.8 kg/ha/year P and 6.4 kg/ha/year N) this is a significant increase over native pasture (0.015 kg/ha/year P and 0.387 kg/ha/year N). This indicates that agricultural/horticultural enterprises are significant exporters of nutrients to the environment.

D: Fertilizer Application Impact Studies

A further area of general agricultural research which has yield data about nutrient loss is studies into the affects of fertilizer applications to agricultural lands on the nutrient runoff from these said lands.

Literature in this field seems to mainly focused on the dairy industry either directly though runoff from fertilisers applied to pastures and the like or indirectly with application of dairy manure to agriculturally productive lands, to date there has not been much research conducted on chemical fertiliser applications effects on runoff.

Greenhill et al (1983), investigated the nutrient content in runoff from pastures in Victoria, the study used three different sites for the experiment with detailed background information about each the sites, including the farming and chemical application history.

The experiment involved differing superphosphate rates applied to randomly selected plots with each of the three sites.

Chemical analysis of runoff from the sites included total phosphorus, Ca, S, K, nitrite N and nitrate N but no ammonium N as is common in other nutrient loss studies.

The results of the study indicated increasing the superphosphate application rate to pastures increased the concentration of Ca, S, K and Phosphorus in the runoff.

Gilley and Eghball (2002) investigated the residual effects of compost and chemical fertiliser on nutrient content over a 3 year period on silty clay loam soils in the united states, they found that composted manure and inorganic chemical fertilisers had similar effects on the runoff.

Grande et al (2005) investigated the effect of crop residue and application timings effect on phosphorus losses. The study involved manure applications in autumn and spring as well as no application, as well as the manure treatment there were three residue cover treatments (high, moderate and low). They discovered that crop residue cover had little effect on phosphorus enrichment of runoff water except with interaction with manure however manure application timing alone did have a significant effect on phosphorus content in runoff. The conclusions drawn from these results were applying manure with high residue cover loads can lower phosphorus loss.

A further study into the affects of manure application on runoff was described in Little et al (2005), however this study differed from the one described previously as the aim was to investigate the effect of different incorporation methods of manure on nutrient and sediment losses. The study found that unincorporated manure caused the highest nutrient concentrations in the runoff, whereas incorporation with a mouldboard plough reduced the risk of nutrient runoff.

McDowell, et al (2006) has also covered nutrient and sediment loss in runoff, this study covered both pastures and cropping land and used cattle manure as the fertiliser source. The only nutrients which are discussed in the paper are nitrate, ammonium and phosphate. The paper identified that P concentrations were greatest from the pasture plots than those of the crop plots and that ammonium losses followed similar patterns to that of P. As the reports main focus was on dairy production the conclusions were that careful management of lands prone to runoff were needed when manure was used as fertiliser particular in regards to grazing management of pastures.

From these papers it is possible conclude that incorporation and timing, as well as type of fertiliser have a significant impact on the movement of nutrients from agricultural soils.

2: Enterprise Specific Research

Nutrient loss research has not been limited to just catchment studies, there has also been studies done on individual crops or enterprises, in particular there has been a focus on intensive dairy production and the associated wastes and irrigated pastures.

Douglas, King and Zuzel, (1997) discussed nutrient containing surface runoff from a wheat-pea rotation, and whilst this is not a typical Australian rotation, the runoff data from the wheat part of the rotation provides an indicator for what could be expected to be lost from a wheat crop. However it is important to note that the conditions that the soil was subjected to was substantially different from those found in Australia (the soil used in the study underwent freezing and thawing cycles), though I don't expect that this cycle would have a significant impact on nutrient loss rates.

The experimenters analysed for both sediment and solution borne nitrogen and phosphorus from each part of the rotation (wheat, pea and fallow). Over the five years that the study was conducted it was found that in solution between 0.5 and 2.5 kg per ha (mean of 1.2 kg per ha) of N and between 0.1 and 0.3 kg per ha (mean 0.1 kg per ha) of P was lost in the solution, for the sediment transportation it was found that between 8.7 and 73.8 kg per ha of N (mean 28.6 kg per ha) and between 7.1 and 29.4 kg per ha of P (mean 11.8).

These results clearing show that as expected significant amounts of nutrients are lost in the sediment (particularly P) but there is also significant loss of N in the runoff solution.

Vietor, *et al* (2004) which looks at a number of issues, which affect nutrient loss from turf grass production, the factors include nutrient source (chemical fertilizer or manure), fertiliser application (surface or sod layer) and how the turf is established.

Results from the study indicated that when the fertilizer is applied as a top dressing to turf there is a 66% increase in the probability that the nutrient will be transported in the surface runoff.

3: Cotton Specific Research

In terms of cotton specific research there is not a lot of published material available however what there is available has been produced in the United States and focuses on upland (dryland) cotton production on lighter textured soils (such as loams and silty soils) this is a radically different system to how cotton is grown in Australia, with Australian cotton being mostly growing under irrigated conditions of heavier textured soils such as the red and black vertisols found in many of the main cotton growing river basins

Of the available literature there is two good papers which deal with nutrient loss from cotton directly. The two papers which look at cotton directly, Yoo, et al (1988) and Yoo, et al (1989) both look at the effects of different cultivation methods on nutrient loss. Both studies performed similar chemical analyses on both sediment and solute samples taken from the field runoff. Both papers tested for nitrogen (in the form of NH_4, NO_3 and TKN) P, K, Ca and Mg being tested for in solution and P, K, Ca and Mg in the sediment, dissolved and suspended solids where also measured.

The 1988 paper looks at three different systems, no-till, reduced till and conventional till, where as the 1989 paper compared only reduced tillage (with and without a cover crop of wheat) and Conventual tillage.

Both studies were contacted over one season in the northern Alabama in the United States, using natural rainfall as there water source.

Table 5.3 – Nutrient Yields

		Nutrient Yield in Runoff and Sediment (kg ha^{-1})									
		NH_4		*NO_3*		*TKN*		*P*		*K*	
Paper	**Year**	**Mean**	**Range**	**Mean**	**Range**	**Mean**	**Range**	**Mean**	**Range**	**Mean**	**Range**
Yoo, et al	1988	0.7	0.29-1	1.8	0.56-3.44	2.7	0.88-4.11	0.42	0.2-0.64	4.9	2.35-6.82
Yoo, et al	1989	0.6	0.23-0.94	1.8	0.51-3.39	2.2	0.68-3.34	0.79	0.18-1.42	-	-

It can be seen that both the 1988 and 1989 studies yielded similar levels of nutrient loss in runoff, these results are a combination of both the solute and sediment transported nutrients. For the 1989 paper there were no K results reported.

There have been no Australian studies on nutrient loss from cotton to date and thus there is no data to present on this, but results similar to those published by Yoo, et al could be expected from an Australian study?

4: Management

The management of nutrient loss is an important issues as the nutrient loss itself and is thus an important component to consider in a review on nutrient loss, in most cases the management of the nutrient loss is mandated by environmental protection bodies such as U.S Environmental Protection Agency (USEPA) or the NSW EPA.

In the literature there are several reports and papers which look a the management of nutrient in general in the environment as well as nitrogen and phosphorus specifically.

In the literature there have been a few significant publications on management strategies for controlling nutrient runoff from agricultural land.

Sharpley *et al.* (2001) in their discussion on phosphorus from land to water identify that the increase in agricultural nutrient export to waterways in past few decades has most likely been caused by the dissociation of different agricultural enterprises from one another, causing increased movement of nutrients in the landscape and their management solution for phosphorus export in runoff involves the optimisation fertiliser and animal inputs in terms of P as well as conservation practices targeted at the small patches of land that are more prone to runoff and erosion (refer to part 1, page 19).

Nord and Lanyon (2003), initially applied similar ideas to Sharpley *et al.* (2001) for the control of nutrient loss to a small 740 ha watershed. However in their study they also found that intensive animal enterprises make a significant portion of the nutrient inputs and outputs of their study area (80% of the total nutrient transfers on less than 50% of the total study area).

They concluded that a place based nutrient management system (that is one which attempts to balance all inputs and out puts in an given area) was ineffective due to not all enterprises in a region being interconnected and thus alternative approaches would have to be considered.

Oenema *et al.* (2005) isn't so much a study into a management practice but more of report on the effectiveness of lowering N and P surpluses in agriculture in the Netherlands, the findings of the paper showed that a decrease in 1 kg/ha in the N surplus in agriculture decreased the leaching of nitrate to ground water by 0.08 kg/ha and N movement in surface waters by around 0.12 kg/ha.

However this decrease in agricultural input served to highlight other sources of nutrient pollution in waterways, indicating a need for a whole approach to management embracing both agricultural, domestic and industrial sources of nutrients in waterways.

Withers *et al.* (2006), investigated the tramline farming and different methods of cultivation as a means of reducing erosion and sediment transport from soils prone to erosion and found that with cultivation and tramlines running with the slope there was 46% increasing in runoff and a 400% increase in P loss compared with that of reduced tillage plots with tramlines, it was also found that plots with tramlines running along the slope had no significant change in erosion, runoff or nutrient under either reduced tillage or conventional tillage operations.

The conclusions that could be drawn from the report are that tramlines are viable method of reducing nutrient loss and erosion from soils prone to these occurrences if used appropriately and in conjunction with reduced tillage.

VII: Conclusions

After reviewing the literature of research which has previously conducted into nutrient loss from agricultural land it can be extensively seen that nutrient loss is occurring from agricultural lands in quite significant quantities. As every paper published on the topic indicates that there is nutrient in the runoff. However there are some points which make comparison between the studies difficult, these include the different units used (mg L^{-1} and kg per ha) for reporting the nutrient loss, also the lack of reference area (non-agricultural and uncleared land would be ideal) to compare to the studies too hinders the ability to draw accurate conclusions about the true scale of the problem.

However what the studies do supply in most cases is a control which does give some indication to the difference between one treatment or another.

Further compounding this issue of comparison is that because the studies are done in range of geographically different areas, a study of nutrient runoff in one region will most probably not apply to another region.

On the other hand the published literature does provide an indication of nutrient loss from agriculture and it is well published what the effect of these lost nutrients are on the environment. Given this it is imperative that management of nutrient loss is undertaken to prevent or at least limit the impact on the environment and much of the published literature provides the first step in this management, that being monitoring of the problem.

It is also clear from the literature that there is a large amount of variables which affect nutrient runoff including the soil type, fertiliser type, crop, crop spacing, soil cultivation, fertiliser incorporation and climate, and thus a change in anyone of these factors can lead to change in the nutrient loss.

However for the cotton industry there has been very little monitoring of nutrient loss and therefore only limited management has been undertaken, this gap of knowledge about nutrient runoff about cotton is the base reason behind research currently being undertaken by the author into nutrient loss from Australian cotton operations.

From an environmental point of view nutrient loss from Australian cotton operations is not a significant problem because of the reuse of water on the properties and almost no discharge into waterways except in floods or 1 in 10 year storms.

Further management strategies which have stemmed from nutrient loss monitoring studies as described previously include total catchment management schemes which aim to limit nutrient movement from the catchment as a whole to site and farm specific management such as the application soil stability agents (such as poly-acycrilimides) or whole farm management strategies such wetlands and sediment settling ponds. Research into many of these areas is still on going but would not have been possible without the many of the basic studies discussed above.

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Nutrient loss in cotton production: A preliminary investigation of major nutrients being transported in the irrigation tail waters

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Abstract:

There is little published information about nutrient loss from cotton fields in surface waters and there is no data for Australian irrigated cotton. As such the study set out to fill this void of information and to determine if nutrient loss from cotton was environmentally and/or economically significant, with the emphasis being on nitrogen, potassium and phosphate. Other environmentally significant ions were also tested for such as calcium, chloride and sodium. The ions in question were analysed using a variety of analytical means which included chromatographic and spectrometric methods.

The results of the experiment indicated that for all ions there was no statistical significance for nutrient loss from cotton fields and that there was no trend for nutrient loss to increase or decrease with the length of runoff. However there was a trend for nutrient enrichment between water that is applied to field and water that is coming off.

The two most significant enrichments where phosphate and ammonium which were found at levels of 0.002 and 0.0003 mg L^{-1} respectively, however at these levels there is no environmental risk. All other ions were also determined to not be of any risk environmentally.

After the conclusion of the study it was determined that there was significantly more work to be conducted in the field before a reasonable understanding of nutrient loss from irrigated cotton in Australia can be gained

Keywords: Cotton, nutrients loss, nutrient transport, surface flows, irrigation

Table of Contents

Introduction:

Background Information:

The Australian cotton industry is a significant rural industry predominantly based in north-western New South Wales and south western Queensland in the Darling and Namoi river basins (Stanley, 2006). In the 2004-05 season the total area under cotton production was just over 300,000 ha with 81% of this irrigated (Trewin, 2005_a), the total value of the crop in this season was $994 million (Trewin, 2005_b). The Australian industry cotton is almost exclusively grown on the thick black vertosols which dominate the flood plains of the inland river systems.

It is well publicized that nutrient loss from agricultural lands does occur and does pose a significant environmental threat, however research into loss of nutrients from cotton has not been widely studied. Studies that have been conducted have been almost exclusively based in the United States where cotton is grown on much lighter textured loams, however these studies have confirmed that nutrient loss is occurring (Thornton *et al*, 1998). The study by (McDowell *et al.* 1989) reported significantly higher results for ammonium and phosphorus in sediment than in the surface runoff (4 and 14 times difference respectively). Most of the previous studies have been focused on nitrogen and phosphorus yields in runoff. Due to the greater environmental risk associated with these ions through eutrophication of waterways and associated algal blooms which can damage aquatic ecosystems and render water sources unusable (Chambers *et al.* 2006).

Sediment loss from agriculture is slated as one of most significant methods that positively charged ions are transported in waterways and significant values have been obtained for sediment movement ranging 200 to 800 kg ha^{-1} (Nyakatawa *et al.* 2006) from light textured American soils, for Australian vertisols (Silburn and Glanville 2002) reported much lower values.

Nitrate and ammonium are the two most significant forms of nitrogen commonly found in agriculture and are usually present due to the breakdown of other nitrogen forms (such as urea) by microbial activity. Ammonium is also formed by the action of rhizobium bacteria from atmospheric nitrogen by nitrogen fixation or from the conversion of ammonia to ammonium via chemical equilibrium ($pK_a = 9.2$ Stumm and Morgan, 1996). Nitrate is generally considered to be the greatest environmentally threatening form of nitrogen is formed by the activity of nitrifying bacteria from ammonium in aerobic systems (Kennedy, 1996). Nitrate is of environmental concern for a number reasons including it role in eutrophication, as well as it toxic affects on livestock and aquatic organisms (Kroupova *et al.* 2005) and (Robson 2003).

