Pasture burning post irrigation of dairy factory effluent at Edgecumbe, New Zealand

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Kelli Patterson

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Abstract

Pasture "burning" occurs when pasture turns yellow and dies back following irrigation of high strength effluent from the Fonterra Edgecumbe dairy factory. Pasture burning generally occurs intermittently during spring and continues into early summer. The objectives of my thesis were:

- review literature related to pasture burning and relate literature to potential causes,
- monitor pasture burning events and activities at Fonterra Edgecumbe dairy factory to endeavour to find potential causes of pasture burning,
- and undertake an experiment(s) to determine the concentration at which components of the effluent cause pasture burning.

Preliminary observations and a literature review identified multiple potential causes of pasture burning including effluent with high or low pH, high temperature, low osmotic potential/high osmolality as well as UV-radiation damage, excess nutrients, and salt build up in the soil and plant leaves. The weather at the time of irrigation and daily changes in the effluent composition may influence the severity of burning. It is likely that pasture burning is caused by a combination of effects.

The osmolality measures the concentration of a solution. Osmolality was chosen as a measure of pasture burning as the osmolality measure the solute concentration in a solution. Fresh clover (400 - 500 mmol/kg) and ryegrass (500 - 600 mmol/kg) had a similar mean symplasmic osmolality to burnt clover and ryegrass. The high strength effluent had a lower mean osmolality (217 mmol/kg) compared to fresh clover (440 mmol/kg) and ryegrass (535 mmol/kg) and burnt clover (478 mmol/kg) and ryegrass (556 mmol/kg). If there are spikes in the concentration of effluent, the osmolality of the effluent may exceed that of the pasture causing reverse osmosis and the water in the plant cells to move out of the leaf causing dehydration.

A pilot trial to determine if there was a relationship between osmolality and pasture burning was undertaken. Effluent was spiked with KCl and lactose solution to increase the osmolality. The pilot trial showed that as the osmolality of the effluent increased, clover and ryegrass burning increased.

A main experiment was then designed to determine the cut off point for the osmolality of the effluent to prevent pasture burning.

The main experiment was also designed to determine if younger growth was more susceptible to pasture burning. One block had progibb and urea applied to enhance the growth of the pasture. The main experiment however, was unable to determine if new growth was more susceptible to pasture burning as the weather and nutrient content of the soil was optimal for pasture growth in both blocks.

In the pilot trial, there was a positive correlation ($R^2 > 0.5$) between ryegrass burning and osmolality, pH, electrical conductivity, total magnesium, sulphate, total sulphur, total sodium, total nitrogen, dissolved reactive phosphorus, total kjeldahl nitrogen and the sodium absorption ratio.

In the main experiment, there was a positive correlation ($R^2 > 0.5$) between clover burning and electrical conductivity, exchangeable sodium percentage, total potassium and chloride. However, there was no strong correlation between ryegrass burning and any of the effluent properties.

When the pilot trial and main experiment results were combined, there was a positive correlation ($R^2 > 0.5$) between clover burning and electrical conductivity, chloride, total potassium and osmolality.

My results suggest that the effluent osmolality should not exceed 450 mmol/kg and the electrical conductivity should not exceed 1500 mS/m to prevent strong to very strong pasture burning. Effluent that exceeds either 450 mmol/kg and/or 1500 mS/m should be recirculated through the holding tanks to reduce the concentration of the “spike”.

Clover was more susceptible to severe pasture burning than ryegrass. Further research into pasture burning is required to isolate and better understand the exact cause.

Acknowledgements

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Chapter 1

Introduction

1.1 Background

Land disposal of effluent has been occurring since humans first became established in fixed settlements (Lofrano & Brown, 2010). In New Zealand, the application of dairy factory effluent to land has been occurring in some places, such as Hautapu, for 22 years (Watkins and Nash, 2010). As dairy factory effluent became recognised as a resource, land treatment of effluent became more common in New Zealand and around the world. Many large companies now dispose of their effluent by applying it to land. The disposal of effluent to land is designed to enhance the growth of pasture (Watkins and Nash, 2010), by providing nutrients and water, to prevent high amounts of effluent being diverted to waterways. The fertiliser value of dairy factory effluent is dependent on the products being made in the factory and how the effluent is treated before it leaves the factory (Watkins and Nash, 2010). Due to the high milk mineral content and cleaning products present in dairy factory effluent, application to land must be managed carefully to prevent environmental degradation in that area (Watkins and Nash, 2010).

The Fonterra dairy factory at Edgecumbe was built in 1923 (Fonterra, 2014) and is 500m from the town of Edgecumbe. Fonterra Edgecumbe was known as Bay Milk Products until 1985 (Figure 1-1, Nicholson, 2000). In June 1997 Bay Milk Products became Anchor Products when three major co-operative dairy companies in the Bay of Plenty merged. In 2001 Fonterra was formed when two large co-operative companies merged, NZ dairy group and Kiwi co-operative dairies (Dana & Schoeman, 2010 after Ohlsson, 2004). Anchor products Edgecumbe then became Fonterra Edgecumbe. Fonterra Edgecumbe has a cream plant, protein plant, whey plant, ethanol plant and lipid plant (Fonterra, 2014). Fonterra Edgecumbe is one of two sites that produces caseinate and is the only site to produce prepared edible fat (PEF) which is used in confectionary products (Fonterra, 2014). Products are exported to many countries all over the world (Fonterra, 2014).

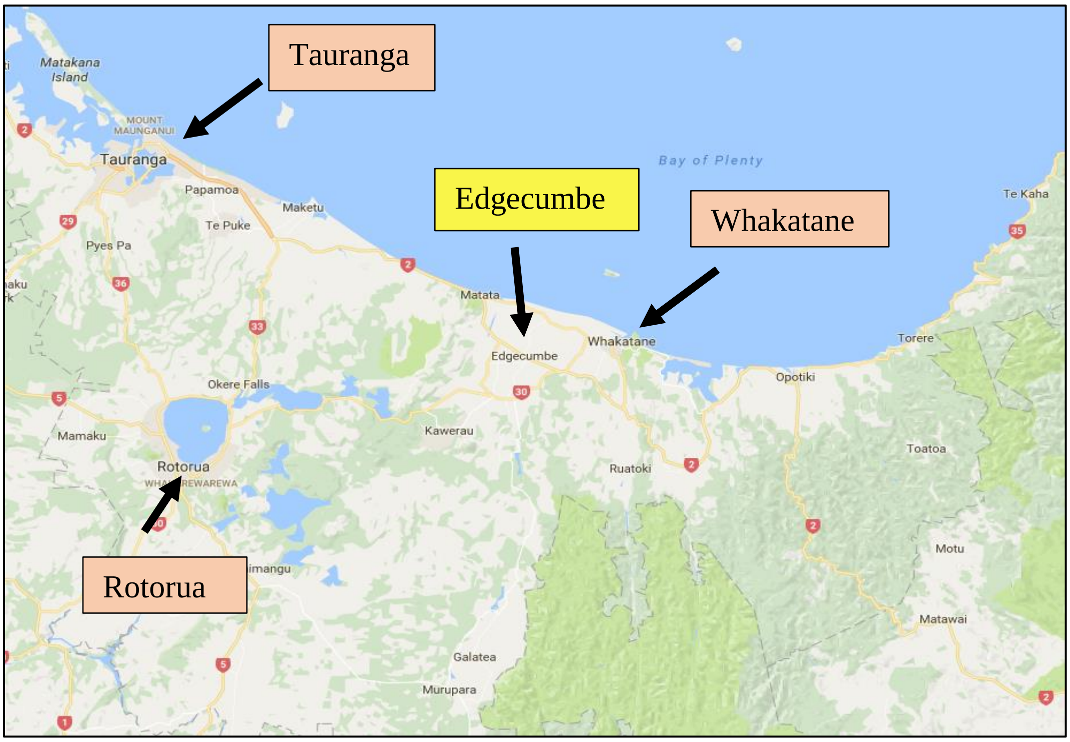


Figure 1-1. The study area is in Edgecumbe which is approximately 20km from Whakatane, Bay of Plenty (Map from Google, 2017).