However other ions are also significant in runoff such as potassium although its generally not considered to be environmental risk. It has however it has been shown that an over abundance of potassium can also be potentially damaging and for cotton it has been observed that levels greater than 4 mM (which is equivalent to 0.159 g of potassium per L.) are damaging (Rajeev *et al.* 2001).

Australian studies into nutrient loss from cotton have been predominantly limited to deep drainage with no published literature on nutrient loss in surface runoff. In drainage waters its has been observed that on average 21 – 200 kg ha^1 of nitrate is being lost from irrigated cotton grown on vertosols (Hulugalle *et al.* 2005).

The major casual agents behind nutrient export from agricultural land appears to be surplus nutrients being supplied to crops, in other words over-fertilization and this has been found to be the case in several published studies including (Oenema *et al.* 2005), (Slaton *et al.* 2004) and (Ekholm *et al.* 2005).

Aims:

The experiment described was conducted with the purpose of providing preliminary analysis of the loss of major plant nutrients (nitrogen, phosphorus and potassium) from cotton fields in the irrigation tail-water as well as to provide basic quantification of the scale of nutrient loss.

A secondary aim was to evaluate water quality indicator ions in the tail water such as chloride, calcium and sodium.

Hypothesis:

The primary hypothesis for this experiment was that environmentally and economically significant concentrations of nutrients were being lost in the irrigation tail waters from cotton when compared to the head waters. The null hypothesis is that there is no significant nutrient loss from irrigated cotton.

A further hypothesis was that there would be higher nutrient loads at the start of the irrigation compared to end, indicating a “first flush” effect.

Site Description:

Sampling for the experiment took place on two cotton properties located near Narrabri in the Namoi river valley in north-western New South Wales. The first property “Mollee”, was located approximately 20 km west of Narrabri predominantly based on black vertosols. The second property “Willawah” was located 5km south east of Wee Waa, where the predominant soil type being red dermosols.

The three fields selected on “Mollee” were field 20, 21 and 22. All of which had similar fertilizer regimes for the 2005-06 season which consisted of the application of 250 kg of Urea (115 units of N) per Ha in September, 7 L Ha^{-1} of starter fertilizer (5% N,20% P, 8% K and 5% Zn) in November and 10 L Ha^{-1} top dressed fertilizer (5% N, 15% P and 35% K) in December.

Field 20 was a relatively small field with a total area of 10 ha; the field was sown with the variety Sicala 60 BGII/RR planted on October 10. Field 20 received its water from three sources, two bore pumps and river water with mixture usually round 60% bore, 40% river water. Figure 1 shows the tail drain of field 20 looking north

Figure 1 – Tail Drain of Mollee Field 20

Field 21 had an area of 35.2 ha and was the largest field on “Mollee” that was sampled.

The field had three main water sources, bore water, river water and tail water from field 20. The exact mixture depended on where in the head channel sampling occurred and whether field 20 and 21 were both being irrigated at the same time. The variety cotton sown on this field was Sicala 71 BG II/RR. The figure 2 below shows the tail channel of field 21 with the tail drain located in the mid-ground of the image.

Figure 2 – Tail Drain of "Mollee" Field 21

Field 22 of "Mollee" had an area of 10 ha. This field was located at the end of the irrigation system on "Mollee" with all of the supply pumps located above it. Therefore the water flowing directly into the field was a mixture of tail, bore and river water. From time to time this field was irrigated with tail water depending on the volume of water in the tail water return system.

On "Willawah" the three fields selected were fields 1, 2 and 3 which had a variety of water sources but the same agronomic practices. All fields were sown with the variety 289 BR.

Chemical fertiliser inputs were the same for all fields, with 150 kg of N per ha as ammonia (Big N) along with 8.25 kg ha^{-1} of N in the starter fertilizer prior to planting, there was also a top dressing of 69 kg ha^{-1} of N as urea applied in December. Phosphorus was applied at a rate of 14.4 kg per Ha in the starter fertilizer prior to planting. Potassium was also applied prior to planting as starter fertilizer with 30.75 kg per hectare applied.

“Willawah” field 1 only received water directly from a bore pump and as such it was free from suspended sediment or other mater matter.

The field had an area of 16.03 ha and was relatively short at approximately 200 metres in length. The depth of water at tail drain on this field was relatively shallow which made it difficult not to sample the top part of the flow, this was over come by inserting the sampling bottle into the drain itself.

"Willawah" Field 2 had an area of 28.77 ha. Its water source coming from the main storage dam on the property which in turn had been drawn from the Namoi River. One other point of interest with this field was that during sampling of the 2nd irrigation the field was sprayed with the growth retardant "pix". Sampling occurred from just behind the tail drain which can be seen Figure 3. The drain itself was actually raised off the soil surface by about 50cm.

Figure 3 – Tail drain for field 2 on "Willawah"

Field 3 was the largest field sampled from on “Willawah” with an area of 68.53 hectares. Field 3 was generally irrigated in two stages, with sampling for the sample taken from runoff from the eastern end of the field. The water source for this field was identical to field 1 as they were located close together and shared the same bore as their water source. Figure 4 shows the tail drain for field 3.

Figure 4 – Tail drain of “Willawah” field 3

Methods:

Sampling and Field Methods:

All sampling for the experiment was conducted in the middle of the cotton growing season as the canopy was filling, between January and February, 2006.

At each of the three irrigations on the six fields water samples were collected from both the head ditch and from the tail drain using a grab sampling pole (as shown in figure 5) and 600 mL poly-urethane sample bottles. Sampling was conducted from near the centre of the channels/drains and by inversion of the bottle beneath surface to avoid sampling the surface water. All samples were collected in the early hours of the morning approximately 8 hours after the irrigation for each field was started, as this is the average length that it takes irrigation water to reach the tail channel .

Figure 5 – Grab sampling technique

For the first irrigation on each field individual 600 mL samples were collected, with triplicate samples collected from the head ditch at the time of arrival and departure from the field (approximately 0 and 220 mins respectively). Tail samples were collected in triplicate at 40 min intervals. The individual samples were collected at 40 min intervals so that a time series for nutrient loss could be established.

For each field at irrigation 1 a total of 24 samples were collected with 6 samples being head water and 18 being water tail.

For the two subsequent irrigations (2 and 3) composite grab samples were collected in triplicate from both the head ditch and tail drain. For the head ditch this involved the collection of about 300 mL of water per sample at arrival and departure from the field (0 and 220 minutes) and combining them. For the tail samples 100 mL was collected every 40 minutes and combined to make 600 mL. In total there were six samples for each field from irrigation 2 and 3, three replicated head ditch samples and three being tail drain replicates.

Temperature, pH and EC were measured at the time of sampling for each irrigation event using a horiba D-54 pH/conductivity meter.

After collection the samples were stored for several days in a 4°C cool room after which 100 mL of sample was filtered using 2 micron glass fibre filter paper and a suction flask to provide a measure of total suspended solids as well as a filtered sub-sample for instrumental analysis. All filtered samples were stored in 50 mL poly-urethane screw-top centrifuge vials. Immediately following this filtration step both the filtered and unfiltered were placed in a -18°C freezer for storage and later transport back to Sydney for analysis.

Prior to analysis the 50 mL filtered sub-samples were removed from the freezer and allowed to completely thaw at 4°C before analysis of the samples was undertaken.

***NB** – Irrigation 1, 2 and 3 do not refer to the 1st, 2nd, 3rd irrigations in the season but rather the three successive irrigation events that were sampled.*

Irrigation 3 data only includes 3 fields because of prevailing weather conditions and time constraints prevented sampling from occurring for all fields at irrigation 3..

Analytical Methods:

Chloride, phosphate and ammonium were analysed via flow injection analysis (FIA) using a FOSS FIAstar 5000 analyser with 5027 autosampler used in conjunction with SoFIA computer software.

Preparation of the samples involved taking a small 5mL sub-sample and transferring it to a 13 mm test tube.

All standards, sub-samples and dilutions were made in acid washed (0.01M HCL) glass and plastic-ware rinsed with nano-pure water with a conductivity less than 16.7 µs cm^{-1}.

For analysis of chloride the chloride cassette was inserted into the instrument (part # FOSS 10012345), with the reference filter set at 720 nm and the measurement filter set at 470 nm. Reagents were thiocyanate solution (0.00253M) and iron nitrate solution (0.18187M). The stock standard was made up using NaCl dried overnight in a 105*C oven to 2000 mg $Cl^- L^{-1}$. The stock standard was diluted 200 mg $Cl^- L^{-1}$ which was subsequently used to the standards for analysis which were 0, 30, 60, 90, 120 and 150 mg $Cl^- L^{-1}$ which was used to plot a standard to which a line was fitted and a r^2 value of 0.998 obtained. Further detail on the methods used can be viewed in appendix D. The limit of detection (LOD) of this instrument is 0.06 mg L^{-1}.

For the analysis of ammonium, the ammonium cassette was inserted (Part # 10059730) and filters set at 590 nm for the measurement filter and 720 nm for the reference. Solutions of 0.5 M NaOH and an indicator solution (Part # 5000 0295) were the reagents used. A stock standard of 1000 mg L^{-1} was made using ammonium chloride dried at 105°C for 2 hrs, which was then diluted to 10 mg L^{-1} to make standards of the following concentrations 0, 250, 500, 750 and 1000 µg NH_4^+ L^{-1} the absorbance of which were plotted and a line fitted with a resulting r^2 of 0.997. Further details can be viewed can be viewed in appendix D. The LOD of this instrument is 1 µg L^{-1}.

For analysis of phosphate via FIA, appropriate analytical cassette was inserted into the instrument (part # 10010091) and the filters set at 720 nm and 1000 nm for the measuring and reference wavelengths respectively. Following this reagents were made up of ammonium molybdate (5g of $(NH_4)_6Mo_7O_{24}$ x $4H_2O$ and 17.5 mL of conc. HCL in a 500 mL volumetric flask) and stannous chloride (1g hydrazinium sulphate and 0.1g stannous chloride with 14 mL of conc. sulphuric acid in a 500 mL volumetric flask).

For standards a 100 mg PO_4^{3-} L^{-1} stock standard was created using 0.4393 g of potassium dihydrogen phosphate, this was used to create an interim standard of 1 mg PO_4^{3-} L^{-1}. The interim standard was then used to create a standard range of 0, 50, 100, 200, 400 µg PO_4^{3-} L^{-1} which was analysed and used to produce a standard curve with a fitted r^2 of 0.9989. The LOD for this instrument is 1 µg L^{-1}.

Figure 6 – Flow Injection Analyser

Analysis of potassium, sodium and calcium was conducted using flame atomic absorbance spectrometry (AAS) using a Varian SpectroAAS FS instrument.

Initially undiluted samples were run to determine dilution levels necessary from this analysis. For potassium and calcium analysis a one in twenty-five dilution was necessary and for sodium a 1 in 100 dilution was carried out. All dilutions were conducted using a Hamilton auto-dilutor.

Potassium standards prepared at 0.5, 1, 1.5 and 2 μg K^+ ml^{-1}. Calcium standards were 1, 2, 3, 4 and 5 μg mL^{-1} and sodium standards were 0.5, 1 and 1.5 μg mL^{-1}. The standard curves for all elements can be seen in appendix C. All analyses using AAS were undertaken using a acetylene/air mixture.

For each analyte (K, Ca and Na) the appropriate lamp was inserted and instrument adjusted to obtain to achieve the best possible absorbance for the ion in question.

The LOD for each of the methods was 0.003 μg L^{-1} at 766.5 nm for potassium, 0.003 μg L^{-1} at 589.0 nm for sodium and 0.0005 μg L^{-1} for calcium.

Analysis for nitrate in the samples was conducted using high performance liquid chromatography (shimadzu HPLC) using a Hamilton PrP x100 column. Prior to analysis samples were prepared by placing 5-10 mL of sample solution into a scintillation vial and adding a small amount dowex 50W-X8 and shaking vigorous and regularly over 15 minutes, after which time samples were drawn up into a sterile syringe and pushed through sterile 0.2μm cellulose acetate filters into acid-washed HPLC sample vials for analysis.

Figure 7 – High Performance Liquid Chromatograph

Results:

NB – All graphs presented indicate mean values from triplicate samples with error bars indicating standard deviation.

Electrical conductivity (EC) and pH

The pH of the runoff was measured at 80 min intervals over each sampling event for both irrigations 1 and 2. Figure 5.1 shows the average pH value for each property for both irrigations 1 and 2 the error bars represent one standard deviation from the mean. It can be seen that pH remains fairly constant during an irrigation event. There is a not large amount of variation within the observed pHs for each property and irrigation (0.6 pH units. However for both properties the pH of the water leaving the field was relatively alkaline with pH values ranging between 8.2 and 8.8.

The pHs of the two properties at the two irrigations were not statistically significantly different (at 95% confidence) which is indicated on Figure 8 by the errors bars which represent one standard deviation.

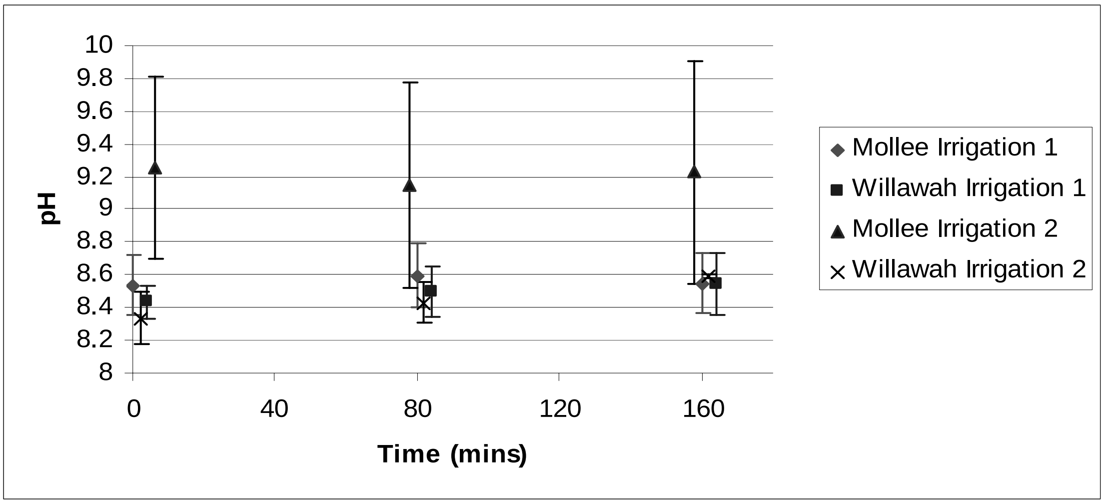

Figure 8 – pH changes over time for irrigations 1 and 2

The average electrical conductivities for the two properties at irrigation events one and two are show below in Figure 9. It can be seen that there was a trend of the EC remaining steady during sampling. However, similarly to pH, that there is a large standard deviation in the samples as indicated by the error bars. Between irrigation 1 and irrigation 2 there is an increase in the EC for both properties of around 10 µs cm^{-1}. However this increase is not statistically significant.