Most of the effluent from the Fonterra Edgecumbe Dairy Factory it is irrigated onto surrounding farms under resource consent 65800-AP (Figure 1-2). Some of the effluent is treated and discharged into the Rangitaiki River.

Figure 1-2. Map of Fonterra Edgecumbe, study area and experiment area (Base map from google Maps, 2016)

The effluent runs through a large underground network of pipes to each farm. There are 4 main effluent lines that move the effluent to the farms (Figure 1-3).

Pasture "burning" occurs often during September through to January following irrigation of high strength effluent, causing the pasture to turn yellow and die-back. Pasture burning generally occurs during spring and continues into early summer.

Figure 1-3. Map of the Fonterra Edgecumbe effluent lines (Mark McKenzie, pers comm, 2017).

1.2 History of pasture burning at Fonterra Edgecumbe

Pasture burning was first observed by Fonterra Edgecumbe in 1996 (Bram Beuger, pers comm, 2016). Pasture burning occurs on some farms that Fonterra Edgecumbe irrigates their high strength effluent onto (Truong & Barnett, 1996). Since 2005 two trials have been carried out by Bram Beuger and Crush et al., (2005) to determine the cause of pasture burning. The conditions pasture burning occurs under need to be understood in more detail to prevent future loss of pasture. Finding the cause of, and thus preventing, pasture burning is important as there is potential for the irrigation of effluent to be stopped if adverse effects on pasture become widespread.

1.3 Objectives

The overall purpose of this study is to investigate the occurrence and cause of pasture burning which occurs on farms at sites irrigated with dairy factory effluent from the Fonterra Edgecumbe plant.

Specific objectives are to:

1. Review literature related to pasture burning and relate to potential causes.
2. Monitor pasture burning events and activities at Fonterra Edgecumbe dairy factory to endeavour to find potential causes.
3. Undertake an experiment(s) based on the above results to determine the concentration at which components of the effluent cause pasture burning.

Chapter 2

Literature Review

2.1 Introduction

The purpose of this chapter is to review the literature related to pasture burning from dairy factory effluent. The topics that will be covered include the composition of dairy factory effluent, pasture characteristics, soil properties, nutrient deficiencies, and possible causes of pasture burning and a summary of previous investigations in pasture burning undertaken at the Edgecumbe effluent irrigation site.

2.2 Composition of dairy factory effluent

The irrigation effluent from dairy factories contains soluble organic materials and trace inorganics as well as suspended solids (Shete & Shinkar, 2013). Effluent composition changes depending on the processes occurring at the dairy factory. Effluent can include; oil and grease, protein, lactose, casein, ash, minerals, nitrogen, calcium, sodium, phosphorus, magnesium and potassium, and cleaning products (Table 2-1, Ghani et al., 2005; Shete & Shinkar, 2013). Whey contains organic matter – lactose, protein, phosphorus, and some nitrates, and nitrogen (Shete & Shinkar, 2013). The content of dairy factory effluent causes the effluent to have a high biological oxygen demand (BOD) and chemical oxygen demand (COD) (Shete & Shinkar, 2013). BOD is the amount of oxygen needed by aerobic microorganisms to break down the organic material in the effluent. COD is the amount of oxygen "consumed in the oxidation of organic compounds by oxidizing agents" in solution (Yao et al., 2014).

Table 2-1. An example of dairy factory effluent composition (Adapted from State Government of Victoria, 1997; Ghani *et al.*, 2005; Watkins and Nash, 2010.).

pH	4 - 12	NO_{3-} (%)	<0.001
Total C (%)	1.942	SO_4^{2-} (%)	0.073
Total N (%)	0.065 - 1400	K^+ (%)	0.012 - 160
Total P (%)	0.063 - 640	Na^+ (%)	0.032 - 807
Total S (%)	0.075	Mg^{2+} (%)	0.018 - 49
NH^{4+} (%)	0.000	BOD	700 - 35000
Cl- (mg/L)	48-469	Ca+ (mg/L)	57-112

2.3 Pasture Characterisation and Properties

2.3.1 White clover

Clover (*Trifolium sp.*) is a key plant in New Zealand's pastures (Caradus, Hay & Woodfield, 1995; Brock & Hay, 2001). There are many varieties of clover, white clover being the most widely grown in New Zealand (Caradus et al., 1996). White clover is distinguished by leaf size and grows via stolons along the ground surface (Rattray, 2005). White clover has large leaves which are suitable for dairy grazing – Pitau and Kopu are two varieties grown in the North Island that are suitable for flat land and warmer climate (Caradus, Hay & Woodfield, 1995). The optimal temperature for white clover growth is 24^{o}C and optimal soil pH is 5.8-6 (Rattray, 2005).

Clover fixes atmospheric nitrogen, via rhizobia bacteria which infect the root nodules of the clover, and boosts pasture growth (Rattray, 2005). Clover grows during late spring and summer where nitrogen fixation is at its peak (Rattray, 2005). The symbiosis relationship between the clover and the rhizobia is important to New Zealand's pasture and economy (Ronson & Lowther, 1996). White clover provides New Zealand with ~$3.1 billion annually through its ability to fix nitrogen creating a low-cost natural fertilising system (Harris, 1997; Rattray, 2005). When clover is established in a pasture, it is dominant and fixes nitrogen from the soil and atmosphere. However, as the sward develops, clover growth slows due to competition from grasses (Ball & Crush, 1985; Brock et al., 1989 as cited in Rattray, 2005).

Nitrogen fixation, and therefore clover growth, is affected by minerals, "moisture stress, low soil fertility, grazing, temperature, grass competition, and appropriate rhizobium strains" (Caradus et al., 1996). Clover requires phosphorus, potassium and sulphur as well as optimal superphosphate and molybdenum levels (Rattray, 2005). In some cases, there may be excess nitrogen present but the nitrogen may be unavailable to the plant thus reducing plant growth (Rattray, 2005). Clover is susceptible to high moisture conditions in summer causing it to die off (Rattray, 2005).

2.3.2 Ryegrass

Ryegrass (*Lolium sp.)* requires high levels of nitrogen to grow effectively which is why it best accompanies clover (Cook, 2014). Ryegrass continues to grow in the cooler months of the year i.e. winter and spring (Cook, 2014). Ryegrass growth starts from a tiller which then grows into leaves (Guest, 2008 & Cook, 2014).

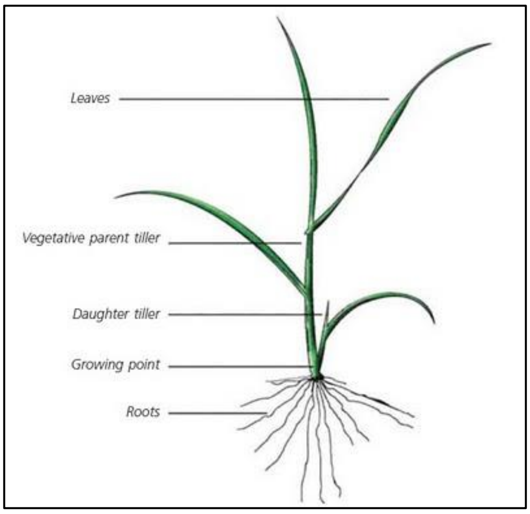


Figure 2-1. Ryegrass plant (Guest, 2008).

Each ryegrass plant is connected to another ryegrass plant at the base of the plant, but each tiller has its own root system (Figure 2-1, Guest, 2008). As each ryegrass plant is connected at the base, the ability to spread is limited (Cook, 2014), unlike clover that spreads easily via stolons (Rattray, 2005). Ryegrass has an annual root system that is replaced every spring (Cook, 2014). Ryegrass has a good tolerance to low temperatures and requires sun to thrive (Cook, 2014). During hot summer periods ryegrass grows well when irrigated (Cook, 2014).

Ryegrass's need for water means that during summer ryegrass struggles under high temperatures if not irrigated (Hall, 1992). Ryegrass grows well when the soil is fertilised and well-drained (Hall, 1992). Optimal soil pH for ryegrass growth is between about six and seven (Hall, 1992).

2.4 Granular and Foliar Fertilisation

The irrigation of effluent provides plant nutrients, directly to the leaf and through the soil. Foliar fertilisation is one of the most effective method for quickly correcting nutritional deficits (Fageria et al., 2008; Gary and Grigg, 2011). Foliar fertilisation involves the absorption of nutrients (inorganic and organic) through the leaf surface via physical and chemical processes (Franke, 1967 as cited in Fageria et al., 2008; Gary & Grigg, 2011).

Nutrients are absorbed through the cuticle, cell wall, membrane, stomata and chloroplast layer (Middleton and Sanderson, 1965; Franke, 1967; Burkhardt et al., 1999 as cited in Fageria et al., 2008). The leaf surface has a negative charge and therefore nutrients that enter the plant via the leaf must be small and able to neutralise the negative charge to be absorbed (Gary & Grigg, 2011). Nutrients must have a neutral charge for absorption (Gary & Grigg, 2011). Macronutrient requirements are rarely reached via foliar fertilisation alone, meaning there must be several applications of fertiliser (Fageria et al., 2008). Foliar fertilisation is optimal for micronutrient deficiency correction and for young plants that do not have a well-developed root system (Fageria et al., 2008). Foliar fertilisation enables nutrient deficiencies to be corrected after 3 to 4 days, unlike granular fertilisation which takes 5 to 6 days (Fageria et al., 2008).

A disadvantage of foliar fertiliser is that if too much is applied or the wrong concentration of nutrients is applied, it may burn the plants (Fageria et al., 2008; Gary & Grigg, 2011). If it rains soon after irrigation, the fertiliser can be washed away preventing burning (Fageria et al., 2008).

Foliar fertilisers work most efficiently when the temperature and pH is stable and there is plenty of sunlight (Gary & Grigg, 2011). Gooding and Davis, (1992 as cited by Fageria et al., 2008) found that nitrogen fertilisers burnt cereal plant leaves at the tips. Alkier et al., (1972) found that pasture burning was more common when the nitrogen source comes from ammonium nitrate or ammonium sulfate. Ammonium nitrate or ammonium sulfate contain high levels of salt meaning water in the leaves will move out via osmosis killing the leaf (Gooding and Davis., 1992 as cited by Fageria et al., 2008). If the same amount of nitrogen was applied to the leaves as would be applied to the soil in one application then pasture burning was severe (Poulton et al., 1990 as cited by Fageria et al., 2008).

2.5 Soil Chemical Properties

2.5.1 Cation exchange capacity (CEC)

The cation exchange capacity (CEC) is a measure of the soil's ability to hold readily exchangeable cations (positivity charge ions) (Rhoades, 1982). CEC is often expressed as meq/100g (Peverill et al., 1999). Soil contains both positive and negative ions. As the soil retains and holds positively charged cations, the soil can be neutralised if it was unbalanced by negative ions (Rhoades, 1982). CEC determines potential, nutrient availability, and pH buffering capacity (Hazleton & Murphy, 2007). CEC varies depending on the percentage of clay present, type of clay, and amount of organic matter. Clay and organic matter have negatively charged surfaces which enable positively charged cations to attach via an electrostatic force (Sorption, Retention, and Release of Contaminants, 2008). Potassium, sodium, calcium and magnesium are the four main base cations in CEC (Mengel, n.d.). When measuring the CEC of a soil, these four base cations are tested to give an overall measure of the base saturation (Mengel, n.d.).

As the four base ions are not always present, understanding the soil pH and what ions are present is important when calculating CEC (Mengel, n.d.). Changes in soil pH cause other cations to attach to surface site altering the nutrients available to plants (Leticia et al., 2014). Other cations that are key for plant survival include ammonium, manganese, iron and copper (Leticia et al., 2014).

Plants can only absorb cations in certain forms e.g. phosphorus can only be absorbed in the form of phosphates (University of Hawaii, 2007-2016, Table 2-2).

Table 2-2. Form of nutrients available to plants (University of Hawaii, 2007-2016).

Element	Form absorbed by plants
Nitrogen	NH^{4+} (ammonium) and NO^{3-} (nitrate)
Phosphorus	H_2PO^{4-} and HPO_4^{-2} (orthophosphate)
Calcium	Ca^{+2}
Magnesium	Mg^{+2}
Potassium	K^+
Sulphur	SO_4^{-2}(sulfate)
Iron	Fe^{+2} (ferrous) and Fe^{+3} (ferric)
Manganese	Mn^{+2}
Boron	H_3BO_3 (boric acid) and H_2BO^{3-} (borate)
Copper	Cu^{+2}
Zinc	Zn^{+2}
Molybdenum	MoO_4^{-2} (molybdate)

Important ions for plant survival may become unavailable due to the addition of acidic or basic ions from the dairy factory irrigation.

2.5.2 Sodium absorption ratio (SAR)

The sodium absorption ratio (SAR) is a measure of the sodicity of irrigation water and the likelihood that sodium ions in the irrigation water will exchange with calcium and magnesium in the soil (Clark & Mason, 2006). The SAR calculation is (Clark & Mason, 2006):

$$SAR = \frac{Na^+}{\sqrt{½[Ca^{2+} + Mg^{2+}]}} \qquad 2$$

where Na, Ca and Mg are in concentrations in me/l.

If the SAR is <3, the irrigation water is considered safe (WateReuse Foundation, 2007). If the SAR is > 9 soil structural issues could arise, and more so in fine grained soils (WateReuse Foundation, 2007). Plants each have a different tolerance to the SAR of irrigation water (Table 2-3).

Table 2-3. Plant tolerance to the sodium absorption ratio (ANZECC, 2000).