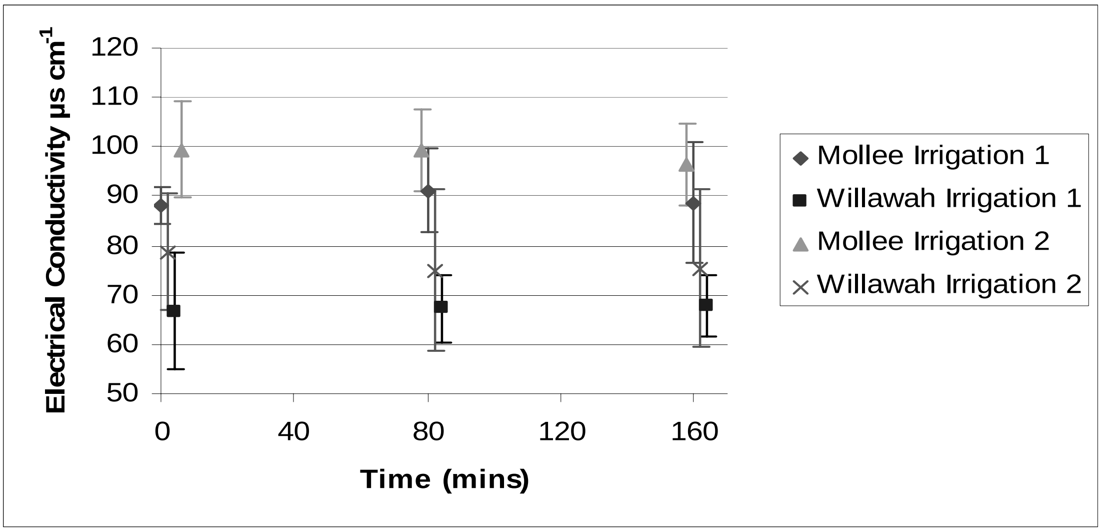

Figure 9 – Changes in electrical conductivity (EC) over time from irrigations 1 and 2 on both properties

Total Suspended Solids

Total suspended solids were measured for all of the samples with a maximum solid component of 700 mg L^{-1}, the mean load was 300 .mg L^{-1} and the minimum values were approximately 1-10 mg L^{-1}.

Potassium

Potassium concentrations in the tail water appeared to be fairly constant irrespective of irrigation for all the fields on both properties

For the first irrigation sampled on "Mollee" there was no obvious upwards or downwards trend in the potassium concentration over time on any of the three fields with concentrations staying fairly steady and not varying by more 0.5 µg mL^{-1} on any of the three fields. Statistically there was no significant difference over time at 95% confidence interval.

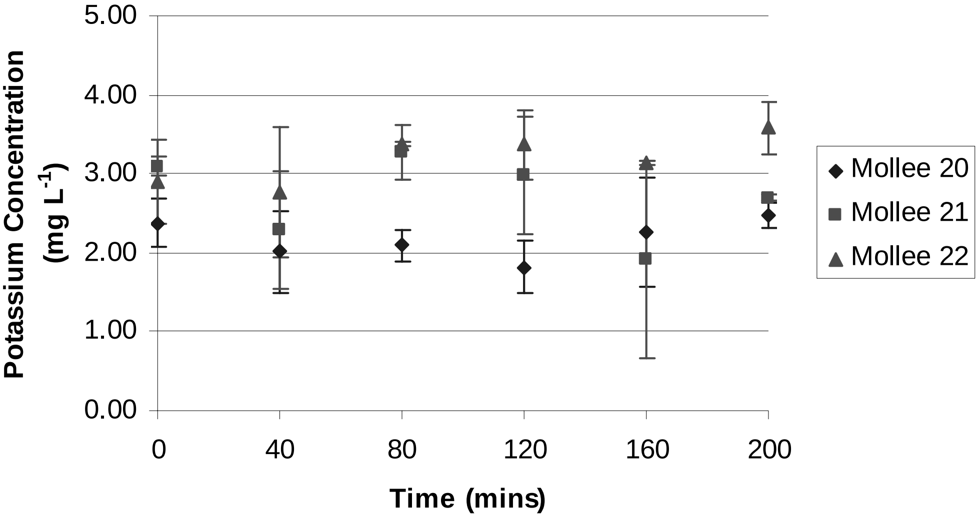

Figure 10 – Potassium concentrations from irrigation 1 on "Mollee"

Analysis of the samples from the first irrigation sampled on "Willawah" indicated that there is potassium in the tail water but statistical analysis indicated that there is no significant difference in over time in regards to potassium concentration at a 95% confidence interval. Figure 11 shows graphically the results from the 3 field sampled on "Willawah", it appears for Fields 1 and 2 the concentration remains relatively stable. However for Willawah 3 there appears to be a downward trend but statistical analysis shows that this is not significant based on the standard deviations (shown by the error bars).

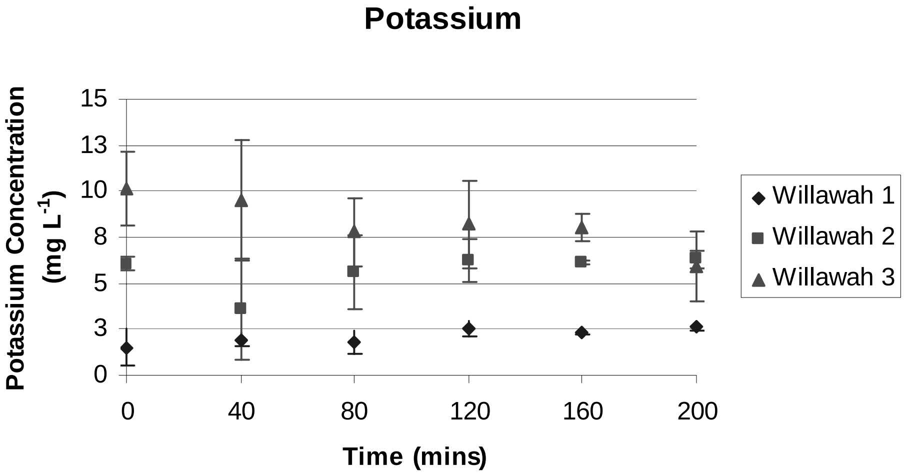

Figure 11 – Potassium concentrations from irrigation 1 on "Willawah"

Analysis of the irrigation 2 samples for potassium appeared to indicate that there was an increase in the K^+ concentration as water flowed down the irrigation furrows. However when statistical analysis was performed it became apparent that there was no significant statistical difference between the two as indicated by the overlapping error bars in Figure 12 (which show standard deviation).

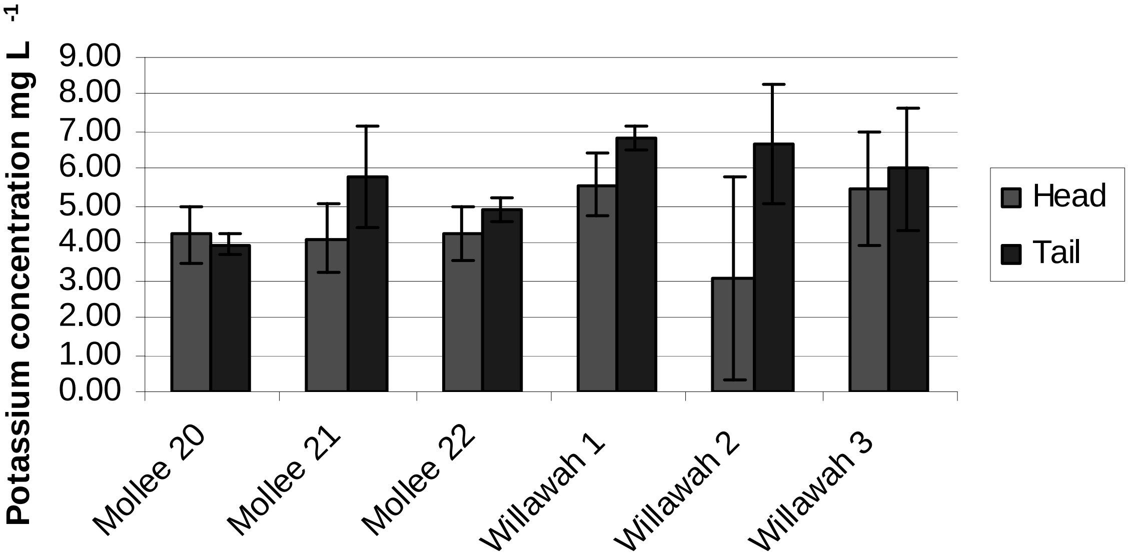

Figure 12 - average potassium concentration in head and tail waters at irrigation 2 including the standard deviation

Analysis of potassium for irrigation 3 as presented in figure 5.6 initially appeared to indicate that there was enrichment of potassium in the tail water however when statistical analysis was performed it could be seen that results were not significant for an increase in potassium with a 95% confidence. This is shown in Figure 13 by the error bars which represent the standard deviation of the averages of the triplicate samples.

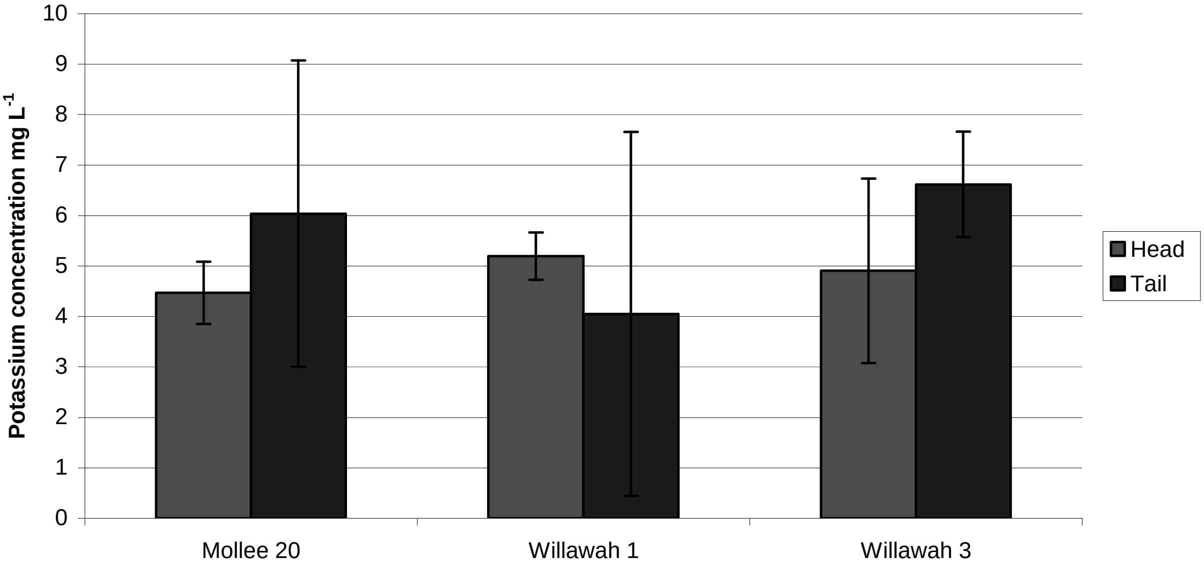

Figure 13 – Mean potassium values from irrigation 3 showing standard deviation

Phosphate

When phosphate was analysed for in the samples from irrigation 1 on "Mollee" it showed that the concentration was relatively stable across the sampling time and this can be seen in Figure 5.7. Also from the figure it can be seen that there was a large standard deviation within the data sets particularly from field 21.

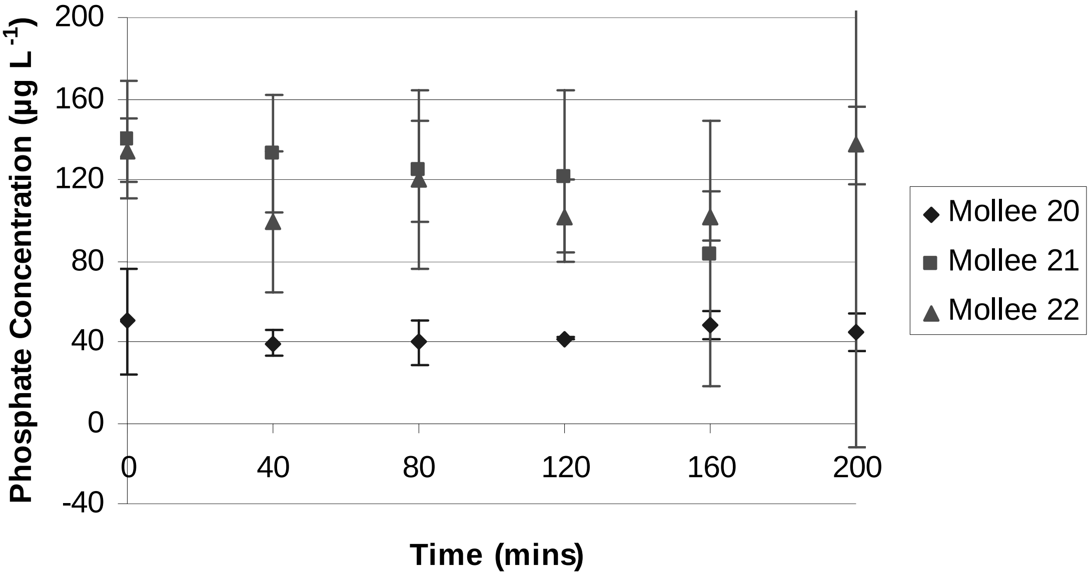

Figure 14 – Changes in phosphate concentration over time from "Mollee" irrigation 1

The phosphate data from analysis of the samples from "Willawah" irrigation 1 (presented in figure 15) indicate that the is stable concentrations of nutrient phosphate loss over time with no significant difference over time for fields 1 and 2 however field 3 seems to indicate there was a decrease in phosphate concentration over time.