Tolerance	SAR of irrigation water	Crop
Very sensitive	2-8	Fruits, nuts, citrus, avocado
Sensitive	8-18	Beans
Moderately tolerant	18-46	Clover, oats, rice
Tolerant	46-102	Wheat, barley, tomatoes, beets, tall wheat grass, crested grass

2.5.3 Exchangeable sodium percentage (ESP)

The exchangeable sodium percentage (ESP) is a measure of the amount of sodium present in solution and its effects on soil structure (Cameron et al., 2003). The ESP calculation is as follows (Cameron et al., 2003):

$$ESP = \frac{100 \text{ x exchangeable } Na^{+} \text{ } (cmol_c kg^{-1})}{CEC \text{ } (cmol_c kg^{-1})} \quad (3)$$

Land irrigation of effluent from dairy factories poses a risk to soil structure as dairy factory effluent often contains high amounts of sodium (Cameron et al., 2003). Previous studies have shown that as the sodium ion concentration increases, the hydraulic conductivity of the soil decreases (Cameron et al., 2003). The hydraulic conductivity decreases because high amounts of sodium cause the soil aggregates to swell and disperse (Cameron et al., 2003 & Warrence et al., 2003). Surface crusting and low infiltration also results from increased sodium loading as the soil hardens which further makes it hard for plants to establish and grow (Warrence et al., 2003).

Soil texture is an important aspect of ESP (Warrence et al., 2003). Soil that contains many particles or are fined grained have a larger surface area exposed allowing additional sodium ions to attach enhancing dispersion (Warrence et al., 2003). A soil with a low ESP is considered non-sodic (<6%), however a very strongly sodic soil has an ESP of >25% (terraGIS, 2017).

2.5.4 Potassium adsorption ratio (PAR) and sodium potassium adsorption ratio (SPAR)

The potassium adsorption ratio (PAR) allows one to calculate the amount of potassium in relation to calcium and magnesium in soil (Sarah, 2004). As potassium is a salt, it can cause an "ion-excess" in plants (Sonon et al., 2015). The "ion-excess" is defined by Greenway & Munns (1980) as "a condition where high internal ion concentrations reduce growth". Salts can enter a plant's transpiration stream and damage plant cells reducing growth (Sonon et al., 2015). The "ion-excess" effect can also cause leaf or tip burning or browning (Sonon et al., 2015). Many plants are sensitive to high salinity when they are young. High salinity soils can be seen diagnosed in the field by a white crust on the surface, leaf tip burn and water stress (Table 2-4.) (Figure 2-15 & 2-16) (Waskom et al., 2010). Leaf tip burn is mostly seen on young plants that are watered using foliar sprinkler systems (Waskom et al., 2010).

Table 2-4. Symptoms of high salt in plants (Waskom et al., 2010).

Problem	**Potential symptoms**
High pH	Nutrient deficiencies manifesting as: stunted, yellow plants. Dark green to purplish plants.
Saline Soil	White crust on soil surface. Water stressed plants. Leaf tip burn.
Saline irrigation water	Leaf burn. Poor growth. Moisture stress.
Sodic soil	Poor drainage. Black powder residue on soil surface.
Saline-sodic soil	Generally, same symptoms as saline soil.

Potassium availability is impacted by calcium and magnesium which means plants can show a potassium deficiency even if there are high amounts of potassium present in the soil (Storey, 2016). Studies have tested soil for SPAR (sodium potassium adsorption ratio) which calculates the ratio sodium + potassium ions and calcium + magnesium ions (Sarah, 2004). The SPAR calculation is as follows (Sarah, 2004):

$$SPAR = \frac{(Na^{+} + K^{+})}{(Ca^{2+} + Mg^{2+})^{1/2}} \quad mmol^{-1} \qquad 3$$

2.6 Potential Causes of Pasture Burning

2.6.1 Introduction

Pasture burning has many potential causes. The additional nutrients and changes in soil pH can alter the soil's ability to supply and retain nutrients (Jensen, 2010). If lactose is present in the effluent, fermentation may occur creating lactic acid (Bylund, 2015) that could contribute to pasture burning. External environmental factors such as radiation, humidity, air temperature, rain and wind may also play a role in pasture burning. Excess nutrients from the effluent or from fertilisation such as nitrogen, sodium, chloride, boron, potassium, copper and phosphorus may also contribute to pasture burning.

2.6.2 Effects of high and low pH on pasture

The pH is a measure of the concentration of hydrogen and hydroxyl ions in solution (Perlman, 2016). White clover and ryegrass thrive at soil pHs between 6 and 7 (Hall, 1992 & Hall, 1993) and pH levels in water of 5.6 to 6.5 (Agricom Ltd., 2012). A low pH effluent that is applied directly to the leaf can damage the epidermis layer (Sant'Anna-Santos et al., 2006).

The availability of nutrients in the soil depends on the soil pH (Figure 2-2). Plants require 6 macronutrients (nitrogen, phosphorus, potassium, calcium, sulfur and magnesium) and 8 micronutrients (boron, chlorine, manganese, iron, zinc, copper, molybdenum and nickel) (Njinga et al., 2013). Nutrients must be present in specific forms to be available for plants (Truog, 1946). A soil pH between 6 to 7.5 is preferable for nutrient availability and therefore plant growth.

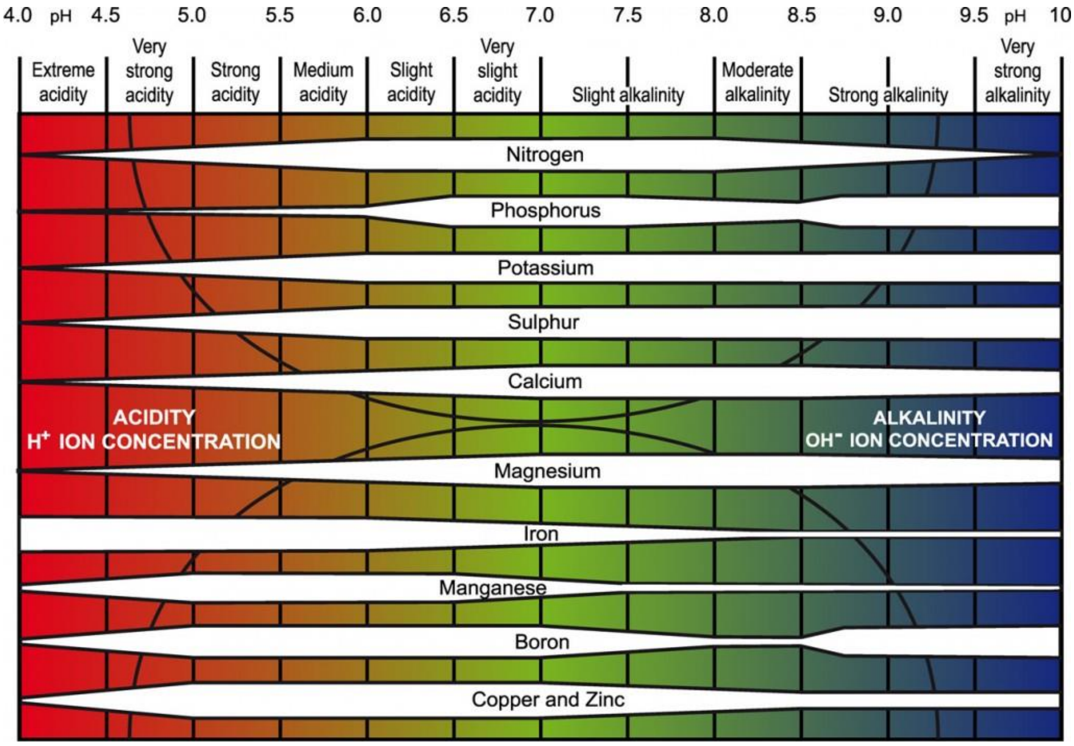


Figure 2-2. pH vs. nutrient availability; the width of the boxes shows the availability of nutrients at different pH's (Potash Development Association, 2011 adapted from Truog, 1946).

2.6.3 Lactic acid bacteria in milk

Milk can contain up to 38% lactose on a dry weight basis. There are bacteria present in milk that can breakdown the lactose solution to produce lactic acid ($C_3H_6O_3$) (Table 2-5, Bylund, 2015). Lactose is a carbohydrate sugar that is only found in milk. Lactic acid is known as 4-0-ß-D-galactopyranosyl-D-glucopyranose. Lactose is classed as a disaccharide, which is a carbohydrate that contains two simple sugars; D- glucose and D- galactose solution (Poplawski, 1997).

Table 2-5. Key lactic acid bacteria that create lactic acid which are found in the dairy industry (Adapted from Bylund, 2015).

Species	Optimal temperautre (^{O}C)	Ferments lactose solution to lactic acid (%)	Ferments lactose solution to other substances	Ferments ciritc acid to:	Protein splitting enzymes
Str thermophilus	40-45	0.7 – 0.8	-		Yes
Lc lactis	25 – 30	0.5 – 0.7	-		Yes
lc cremoris	25 – 30	0.5 – 0.7	-		Yes
lc diacetylactis	25 – 30	0.3 – 0.6	-	CO_2, volatiles, diacetyl	Yes
Leuc cremoris	25 – 30	0.2 – 0.4	-	CO_2, volatiles, diacetyl	Yes
Lb acidophilus milk,	37	0.6 – 0.9	-		-
Lb casei	30	1.2 – 1.5	-		Yes
Lb lactis	40 - 45	1.2 – 1.5	-		Yes
Lb helveticus	40 - 45	2.0 – 2.7	-		Yes
Lb bulgaricus	40 - 45	1.5 – 2.0	-		Yes
Bifidobacterium	37	0.4 – 0.9	Aseptic acid		-

Bacteria breakdown the lactose solution by separating the molecule into glucose and galactose solution via intermediary reactions (Figure 2-3.) (Bylund, 2015).

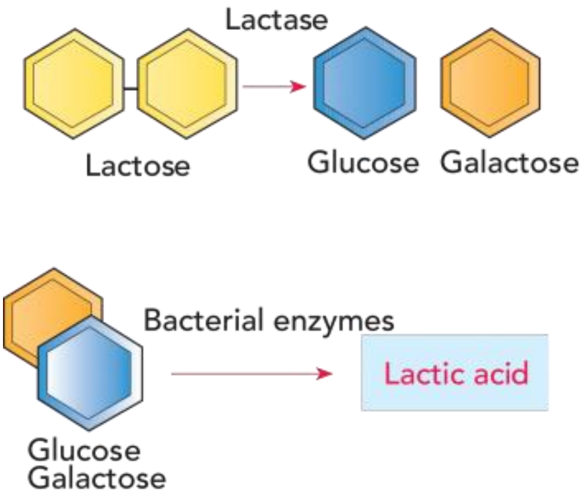


Figure 2-3. Breakdown of lactose solution via bacteria (Bylund, 2015).

The bacteria in milk can be divided into four groups: psychrophilic, psychrotrophic, mesophilic and thermophilic. Psychrophilic bacteria grow at temperatures between 0°C and 15 °C. Psychrotrophic bacteria thrive in temperatures between 20 °C and 30 °C. Mesophilic bacteria thrive at temperatures of 20 °C to 35 °C with a maximum of 50 °C. Lastly, thermophilic bacteria grow between 30 °C and 65 °C. As milk is heated, the pH can change. The change in temperature also influences the bacteria in milk. Most lactic acid producing bacteria are "anaerobic, catalase-negative, non-motile and non-spore forming" (Panesar et al., 2007). Lactic acid bacteria can be placed under these genus: "Lactobacillus (L.) (Figure 2-4.), Lactococcus (Lc.), Leuconostoc (Ln.), Pediococcus (P.), and Streptococcus (S.) as well as the more peripheral Aerococcus, Carnobacterium, Enterococcus, Oenococcus, Teragenococcus, Vagococcus, and Weisella" (Panesar et al., 2007).

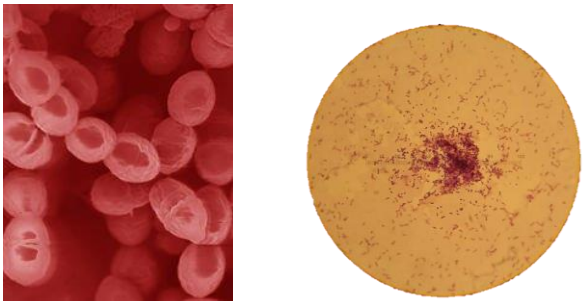


Figure 2-4. Lactococcus lactis bacteria under microscope (Wouters et al., 2001, Muehler, 2009).

When lactic acid is produced, the pH starts around pH 6.5 and drops to ~pH 4.5. Lactic acid production occurs at an optimal temperature of 40-45^{o}C. (Horath, n.d.). Lactic acid has a "sour" taste and smell (Hudson, 2010). Lactic acid may be lowering the pH of the effluent causing pasture burning (Edgecumbe Irrigation team, pers comm, 2017). Lactic acid production occurs under anaerobic conditions where sugar (lactose) and no oxygen is required (Horath, n.d.).

2.6.4 Lactic acid production using whey

Whey is produced at a dairy factory when milk fat and casein are separated from the whole milk. Whey contains large amounts of lactose (46%), protein (8%), lipids, minerals (12%) and salts (Panesar, 2007). Eighty five percent of dairy factory waste is whey. There are two types of whey: sweet whey produced at about pH 6.5 and acid whey produced at pH <5. Acid whey is produced as the pH must be lowered to precipitate casein. The optimal pH for fermentation of whey is 5.5 to 6.5 (Panesar, 2007).

2.6.5 Temperature of effluent

Clover is vulnerable to extreme high and low temperatures (Rattray, 2005). If the water temperature is too hot or too cold, oxygen and nutrient up-take are reduced (Canna gardening USA, 2016). Cold water prevents the roots from absorbing the oxygen fast enough reducing plant growth (Canna gardening USA, 2016). On the other hand, hot water does not contain enough oxygen preventing optimal root growth (Canna gardening USA, 2016). Canna gardening USA (2016) recommends that the water temperature for watering plants should be between 16 ^{o}C and 22^{o}C. The soil temperature should be known before irrigation water is applied to ensure the plants will not become stressed if the temperature of the irrigation water differs greatly compared to the soil temperature. However, if the temperature of the irrigation water is ~15.5^{o}C or above, the yellowing of leaves of certain plant species can occur causing the plant to die off (Bauder, n.d.). When irrigated with water at 21^{o}C yellowing of alfalfa occurred (Bauder, n.d.). The yellowing of the plant continued for weeks even after the irrigation water was absorbed and drained by the soil (Bauder, n.d.). In some cases, yellowing of alfalfa didn't occur until two weeks after irrigation where soil temperature reached a maximum of 32^{o}C (Bauder, n.d.).