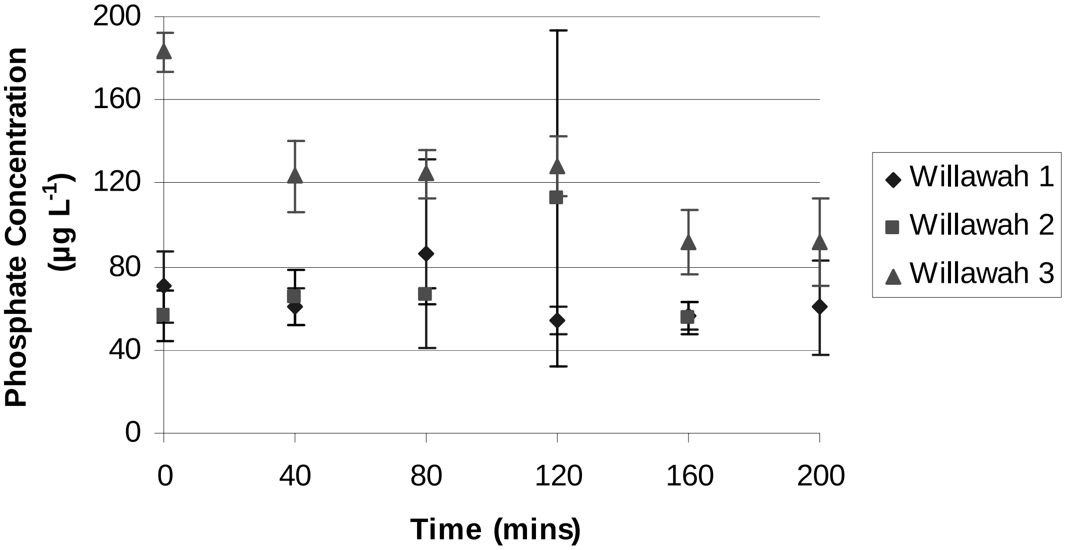

Figure 15 – Change in phosphate concentration over time on "Willawah" at irrigation 1

Analysis of irrigation 2 for phosphate showed that there was a clear trend of phosphate enrichment across all six fields, which is clearly evident in Figure 16. However analysis of the standard deviation and the production of a 95% confidence interval indicated that there was no significant difference in the results.

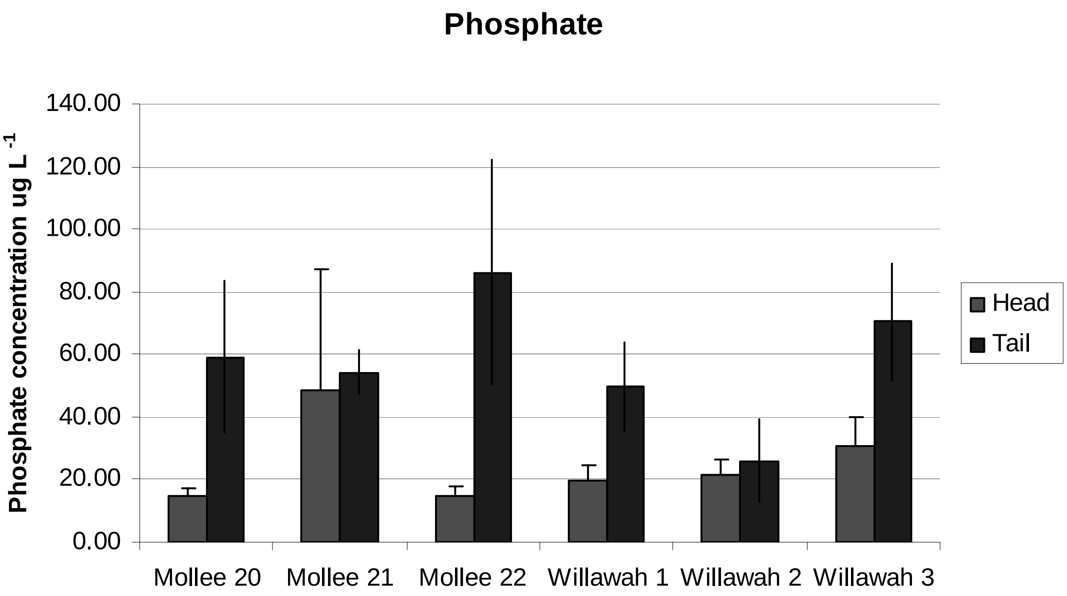

Figure 16 – Phosphate concentration at irrigation 2

Phosphate concentration in the samples collected at irrigation 3 indicate that there is a clear trend for phosphate enrichment in the tail water however there is too much variation for the data to be statistically significant at a 95% confidence interval

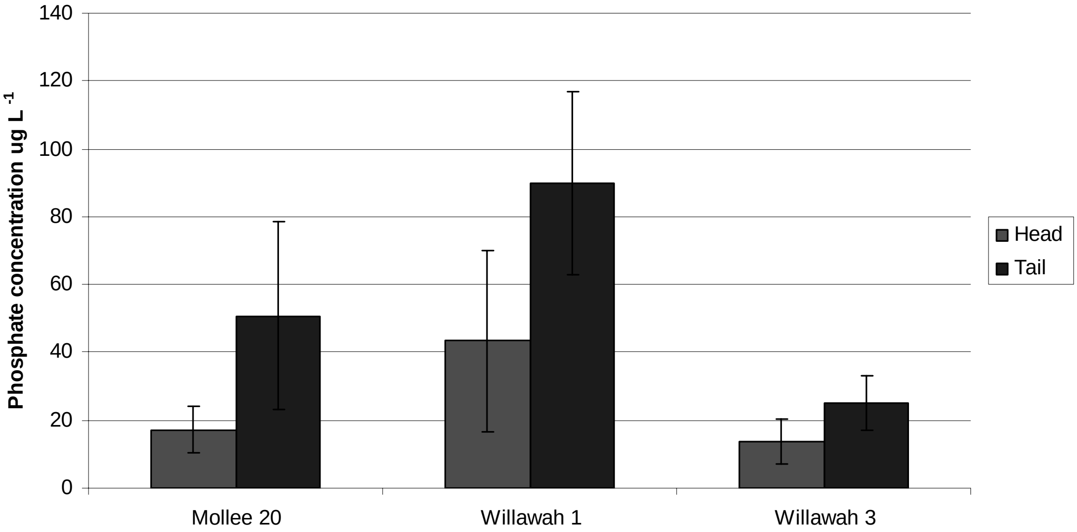

Figure 17 – Phosphate concentrations at irrigation 3

Nitrate

Preliminary analysis of nitrate on 16 randomly selected samples yield nitrate results of between 1.8 mg L^{-1} and 7.74 mg L^{-1} for six of the samples the remaining 10 samples had nitrate concentrations below the limit of detection (LOD) of HPLC which was determined to be 1.8 mg L^{-1}.

When freshly thawed samples were thawed and analysed straight away all samples tested were below the LOD of the instrument.

Ammonium

Ammonium analysis was conducted initially on the filtered sub-samples using the FIA; however these initial results proved by unreliable as repeat analysis of the same sample yielded vastly different results. As a result of this the primary samples were thawed and used for the analysis which yielded more stable results.

This second set analysis when carried out on the samples collected on "Mollee" for irrigation one yielded results which more precise and stable.

For “Mollee” at irrigation it was seen that there was no statistical difference between ammonium concentrations over time on any of the fields. There is also apparent that ammonium concentration stays fairly stable over time.

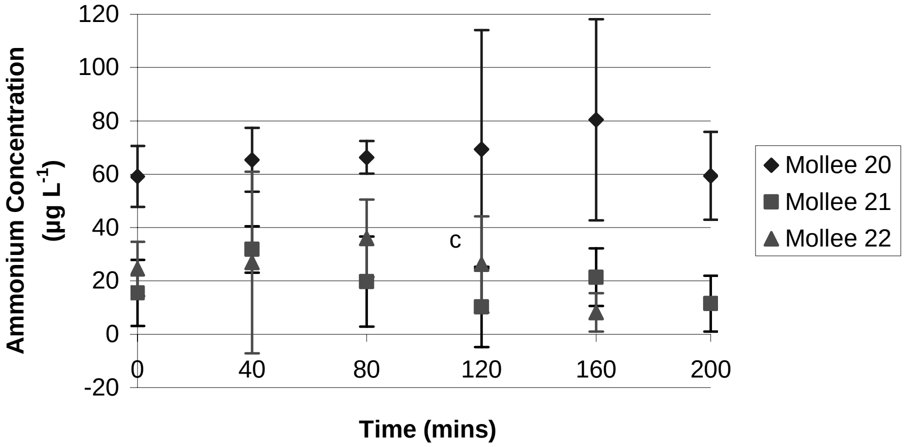

Figure 18 – Ammonium concentration in tail water leaving fields on “Mollee” during irrigation 1.

Analysis for ammonium from irrigation 1 on “Willawah” there was no trend for field 1 however field 2 showed an increase over time whilst field 3 showed an initial decrease in ammonium concentration followed by rapid increase. Statistical analysis however showed that field 2 and 3s change was not significant.

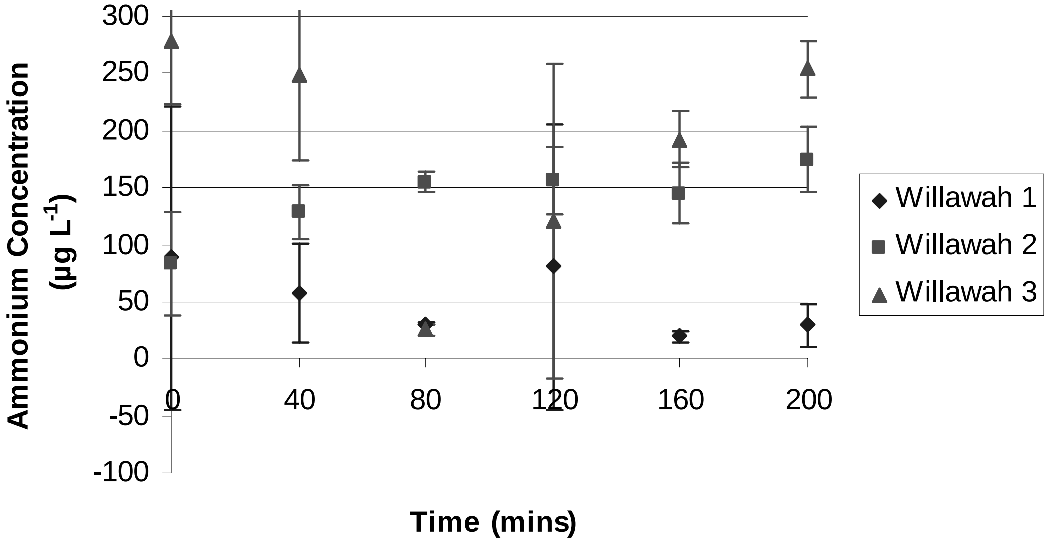

Figure 19 – Ammonium concentration from "Willawah" at irrigation 1

Analysis of the samples from irrigation 2 for ammonium showed that for most fields there was no significant enrichment of the water from head to tail channel, the exception for this was "Mollee" 21 which did show statistical difference indicated that ammonium was being lost from the field, this can be seen in figure 5.13 from the error bars which represent one standard deviation from the mean.

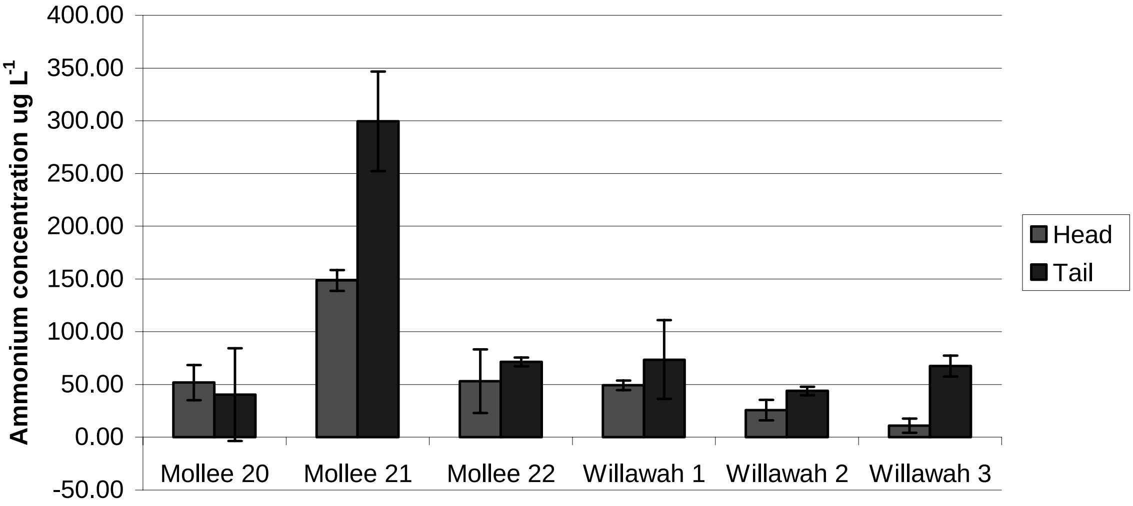

Figure 20 – Ammonium concentration at irrigation 3

Analysis of the irrigation 3 samples indicated that there was significant difference (at a 95% C.I.) in ammonium concentration in the tail water and in the head water; this can be seen in figure 21

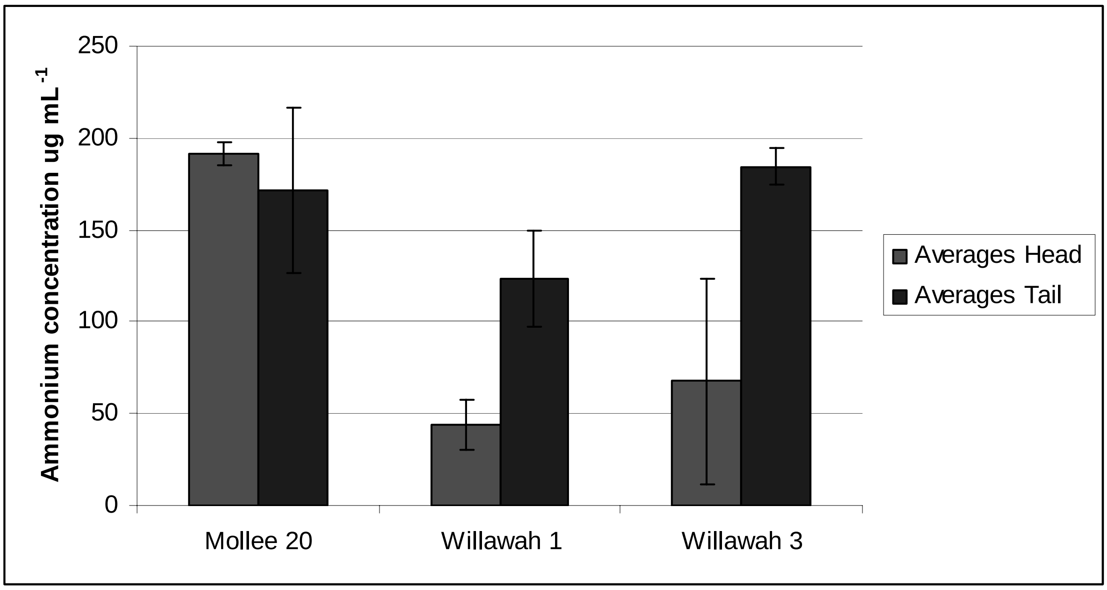

Figure 21 – Ammonium concentration at irrigation 3

Sodium

For sodium there was a significant amount of variation with in the results which limited the significance of the results due to the large standard deviation, however for field 20 there did seem to be a general increasing trend in the results. For field 21 there was also an initial increase up to 120 min where the concentration appeared to plateau. Field 22 remained fairly constant through-out the sampling time.