2.6.6 Temperature of Soil

Castle *et al*., (2002 as cited by Rattray, 2005) recognised that white clover growth is limited by soil temperature. Watson *et al*., (1996 as cited in Rattray, 2005) found that in the Bay of Plenty, clover numbers declined when soil temperatures exceeded 30°C and moisture levels were low. Clover numbers declined because 30°C is the upper limit for stolon survival (Rattray, 2005). An experiment carried out by Hunt and Field (n.d.) on ryegrass growth under controlled environmental conditions showed that when the ryegrass was subject to a soil temperature of 33°C the death rate of leaves was ~25%. High soil temperatures could potentially be a cause of pasture burning. In spring, when there is new clover growth, clover is vulnerable to environmental stressors (Woodfield & Caradus, 1996). Clover tends to decline in winter and it is susceptible to cooler temperatures where growth rate reduces (Rattray, 2005).

2.6.7 Impacts of radiation and light intensity on pasture

Radiation from the sun enters the earth via electromagnetic waves. Electromagnetic waves are split into three groups – UV-A, UV-B and UV-C rays (Stapleton, 1992; Kovacs & Keresztes, 2002). UV-C are energetic and do not reach the ground surface on Earth (Stapleton, 1992). UV-B radiation does reach ground level (Stapleton, 1992). Plants respond to all three wavelengths; UV-A, UV-B and UV-C (Stapleton, 1992). UV radiation damage to plants occurs to their DNA, protein and lipids (Stapleton, 1992; Gaberscik et al, 2013). When gamma-rays hit a plant leaf it can interact with the water present in the cells releasing radicals (Kovacs & Keresztes, 2002). Radicals are uncharged molecules that are highly reactive but are short lived (Kovacs & Keresztes, 2002). Free radicals can damage plant cells (Kovacs & Keresztes, 2002).

Clover is potentially vulnerable to solar radiation (Plants in Action, 2001 & Rattray, 2005). Hofmann et al., (2001) found that plant growth and the epidermis (outer protective layer of a plant) decreased as a result of UV-B making the clover more susceptible to environmental stressors. If the outer epidermis of the plant is damaged or small in size, external stressors could damage the plant (Hofmann et al., 2001). Stapleton (1992) reported that UV-C radiation causes mutations in plant DNA.

Although plants may become damaged due to high radiation exposure, the plant's ability to regenerate healthy cells to repair radiation damage is high (Jenkins, 2009). It has been suggested that water droplets on the leaf surface could act as a lens, intensifying the light, and burning the leaf (Egri et al., 2010). Egri et al., (2010) carried out experiments to test whether water droplets can damage plant leaves. Results showed no burning (Egri et al., 2010). No burning was attributed to the fact that the focal region of the water droplet was below the leaf – for burning to occur the focal region of the water droplet would have had to have been within the leaf (Egri et al., 2010). The water droplet also cooled the leaf meaning the heat needed to burn the leaf was absorbed by the water (Egri et al., 2010). Overall, the experiment carried out by Egri *et al*., (2010) demonstrated that the potential for burnt leaves from water droplets on smooth leaves is low. Burning from sunlight will only occur if the focal region sits on the leaf surface (Egri et al., 2010).

2.6.8 Effects of nitrogen on pasture

Nitrogen is a required nutrient by plants for all growth processes. Nitrogen is absorbed by plants in the form of nitrate and ammonium. Nitrogen is involved in creating amino acids and chlorophyll (Broome, n.d.). If there is a nitrogen deficiency, older leaves will yellow and the plant will have stunted growth (Broome, n.d.). The plant may also go pale in colour due to a lack of chlorophyll production (Broome, n.d.).

2.6.9 Effects of sodium on pasture

When sodium chloride and sodium hypochlorite are added to soils via effluent irrigation there can be an increase in the sodium concentration in the soil (Warrence et al., 2003). The amount of sodium that accumulates depends on the soil type, its drainage ability, and other minerals present in the soil (Warrence et al., 2003). Sodium can cause a soil to lose its structure which can affect drainage and plant growth (Dyer, 2015). Reduced drainage can cause ponding of irrigation water and therefore flooding of pasture, reducing pasture growth. As sodium is a "monovalent cation" (Dyer, 2015) it competes for cation exchange sites in the soil where it attaches to sites that calcium and magnesium would normally attach to.

When the cation exchange sites are used by sodium the structure of the soil is lost (Dyer, 2015). The loss of soil structure reduces soil permeability and can create a surface crust reducing hydraulic conductivity (Warrence et al., 2003). A surface crust forms when the irrigation water evaporates and the salt is left behind. In plants, sodium contributes to the osmotic pressure and water balance (Edmeades & O'Connor, 2003). If there is too much sodium in the water around the plant, the osmotic pressure drops and water in the plant flows back into the soil, dehydrating the plant, and potentially causing death of plant leaves (Queensland Government, 2015). An effluent with an electrical conductivity >5.00 is very salty (Table 2-6.) (Prince, 2016.).

Table 2-6. Salinity limits of water (Prince, 2016.).

EC (mS/cm, dS/m or mmhos/cm)	EC (mS/m)	Approximate total soluble salts (mg/L or ppm)	Status
0-0.80	0-80	0-440	Low salinity
0.80-2.50	80-250	440-1375	Moderately salty
2.50-5.00	250-500	1375-2750	Salty
>5.00	>500	>2750	Very salty

In terms of clover and ryegrass salt tolerance, Agriculture Victoria (2015) determined that the salinity of the irrigation water must reach 1.5 - 3.00 dS/m to cause salt damage to ryegrass and 0.75 – 1.5 dS/m to damage clover (Table 2-7.).

Table 2-7. Tolerance of different plants to salt (Agriculture Victoria, 2015.).

Salinity of irrigation water	Plants that will be damaged
0 to 0.75 dS/m	Will cause damage to clovers: white, red,cluster, suckling, subterranean
0.75 to 1.5 dS/m	Will cause damage to: Balansa clover, persian clover, strawberry clover, Berseem clover, lucerne
1.5 to 3.00 dS/m	Will cause damage to: sorghum, tall fescue, phalaris, perennial ryegrass, cocksfoot, Wimmera ryegrass, crested wheatgrass, barley (hay), wheat, reed canary grass, paspalum.
3.00 to 5.00 dS/m	Will cause damage to: Tall wheatgrass, puccinellia, bermuda grass, barley (grain), saltwater couch, salt bush

2.6.10 Effects of potassium on pasture

Potassium is an important nutrient for plants as it maintains the amount of water in the plant (Van Brunt, 1998). Turgor pressure in a plant is created via osmosis where water moves into an area creating high pressure or moves out of an area causing low turgor pressure (Pritchard, 2001). High levels of potassium is required to increase the tugor pressure and accumulate water around the stomata causing the stomata to swell and open (Van Brunt, 1998). The osmotic pressure can draw water into the roots and potentially excess nutrients which the plant cannot tolerate (Van Brunt, 1998). If there is not enough potassium in the guard cells to accumulate water and open the stomata, the stomata close slowly allowing water to leave the plant causing water stress (Van Brunt, 1998). Leaf scorch or chlorosis (yellowing of the leaf due to loss of chlorophyll) occurs due to a build up of potassium which affects older leaves first and occurs to the tips and on the margins of the leaves (Van Brunt, 1998). Potassium deficiency causes chlorosis in younger leaves.

2.6.11 Effects of phosphorus on pasture

Phosphorus is a key nutrient in plant growth (Njinga et al., 2013). If a plant becomes deficient in phosphorus, it will exhibit stunted growth and cause the plant to turn dark green or purple (Broome, n.d.). Excess phosphorous may reduce the uptake of important nutrients such as iron, manganese, zinc and copper (Malvi, 2011.).

2.6.12 Effects of chloride on pasture

Chloride (Cl^-) is a vital plant nutrient (Smart-fertilizer, 2016). Chloride is taken up by plants in the form of Cl^- ions. Cl^- ions are negatively charged and do not usually attach to the soil making Cl^- ion easy to take up by plants (Ayers & Westcot, 1994; Smart-fertilizer, 2016). The direct absorption of chloride via the leaf does more damage to the plant than absorption through the roots (Prince, 2016.).

Many plants which are able to uptake ions through the roots cannot tolerate with the direct absorption of large amounts of ions through the leaf (Prince, 2016.). If a plant is sensitive to salts, it does not have well developed salt-compartmentation mechanisms that enable the controlled uptake of ions (Lauchi, 1984). Too much salt causes osmotic stress due to ion toxicity and can damage enzymes preventing the plant from functioning (Lauchi & Epstein, 1984).

Chloride is only needed in small amounts, if too much chloride is present toxicity and damage to the plant can occur as it builds up in their leaves (Table 2-8, Smart-fertilizer, 2016).

Table 2-8. Chloride limits for crops from irrigation water (Smart-fertilizer, 2016).

Chloride classification of irrigation water	
Chloride (ppm)	**Effect on crops**
Below 70	Generally safe for all plants
70-140	Sensitive plants show injury
141-350	Moderately tolerant plant show injury
Above 350	Can cause severe problems

In terms of clover and ryegrass chloride tolerance, Spectrum Analytic Inc (n.d.) determined that the maximum amount of chloride present in the soil without damaging the plant is 525 g/m^3 for clover and 1925 g/m^3 for ryegrass. A chloride soil concentration above 525 g/m^3 for clover and 1925 g/m^3 for ryegrass will cause damage however, the severity of the damage is dependent on the climate, soil and irrigation practices (Spectrum Analytic Inc, n.d.). Prince (2016) states that plants that are moderately affected by chloride and sodium can withstand a solution that contains chloride levels of 187-355 mg/L and sodium levels of 114-229 mg/L. Although, Prince (2016) doesn't specifically state the toxic levels of chloride and sodium for white clover, Rogers et al., (1997) reported that white clover has a similar tolerance to chloride as grape which is reported by Prince (2016). The effluent chloride levels stated by Prince (2016) is far lower than the soil chloride levels reported by Spectrum Analytic Inc (n.d.) as the direct absorption of ions into the leaf is more toxic than absorption via the roots.

Toxicities can occur over one irrigation season or after many irrigation seasons (Ayers & Westcot, 1994). Chloride accumulation in plant leaves can cause leaf burn and necrosis (Smart-fertilizer, 2016). If a plant suffers from chloride toxicity, necrosis occurs and the leaf tips will be first to die back (Ayers & Westcot, 1994). The toxicity then spreads through the whole leaf killing plant tissue (Ayers & Westcot, 1994). A concentration of 0.3-0.1 % of chloride in plant leaves causes the death of plant cells (Ayers & Westcot, 1994).

To test for chloride toxicity a chemical analysis of the plant tissue is needed (Ayers & Westcot, 1994). Chloride toxicity is common in plants that are watered via irrigation (Ayers & Westcot, 1994). When plants are irrigated from above the chloride sits on the leaf surface (smart-fertilizer, 2016). The ions are absorbed into the leaves in periods of high temperatures, low humidity, and windy conditions (Ayers & Westcot, 1994). The severity of damage to the plant depends on the length of time it has been exposed to the chloride ions, the concentration of ions, and the crop's sensitivity to Cl^- ions. (Ayers & Westcot, 1994).

2.6.13 Effect of copper Sulphate on effluent and pasture

Copper sulphate pentahydrate ($CuSO_4 \cdot 5H_2O$) is a solid crystalline sulphate salt of copper that is light blue in colour (National Center for Biotechnology Information, 2016). Copper sulphate can be added to dairy factory effluent to remove bacteria and prevent lactic acid production (Bram Beuger, pers comm, 2016). Copper sulphate can be produced by reacting copper with sulfuric acid (Royal Society of Chemistry, 2016). Copper has antimicrobial properties that can inhibit the growth of pathogens and bacteria (Russell, 2005). Copper's antimicrobial properties were first discovered as early as 1761 although its full potential wasn't known until about 1807 (Russell, 2005). Isaac-Benedict Prevost demonstrated that a fungus could be inhibited by copper in 1807 (Russell, 2005). In the 20^{th} century, copper, sulphur and lime were widely accepted as best practice to reduce fungi (Russell, 2005). In the 1800's copper sulphate was used as a foliar spray to remove fungi and bacteria from crops (Russell, 2005). The copper sulphate worked well in removing the bacteria and fungi except that it had phytotoxic effects on the plants (Russell, 2005).

To prevent adverse effects lime was added to the mixture and in 1885, the mixture of copper and lime was found to be the best controller of fungi and bacteria (Russell, 2005). Copper ions can be absorbed into the plant leaves which can kill off plant cells as copper is not selective in the cells that it inhibits (Rosenberger, 2012). Due to copper's non-selective nature, ensuring the correct amount of copper is applied to the leaves of a plant is essential in preventing leaf damage (Rosenberger, 2012).

If copper builds up on a leaf surface and dries, it can be slowly released again each time the leaf becomes wet causing phytotoxicity (Rosenberger, 2012). If copper sulphate dries slowly on the leaves and the droplets are allowed to sit on the leaves, damage to the leaves will be higher compared to if the leaves dried fast (Rosenberger, 2012).

Copper is thought to split the outer membrane of the bacteria causing it to rupture killing the bacteria (International Copper Association, 2015). For copper to work efficiently as an antimicrobial substance, conditions such as temperature, humidity, concentration and chemical form must be considered (Vincent et al., 2016). Copper was found to be most effective at temperatures of 37^{o}C and 100% humidity (Vincent et al., 2016). If copper is applied in wet conditions, it can take hours for the bacteria to be killed off (Vincent et al., 2016). Under dry conditions it only takes minutes (Vincent et al., 2016). Vincent et al., (2016) suggested that copper concentrations 55% and above work best to remove bacteria. For a fertiliser application, to avoid toxicity copper sulphate should be diluted to 0.75kg/ha in 200 litres of water (Ravensdown, n.d). The ANZECC guidelines determined that if effluent was applied over 20 years, there should be 5 mg/L of copper present in the effluent to prevent the buildup of copper in the soil and prevent copper toxicity in crops (ANZECC, 2000).

2.6.14 Other key nutrients and their effects on pasture

Plants require other key nutrients such as calcium, magnesium, iron, zinc, copper and manganese (Njinga et al., 2013). If a plant is calcium deficient, the shoots and tips are affected first. Magnesium and zinc deficiency is shown via chlorosis and first appears in older leaves (Reckitt Benckiser, n.d.). Copper, manganese, and iron deficiencies appear in younger leaves (Reckitt Benckiser, n.d.).