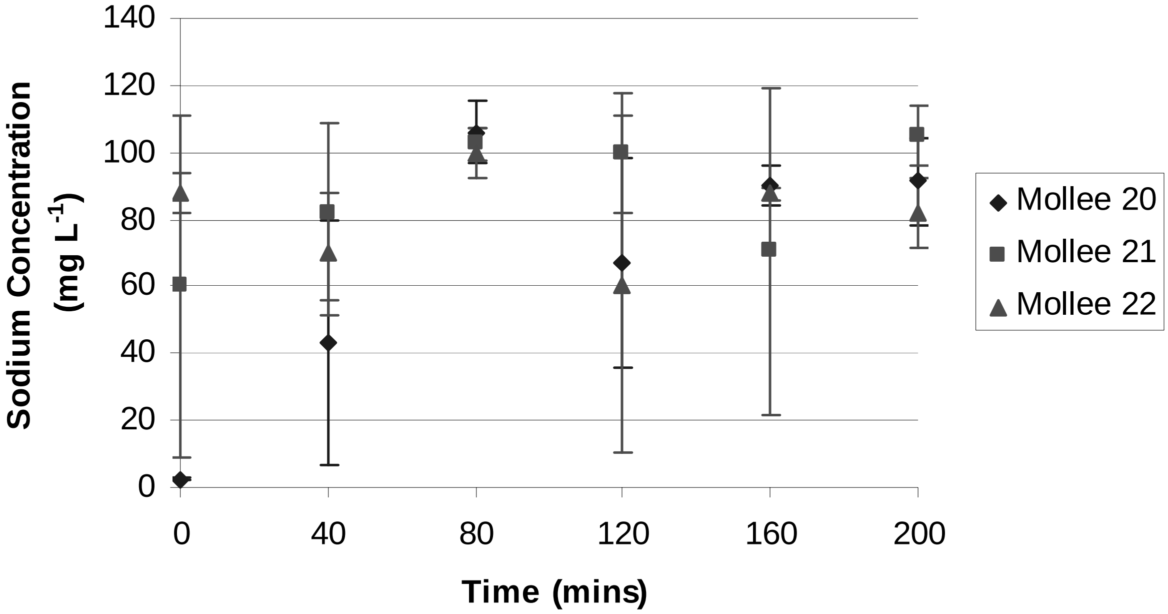

Figure 22 – Sodium concentration over time from irrigation 1 on "Mollee"

The sodium concentration on "Willawah" at irrigation 1 did not exhibit any trend besides a constant concentration across the sampling time. With a large amount of variation between the triplicate samples indicated by the large standard deviation, which when analysed statistically using a 95% confidence interval yielded that there was no significant change in concentration over time.

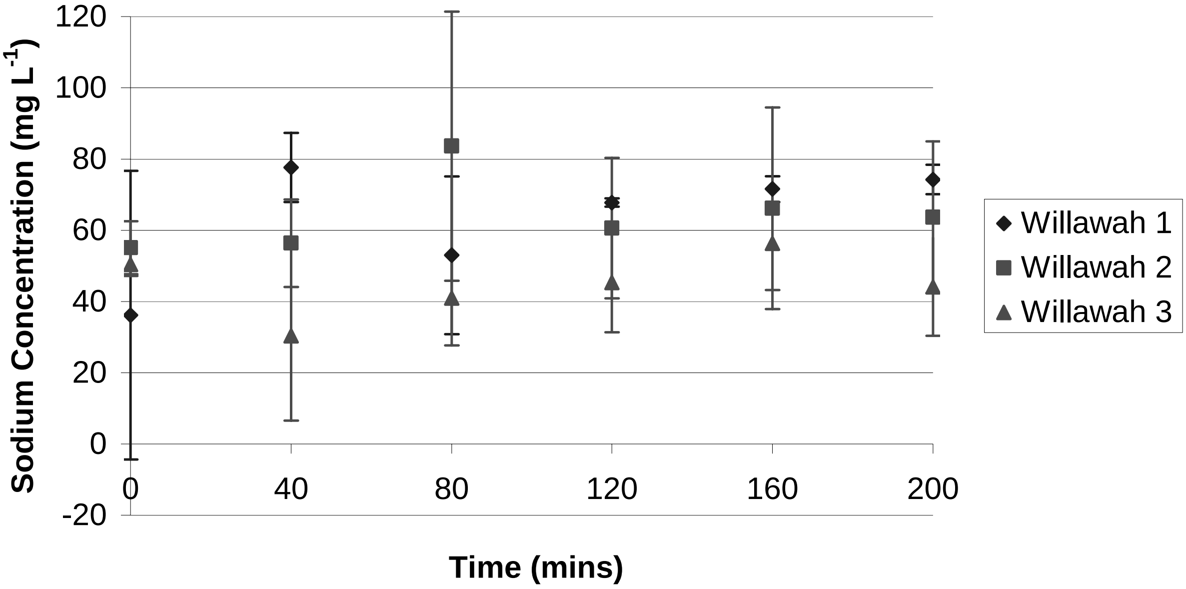

Figure 23 –Sodium concentration at irrigation 1 from "Willawah"

Sodium analysis of the samples from irrigation 2 seemed to indicate that there is a trend of sodium enrichment between the head and tail channels for five out of the six fields sampled. However statistical analysis indicated that there was no significant difference in the samples (p = 0.05).

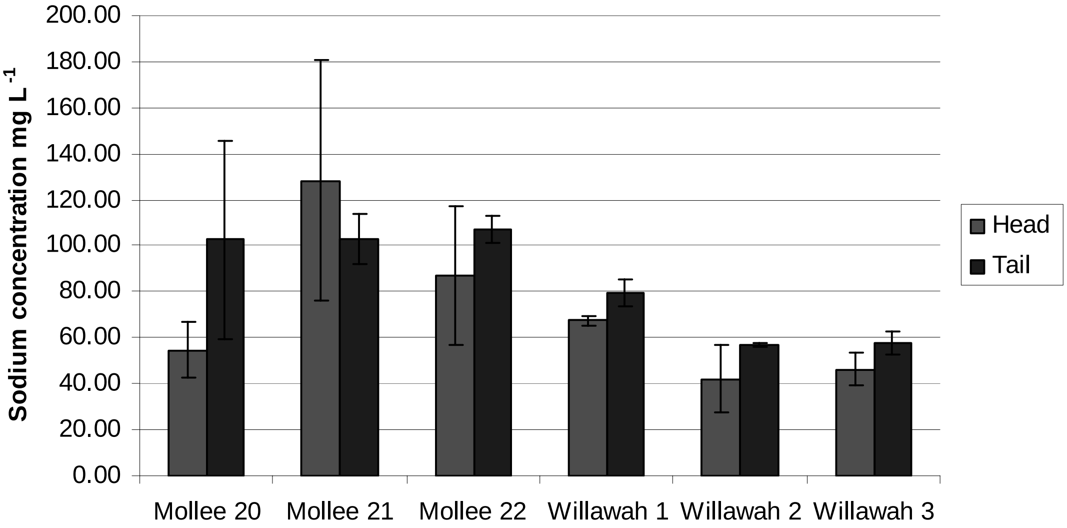

Figure 24 – Sodium concentrations from irrigation 2

At irrigation 3 there was no clear trend for enrichment of sodium except on field 20 of “Mollee”, both “Willawah” fields sampled actually showed a decrease in sodium after the water had flowed down the field. Statistical analysis showed that there was no difference using a 95% confidence interval.

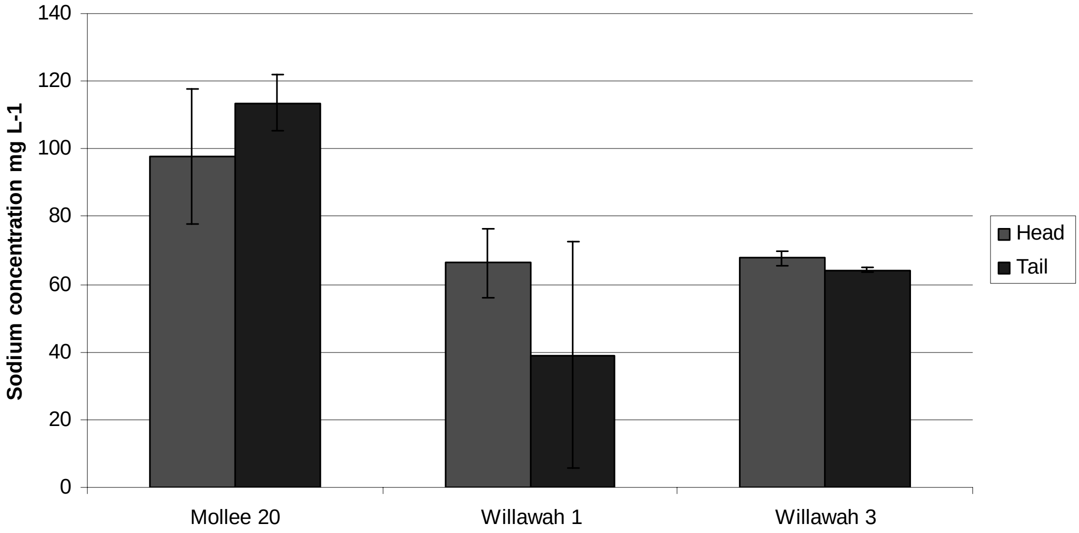

Figure 25 – Sodium concentrations at irrigation 3

Calcium

Calcium concentration over time on Mollee showed a trend of remaining fairly stable with no significant increases or decreases. However there was also a significant amount of variation in the sample as indicated by the standard deviation shown in Figure 26, this also shows that there is no statistical difference in calcium concentration over time.

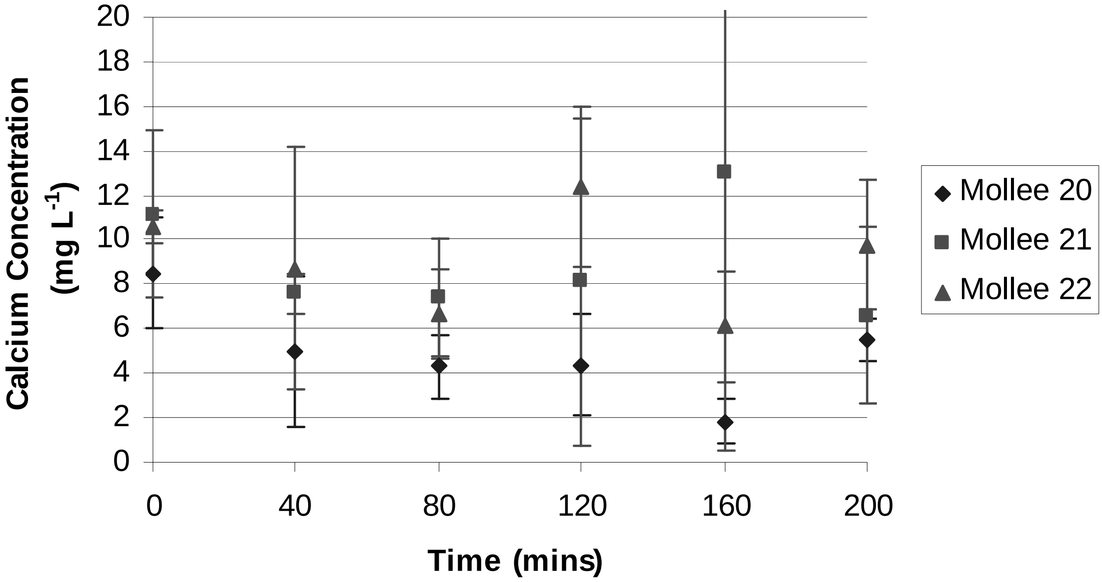

Figure 26 – Calcium concentration at irrigation 1 from "Mollee"

Calcium concentration on "Willawah" at irrigation 1 remained relatively steady over time with no significant trends of increasing or decreasing concentrations. Statistical analysis of the results showed that there was significant difference in calcium concentration over time.

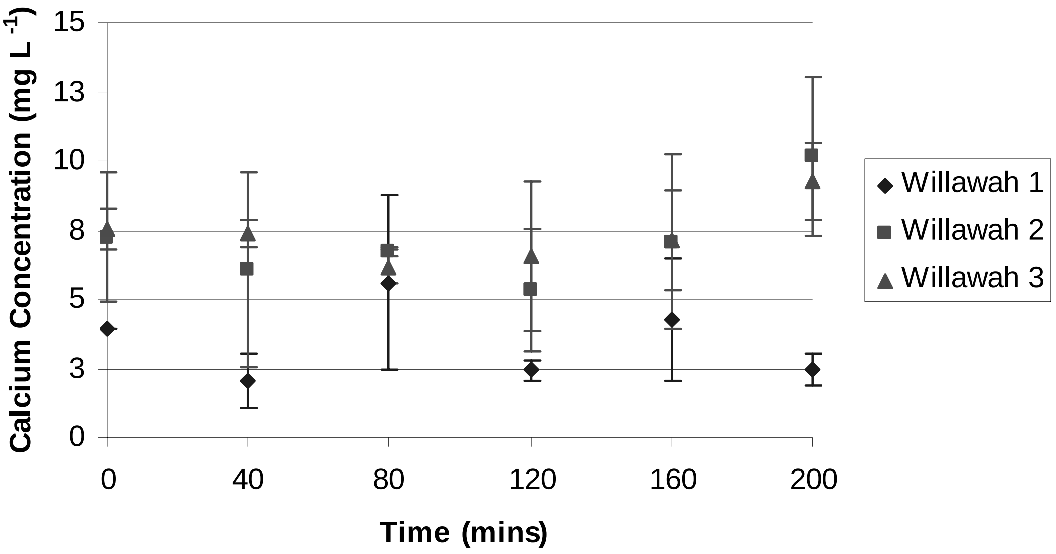

Figure 27 – Calcium concentration from "Willawah" at irrigation 1

Results for calcium from irrigation 2 indicated that on 3 "Willawah" fields and field 22 on "Mollee" there was a trend for enrichment of calcium in the tail waters however it was the reverse for fields 20 and 21 on "Mollee". Statistically however there was no significance in the results using a 95% confidence interval.

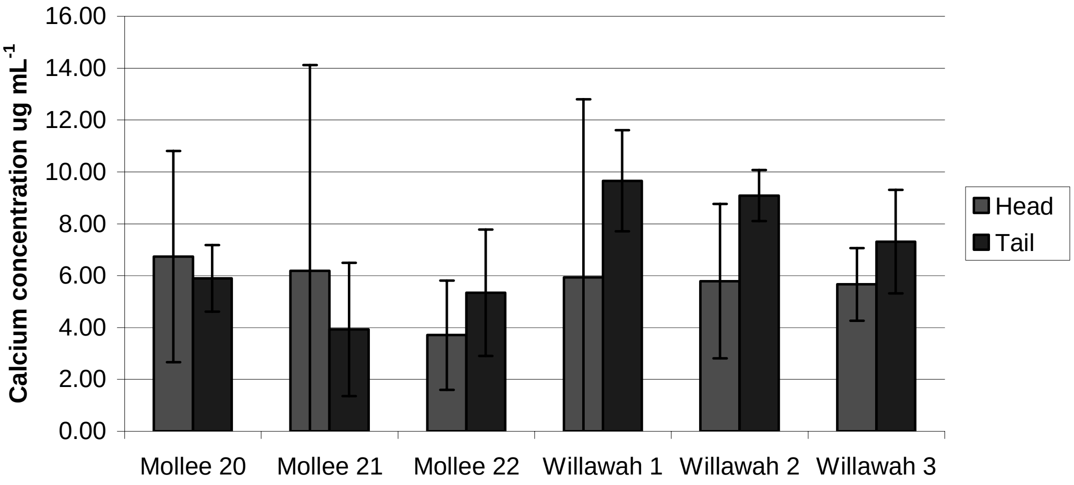

Figure 28 –Calcium concentration at irrigation 2

At irrigation 3 calcium concentration exhibited a trend for enrichment on "Mollee" 20 and "Willawah" 3 however it was the reverse for "Willawah" 1. Statistically however their was no significant difference between the head and tail concentrations when a 95% confidence interval was used.

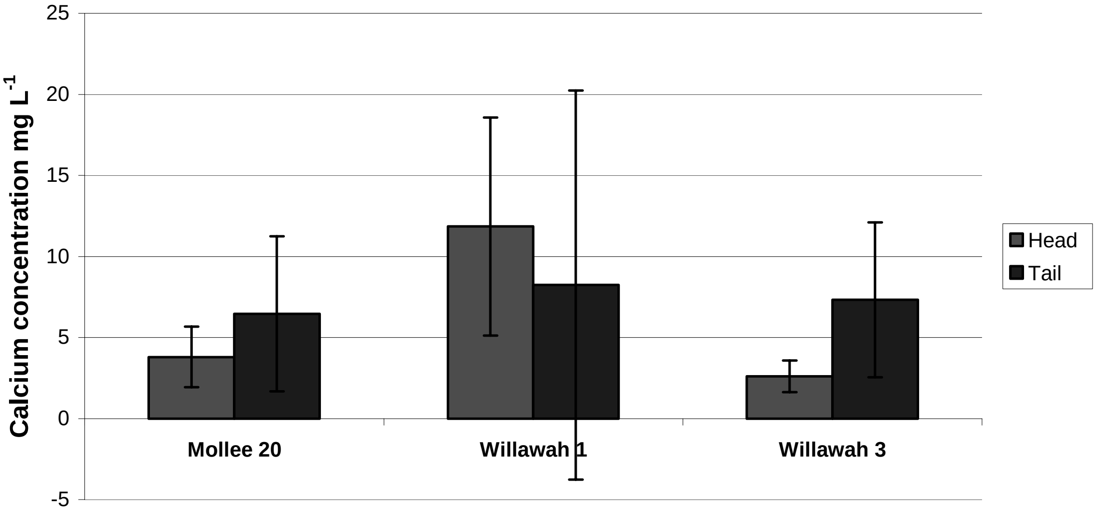

Figure 29 – Calcium concentration at irrigation 3

Chloride

The samples obtained from "Mollee" at irrigation 1 showed a clear steady trend of chloride loss with no significant increase or decrease with the exception of "Mollee" 22 which has a series of decreases followed by moderate increases at 40 and 120 minute mark. However once the statistical significance it taken into account this series of decreases and increases can not be considered significant at 95%.

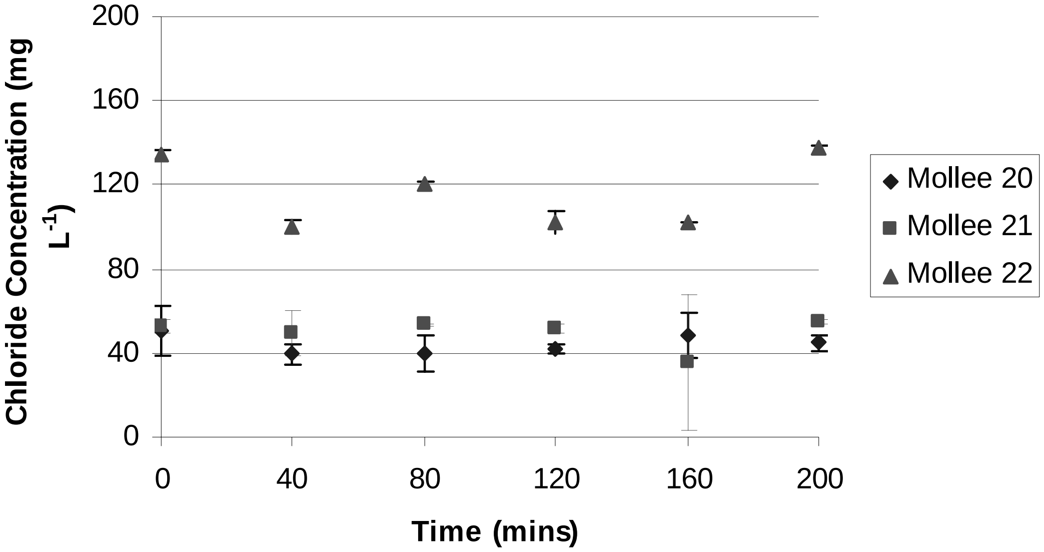

Figure 30 – Chloride concentration over time at irrigation 1 on "Mollee"

Analyse for chloride of the samples collected from "Willawah" at irrigation 1 indicated that chloride loss is independent of time with a steady state of loss over the 200 mins of sampling.

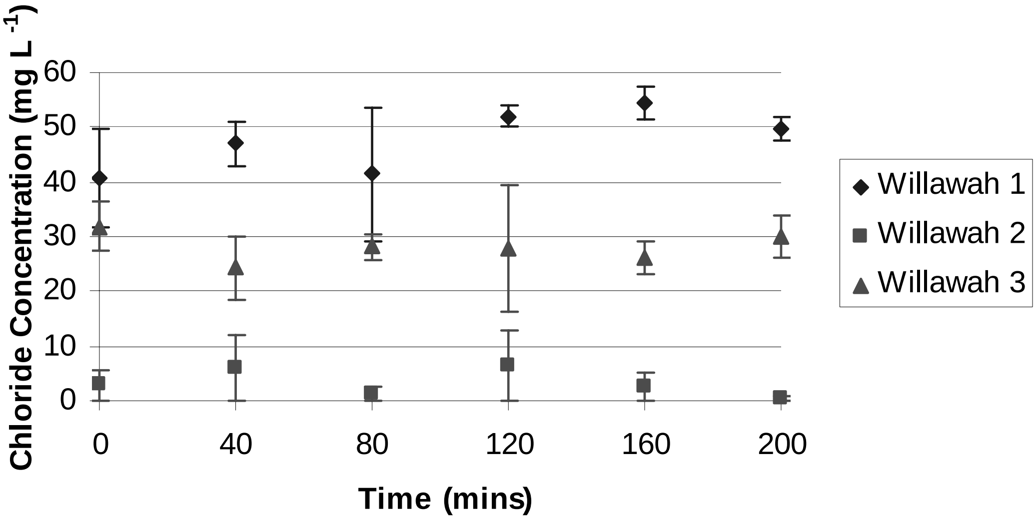

Figure 31 – chloride concentration from "Willawah" over time]

Chloride concentration at irrigation 2 appeared to exhibit a trend for the enrichment of the tail waters and is statistically significant on “Mollee” 22 and potentially so on field 20, fields 21, 2 and 3 also show enrichment but are not statistically significant. Field 1 on Willawah shows a decrease in chloride as from the head channel to the tail drain.

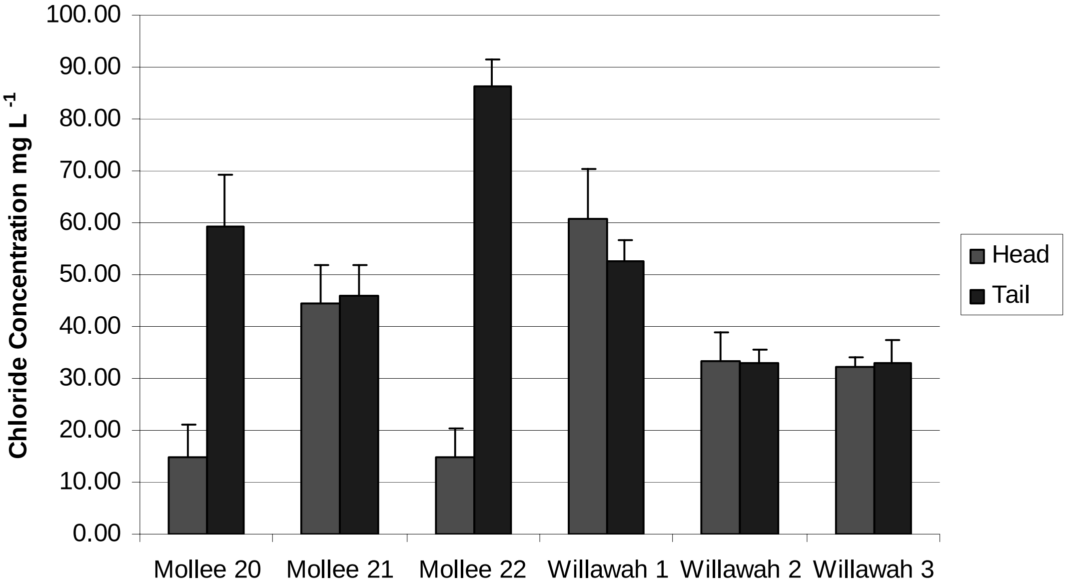

Figure 32 – chloride concentration at irrigation 2

At irrigation 3 a trend for chloride enrichment was clear and was significant for “Willawah” field 1, there was a slight increase on field 20 in the tail water samples and a slight decrease for field 3 these assumptions hold true to a p value 0.05.

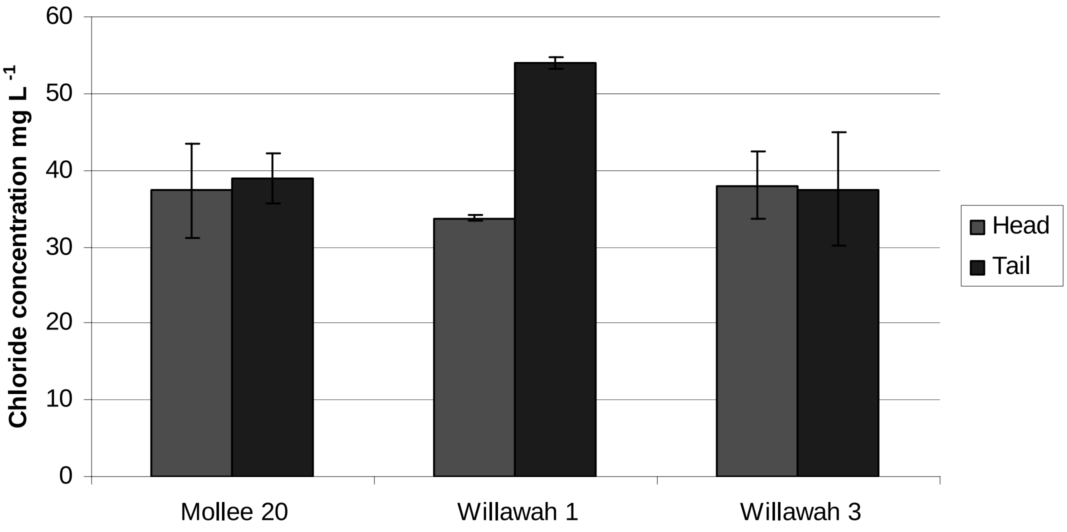

Figure 33 – Chloride concentration at irrigation 3

Summary of Results

Figure 30 below compares two properties head and tail water averages over all fields and irrigation for each of the ions that were analysed for. From this figure it can be seen that for each ion the results appear quite different between the two properties based on the bars alone, however statistically there is no difference between the ions concentrations on the two properties at a 95% confidence interval. There is however quite apparent trends for enrichment for phosphate and ammonium as well as for chloride and calcium on “Mollee”. However for sodium there was a large decrease in concentration from the head channel to the tail drain and the same was true for chloride on “Willawah”

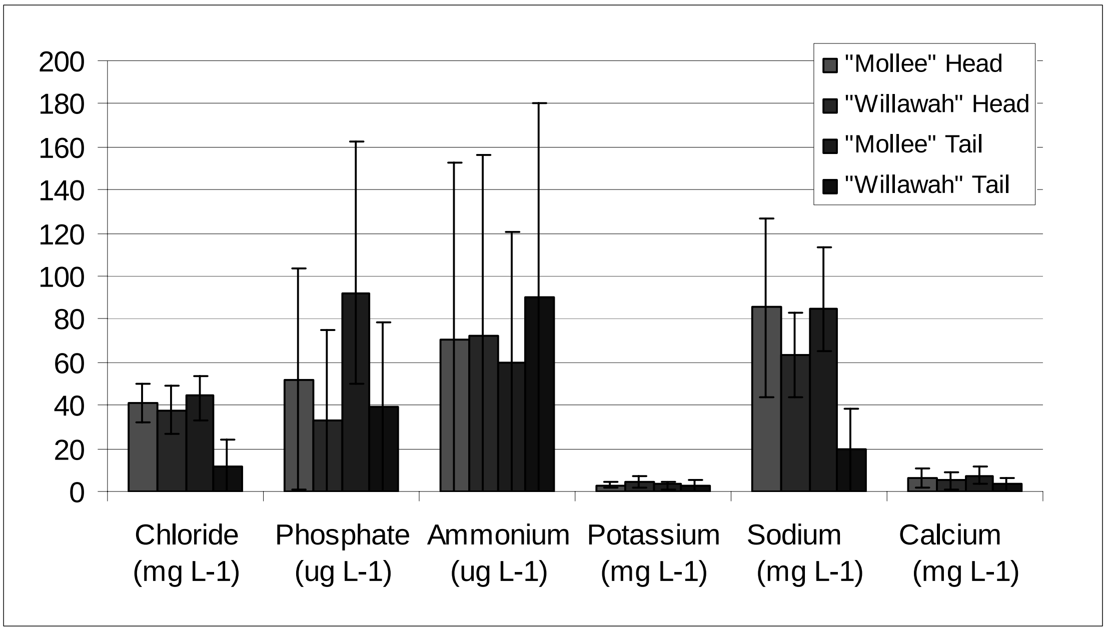

Figure 34 – Summary graph of averages of ion concentration across all fields and irrigations for each property

Table 1 – Table of averages for each ion

	"Mollee" Head	**"Willawah" Head**	**"Mollee" Tail**	**"Willawah" Tail**
		Averages		
Chloride (mg L^{-1})	*41*	*38*	*44.46*	*11.86*
Phosphate (µg L^{-1})	*52*	*33*	*92.23*	*39.07*
Ammonium (µg L^{-1})	*71*	*72*	*60.26*	*90.34*
Potassium (µg L^{-1})	*3*	*4*	*3.16*	*2.59*
Sodium (µg L^{-1})	*85*	*63*	*84.42*	*19.24*
Calcium (µg L^{-1})	*7*	*5*	*7.26*	*3.14*

Table 2 – Standard deviations for each ion

	"Mollee" Head	"Willawah" Head	"Mollee" Tail	"Willawah" Tail
	Standard Deviation			
Chloride ($mg\ L^{-1}$)	*9.03*	*9.48*	*11.25*	*11.86*
Phosphate ($ug\ L^{-1}$)	*51.20*	*70.00*	*42.53*	*39.07*
Ammonium ($ug\ L^{-1}$)	*81.87*	*60.02*	*83.44*	*90.34*
Potassium ($ug\ L^{-1}$)	*1.39*	*1.35*	*2.70*	*2.59*
Sodium ($ug\ L^{-1}$)	*41.39*	*28.92*	*19.55*	*19.24*
Calcium ($ug\ L^{-1}$)	*4.49*	*4.60*	*3.93*	*3.14*

Discussion:

The results of the experiment indicated that there was no statistical difference between ion concentration over time or between the head or the tail waters. The variation in the results was most likely a product of the small sample size (3 samples) for each treatment (sample time/Field/irrigation number); however it was impractical to sample greater replicates given the scale of the project and time limitations. It is also possible that variation was caused by contamination of the samples however this is unlikely due to great care which was taken in sample handling and preparation as well as the care that was taken to ensure all equipment was thoroughly washed before use.

The lack of statistical difference could possibly be overcome using a more complex statistical analysis however a lack of resources meant that this was not a possibility for this project.

However despite the lack of statistical significance the results found there still appears to be a clear trend for the enrichment of phosphate and ammonium in the tail waters compared with headwaters which is indicated in table 3. However other ions such as chloride and sodium indicate that there is a trend for the substantial decrease in there concentration as water flows down the field. Other ions such calcium and potassium show that there is a trend for a small decrease in their concentration.

Table 3 - Average enrichment of ions from all irrigations and field

	Enrichment
Chloride (mg L^{-1})	-11.14
Phosphate (mg L^{-1})	0.002317
Ammonium (mg L^{-1})	0.000363
Potassium (mg L^{-1})	-0.82

Sodium (mg L^{-1})	-22.61
Calcium (mg L^{-1})	-0.65

Using the figures in table 3 it is possible to provide a rough estimate of the economic costs and the percentage of the applied fertilizer lost with the enrichment of phosphate and ammonium. To do this the values must first be first scaled up to a volume which leads itself to easy comparison with application rates such as kg ML^{-1}, which is comparable as 1 mega litre is approximately the volume which is lost as surface runoff per hectare of cotton in one season. This enrichment is shown in table 4 as well as the enrichment as just nitrogen or phosphorus.

Table 4 – Field scale enrichment

	kg ML^{-1}
Ammonium	*0.0232*
Phosphate	*0.0036*
Nitrogen	*0.0178*
Phosphorus	*0.0015*

Economically these losses of these scales do not represent a significant loss, at around 10 cents per Ha, however once deep drainage and sediment bound losses are taken into account the costs could be significantly higher.

Environmentally the enrichment of phosphorus and nitrogen are important as these two nutrients are predominantly responsible for eutrophication which can lead to blue-green algal blooms. In regards to this the Australian and New Zealand Environmental Conservation Committee (ANZECC) has established guideline levels at

0.03 mg L^{-1} and 0.05 mg L^{-1} for phosphate and nitrogen respectively for the limitation of algal blooms these values are published in ANZECC, 2000.

Table 5 shows the comparison between guideline levels for nitrogen and phosphate to minimise the risk of eutrophication of water ways and our results. It is apparent that neither nitrogen or phosphate levels are of concern environmentally. However the phosphate results only report on phosphate in solution there could potentially be far more phosphate leaving the fields bound to sediment which could potentially push the phosphate above guideline levels and be potentially damaging to the environment.

Table 5 – Comparison of guideline levels and experimental results for phosphate and nitrogen

	Guideline Levels	**Results**	**Percentage Difference**
Nitrogen (mg L^{-1})	0.05	0.002	-96
Phosphate (mg L^{-1})	0.03	*0.02*	-22.76

Although the data obtained for the other ions does not indicate that there is a significant difference between water which is applied to field and that which leaves it, the ions in question could still be at concentrations which are potentially damaging to plant growth and the environment.

Sodium concentrations of below 115 mg L^{-1} (ANZECC, 2000) are not generally considered to be damaging to plant growth and it can be seen from the values reported in table 6.5 that our levels are around half this value indicating that the sodium levels are not a concern

Calcium is generally not considered an environmental concern however in the form of Calcium Carbonate it affects the hardness of the water, with ANZECC, 2000 recommending levels of $CaCO_3$ being below 300,000 µg L which equates to 12 µg Ca mL, the averaged observed levels are around half this value.

For potassium Rajeev *et al* (2001) reported that levels above 159 µg K^+ mL^{-1} were potentially damaging to cotton our results were many times below this value indicating that potassium was not a concern for the cotton.

ANZECC indicates that levels above 175 mg Cl^- could be potentially damaging to sensitive crops, our average chloride concentrations in the tail water determined to be significantly (6 times) below these levels indicating the chloride concentrations are not a risk to crop growth.

Table 6 - average concentrations of other ions and guideline values for comparison

	Guideline	**Results**
Potassium ($mg\ L^{-1}$)	*159*	*3*
Sodium ($mg\ L^{-1}$)	*175*	*63*
Calcium ($mg\ L^{-1}$)	*12000*	*6*
Chloride ($mg\ L^{-1}$)	*175*	*34*

There were other factors at work which may have affected the results for example the field pH which was measured to be between 8.5 and 9 on both properties may have had a significant impact on ion equilibrium in the water. This is particularly so for the ammonium equilibrium ($NH_4^+ \leftrightarrow NH_3 + H^+$ pK = 9.2 (Stumm and Morgan, 1996)). At these higher pHs it is quite likely that the ammonium in the samples underwent volatilization to become ammonia which could have diffused into the atmosphere. If this was the case (which it likely was) the ammonium loss (and thus nitrogen loss) could be potentially much higher than the readings reported in this study. However further work would need to be carried out to determine this.

For nitrate the results initially showed that there was some nitrate (albeit very small) concentrations in the tail water however analysis of freshly thawed samples indicated that there was no nitrate present even in those samples which had previously been positive for the presence of nitrate. A Total only 40 of the freshly thawed samples were analysed but all these samples return no measurable nitrate present.

These conflicting results for the nitrate concentration were potentially brought about by presence of nitrifying bacteria in the water samples which under the aerobic conditions (there was 20 mL of headspace in the centrifuge vials) could convert some of the abundant ammonium in the samples to nitrate by the process of nitrification (Kennedy, 1992). Although the process is generally very fast the low nitrate levels detected could have been due to limited oxygen supply (the vials were sealed at all times) and the cool temperature that they were stored at (4°C) (Kennedy, 2006).

Although the results indicated that there was no nitrate in the tail water, this does not necessarily mean that nitrogen is not being lost from the field. There are several methods by which nitrate movement could have occurred and this include via deep drainage and by a “first flush” effect. Transport in the water that drains through the profile this is possible because nitrate is extremely soluble in water and thus is readily transported in such movements (Sparks, 2000). It is also possible that due to the solubility of nitrate that any nitrate movement in the surface water is likely to occur in irrigations at the start of the growing season soon after application of N to field (Thornton *et al.* 1998).

Sodium results across all fields and irrigations provided quite variable results and this is most likely due the difficulty in preventing contamination of sodium and contamination is the cause of the high standard deviations exhibited in the results.

The analysis of chloride from irrigation 1 yielded results which were quite variable across the six fields sampled and this was lost likely because of the variation in water sources, with the fields which received a mixture of waters that included recycled tail-waters (Mollee 22 and Willawah 3) exhibiting higher chloride concentration than those which received water straight out of bore pumps. “Willawah” 1 is also interesting because although it was irrigated with freshly pumped bore water it exhibited the highest chloride concentration of any field on Willawah at irrigation 1 possibly indicating saline waters in the bore.

Although there is no Australian literature on nutrient loss from cotton there has been some research into nutrient loss from cotton in the international literature, although many of these report on results from different conditions. The comparison between our results and those from the literature are presented in table 7 also included is data from a study into nutrient loss from irrigated pasture in Victoria for comparison.

Table 7 – comparison of results

	Crop	**Ammonium ($kg\ ML^{-1}$)**	**Phosphate ($kg\ ML^{-1}$)**
Our Results	Cotton	0.003	*0.02*
Thornton *et al*	Cotton	*0.006*	*0.11*
McDowell *et al*	Cotton	*7.7*	*1.6*
Greenhill *et al*	Pasture	-	*1.56*

Our results for phosphate and ammonium were similar in scale

The outcomes of this project have shown that there appears to be a trend for nutrient loss from Australian cotton in the tail waters however there is still a significant amount of work to be conducted before it can be established inequitably.

One area of future work would be the collection of runoff samples, in conjunction with deep drainage, sediment and soils samples such that a mass balance for nutrient loss could be established and as such determine by which pathway nutrients are lost.

Another area for future study could be the collection of samples over the entire irrigation with the inclusion of flow data in the study to determine if there is a first flush effect from the Australian industry.

Further inside into nutrient might also be gained by comparing the quality of irrigation water with river and bore water.

The results of the study indicate that nutrient loss from cotton is neither environmentally nor economically significant, with all tested ions being significantly below environmentally damaging levels. However the analysis was limited to dissolved ions in the surface runoff. Further work into sediment and deep drainage ion loads may indicate that there is substantial nutrient loss via these pathways which have the possibility of raising concentrations of ions (particularly phosphate) above the guideline concentrations as well as representing a higher economic value.

Conclusion:

It appears that is irrigated cotton under furrow there are trends which indicate that nutrient loss is occurring. However for almost all ions studied there was no significant difference between the concentrations between the head water and tail water. The most significant trends for nutrient loss appeared to be in ammonium and phosphate with all six studied fields showing a greater concentration of ions in the tail water compared with what was applied to the field.

Although the other ions tested did not show a significant difference or a clear trend for nutrient loss the values do indicate the ions such as sodium and chloride are of concern for the environment and do warrant future study.

The results for all ions indicate that there is no reason for environmental or economic concern for dissolved nutrient loss in the surface runoff, however further analysis of sediment and deep drainage nutrient load is needed before conclusions to whether nutrient loss from cotton is economically or environmentally significant.

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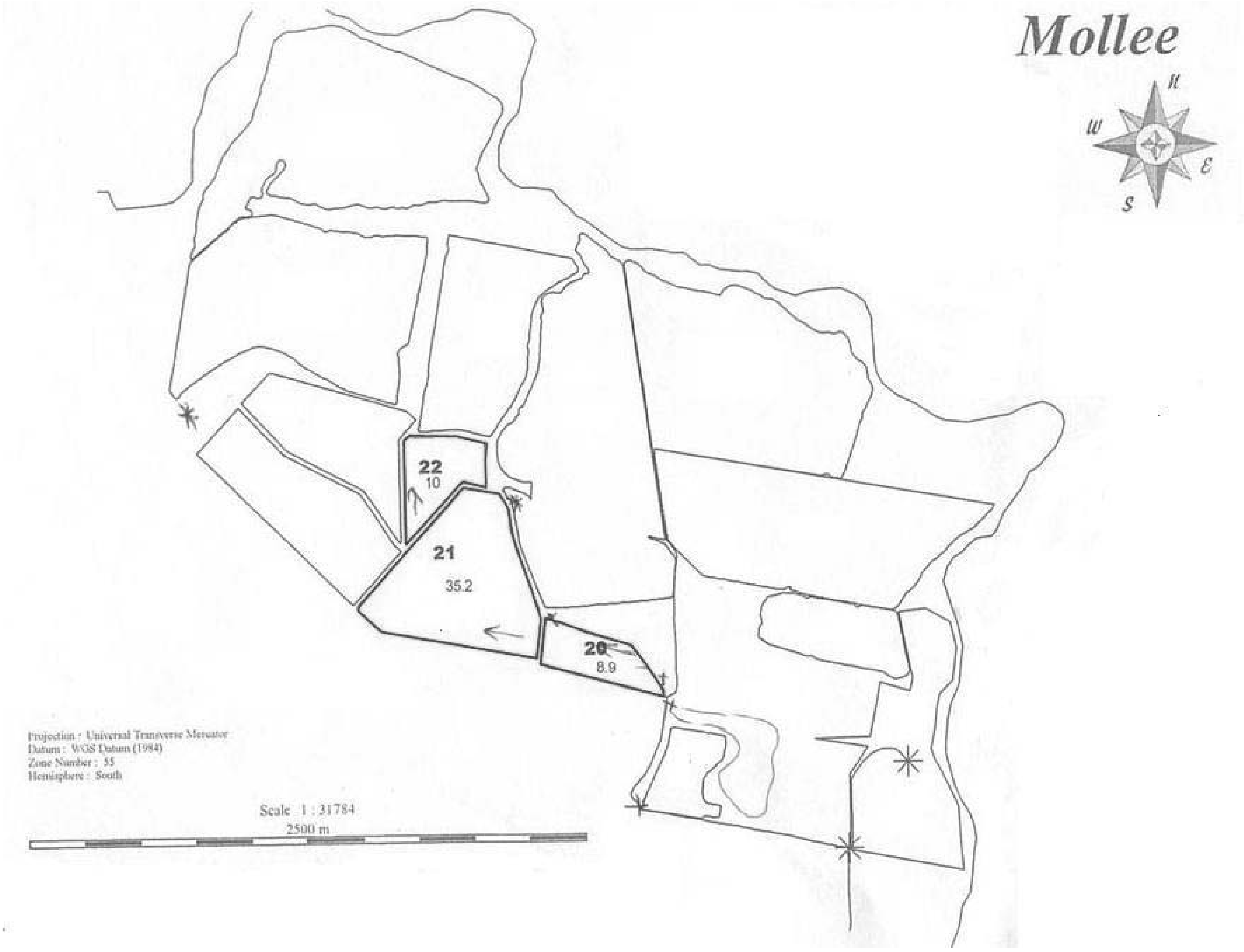
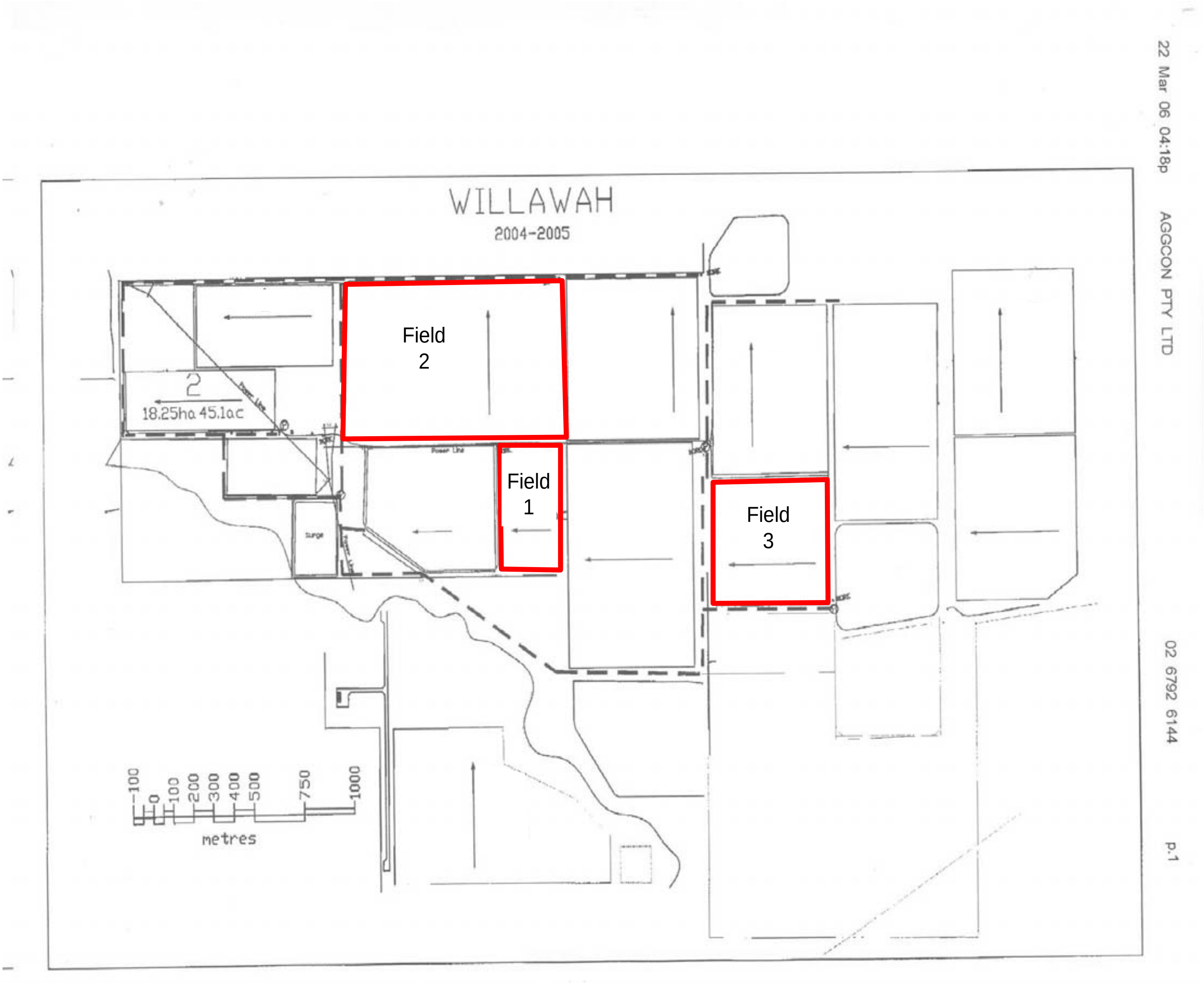
Appendix A: Farm map “Mollee”



Farm map of “Mollee” Showing fields sampled and direction of flow

Appendix B: Farm map "Willawah"



Farm map of "Willawah" showing fields sampled and direction of water flow

Appendix C: Standard Curves

Sodium

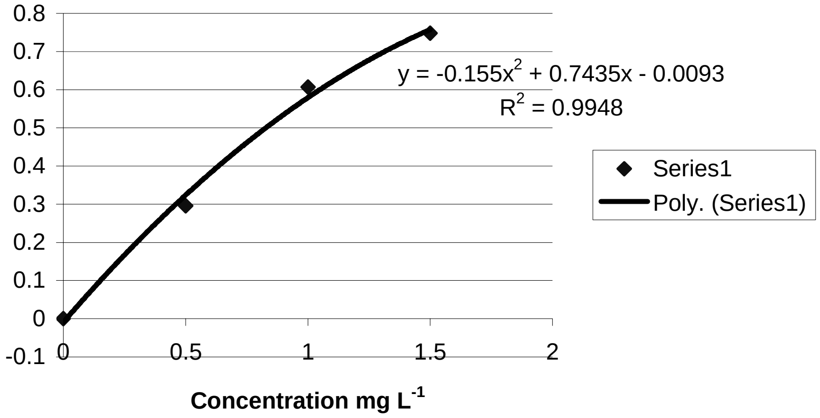


Figure C.1 – Standard curve for sodium showing fitted polynomial

Calcium

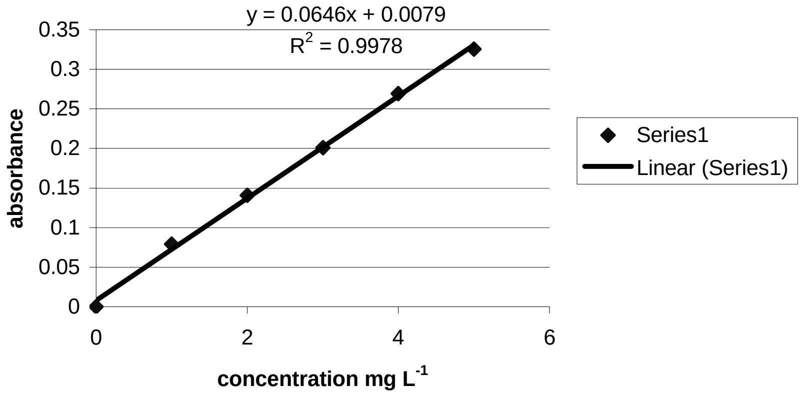
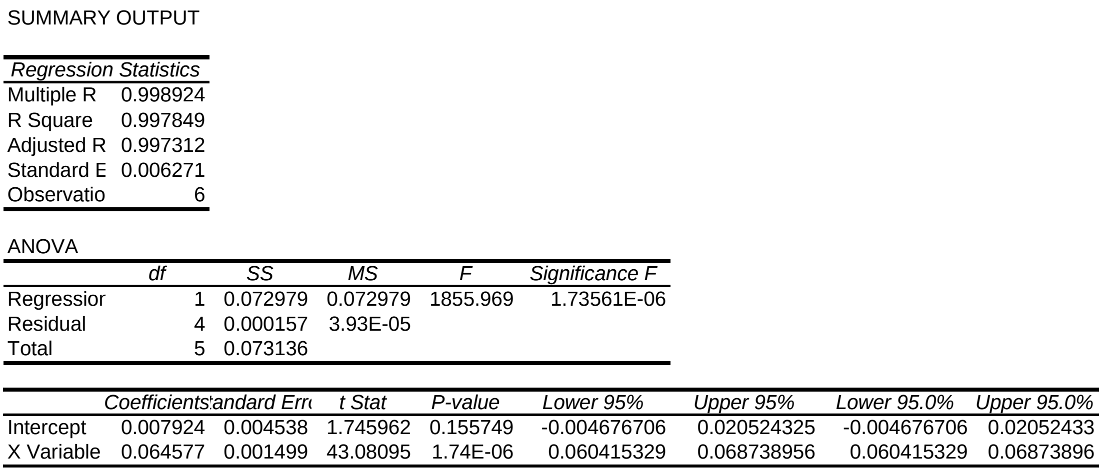


Figure C.2 –Standard curve for calcium showing fitted line



SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.998924
R Square	0.997849
Adjusted R	0.997312
Standard E	0.006271
Observatio	6

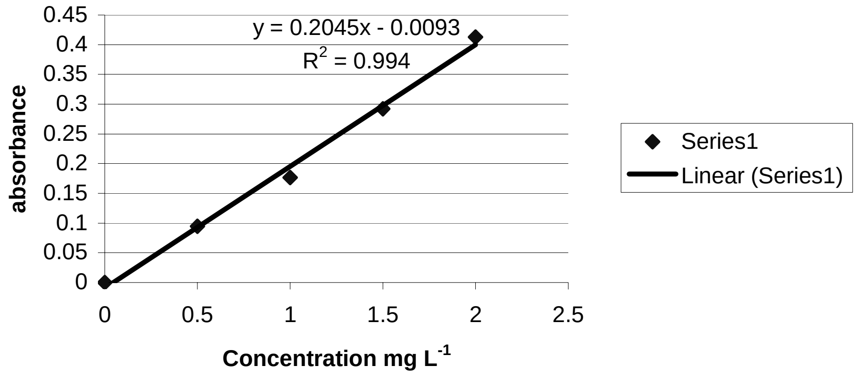
ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regressior	1	0.072979	0.072979	1855.969	1.73561E-06
Residual	4	0.000157	3.93E-05		
Total	5	0.073136			

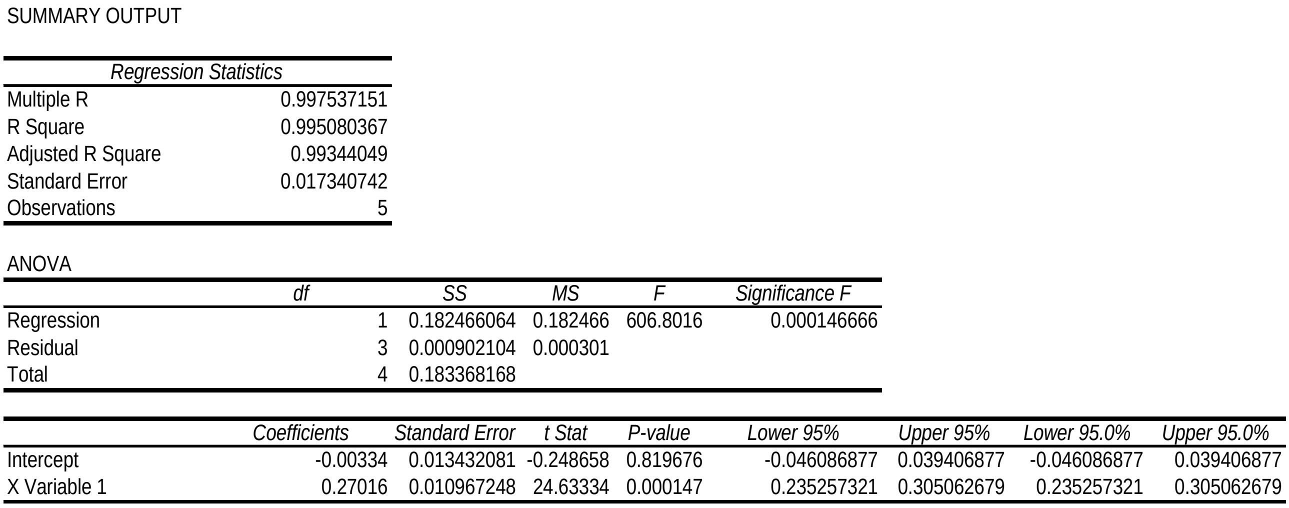
	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	0.007924	0.004538	1.745962	0.155749	-0.004676706	0.020524325	-0.004676706	0.02052433
X Variable	0.064577	0.001499	43.08095	1.74E-06	0.060415329	0.068738956	0.060415329	0.06873896

Figure C.3 – Regression output for calcium from excel

Potassium



C.4 – Standard Curve for Potassium showing linear fitted line



SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.997537151
R Square	0.995080367
Adjusted R Square	0.99344049
Standard Error	0.017340742
Observations	5

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	0.182466064	0.182466	606.8016	0.000146666
Residual	3	0.000902104	0.000301		
Total	4	0.183368168			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	-0.00334	0.013432081	-0.248658	0.819676	-0.046086877	0.039406877	-0.046086877	0.039406877
X Variable 1	0.27016	0.010967248	24.63334	0.000147	0.235257321	0.305062679	0.235257321	0.305062679

C.5 – Regression output for potassium from excel