2.6.15 Effects of fertiliser on pasture

Foliar fertilisation is used in many industries to ensure crops are receiving nutrients that may not be available through the soil (Fallahi & Eichert, 2013). Foliar fertilisers are up taken through the leaf via the stomata and cuticle (Hadrami, 2011; Fallahi & Eichert, 2013). Stomata are found on the surface of the leaf (Haworth et al., 2011). Stomata open and close as the tugor changes in the guard cells which surround the stomata (Haworth et al., 2011). The process of opening and closing of the guard cells is driven by ion exchange (K^+) and regulators such as abscisic acid, jasmonates, auxins and cytokinins (Daszkowska-Golec & Szarejko, 2013). The guard cells close when the ions flow out of the plant (Daszkowska-Golec & Szarejko, 2013). The process of opening and closing enables the intake of CO_2 for photosynthesis, controls the loss of water during transpiration and more importantly allows for nutrient uptake (Daszkowska-Golec & Szarejko, 2013; Haworth et al., 2011). Fallahi & Eichert (2013) state that the stomata and the cuticle move together providing a pathway for nutrient absorption but this depends on the foliar fertiliser applied.

When nutrients are absorbed via foliar fertilisation, there are “no active processes involved” in the type of nutrient or amount of nutrient absorbed (Fallahi & Eichert, 2013). Therefore, any nutrient or substance present on the leaf will be absorbed as long as it is in the correct form and conditions are right (Fallahi & Eichert, 2013). This is unlike the absorption of nutrients through the roots where processes occur to manage the nutrients taken up by the plant from the soil (Fallahi & Eichert, 2013). With adsorption through the leaf, if the nutrient is “incompatible with the plants metabolism leaf scorch occurs” (Fallahi & Eichert, 2013). Fallahi & Eichert (2013) then state that the main challenge in the application of foliar fertilisers is applying the correct amount of fertiliser to avoid leaf scorch.

Phytotoxicity is another form of “pasture burning” (Penn State College of Agricultural Sciences, 2017). Determining if it is phytotoxicity may be difficult as “soil pH, salt injury or fertiliser burn are possible factors that can mimic phytotoxicity” (Cowgill et al., 2013). Impacts of burning can occur without knowledge the problem in its early stages (Cowgill et al., 2013).

After the application of a fertiliser, a uniform pattern may emerge which is a key feature in determining phytotoxicity (Cowgill et al., 2013). Burning due to fertilisers usually develops within days of application (Cowgill et al., 2013). Burning can occur if the substance is applied directly to the plant during harsh environmental conditions, the substance drifts via wind or runoff occurs which may apply the substance to sensitive plants or the constant accumulation in the soil or in the plant (Penn State College of Agricultural Sciences, 2017). To prevent drift spraying should be done on days with low wind (Spark, 2017). Phytotoxic injury that occurs due to conditions at the time of application are most difficult to predict. The application of a solution may have been previously safe to use on plant is now injuring plants (Sparks, 2017). Intermitted injury generally occurs due to applying solutions at a "susceptible, stage of growth, plant stress level, or weather conditions" (Sparks, 2017).

Fertiliser spray concentrations are not in equilibrium with the humidity of the atmosphere and therefore the fertiliser will "evaporate until equilibrium is reached" (Fallahi & Eichert, 2013). This equilibrium is defined as the "deliquescence relative humidity" where the humidity must be high enough for the salt to absorb water from the atmosphere– its hygroscopicity (Fallahi & Eichert, 2013).

If the relative humidity is lower than the deliquescence relative humidity, then the solution will evaporate and salts will crystallize on the leaf. If the humidity is higher than the deliquescence relative humidity then salt crystals will absorb water, dissolve and stay in solution (Fallahi & Eichert, 2013).

Each fertiliser has a specific deliquescence point (Table 2-9.) (Hadrami, 2011). The deliquescence point is described as the point where a leaf will uptake nutrients and is dependent on relative humidity and temperature (Hadrami, 2011). If the relative humidity is higher than the deliquescence point the fertiliser will dissolve and become mobile ready for uptake via the leaf (Hadrami, 2011).

Table 2-9. The atmospheric relative humidity deliquescence point of fertilizers (Hadrami, 2011).

Fertiliser	Deliquescence Point (%)
$CaCl_2$	31
$Ca(NO_3)_2$	54
$Ca(HCOO)_2$	96
KCl	85
KNO_3	93
K_2SO_4	98
$MgCl_2$	33
$Mg(NO_3)_2$	54
$MgSO_4$	90
$ZnBr_2$	9
$Zn(NO_3)$	42
$ZnSO_4$	90

Sprinkler application of fertilisers during hot sunny days will allow the fertiliser to evaporate on the leaf, concentrate, and crystallise, especially salts (Hadrami, 2011). As the absorption or loss of water is dependent on relative humidity and temperature, the fertiliser will constantly cycle between mobile and immobile or dissolved and crystal forms on the leaf surface (Hadrami, 2011).

Early morning or late evening temperatures and humidity can induce the formation of dew on the pasture which will re-dissolve the crystalline fertiliser allowing it to be ready for foliar absorption (Hadrami, 2011).

The dew will dilute the fertiliser, raising humidity making moisture available for absorption (Hadrami, 2011). Chloride fertilisers with high amounts of Cl- present will be absorbed into the leaf at high amounts. Therefore, Cl- ions "burn more than nitrates and nitrates burn more than sulphates" (Hadrami, 2011). Chloride fertilisers may include potassium chloride (KCL), calcium chloride ($CaCl_2$), ammonium chloride (NH_4Cl), and magnesium chloride ($MgCl^2$).

2.7 Osmotic potential and osmolality

All solutions containing dissolved solutes and molecules are considered to have an osmotic potential (Kowles, 2010). Osmotic potential is determined by the solute concentration in a solution (Kowles, 2010) and can be measured in terms of osmolality. The pressure potential (or turgor) in a plant cell is a measure of the hydrostatic pressure within the cell. The water potential of the cell or the solution surrounding it is defined as the sum of the osmotic and pressure potentials. The difference between the water potential inside and outside the cell will induce osmosis causing water to move across a semi permeable membrane until water potential equilibrium is reached on both sides of the membrane (Kramer and Boyer, 1995, Kowles, 2010). The osmotic potential of a plant cell is generally more negative than the water potential of the solution around it, causing the cell to absorb water and develop turgor (Nabors, 1973). If the soil has less solutes compared to the plant cell, the plant will uptake water and ions from the soil. However, if the soil contains a higher amount of solutes compared to the plant cells, the water will move out of the plant cells causing a dehydration affect (Nabors, 1973, Kowles, 2010). Solute concentration can increase in plant cells within a few hours (Kramer and Boyer, 1995). Cell dehydration is based at the cell level and occurs based on how easily water can move across the plasmalemma (Kramer and Boyer, 1995). The amount of solutes that enter a cell are based on metabolic activity and not passive movements (Kramer and Boyer, 1995). An increase or decrease in the amount of solutes present in a cell is referred to as osmotic adjustment and occurs in many plants when they are exposed to high salinities and dry soils (Kramer and Boyer, 1995).

Once the water leaves the plant cells via dehydration, solutes are left behind thus the concentration of solutes increases in the cells (Kramer and Boyer, 1995). The loss of water alters the cell structure and the cell may lose turgor, causing wilting and plasmolysis (Kramer and Boyer, 1995).

Some plant species are able to tolerate wilting and plasmolysis, however, other species cannot, leading to the permanent desiccation of the leaves or the plant (Kramer and Boyer, 1995). The rate of dehydration due to changes in the osmotic potential and pressure potential depend on the properties of the plasmalemma (Kramer and Boyer, 1995). Plants react differently to an increase in certain ions such as K^+, Ca^{2+}, Mg^{2+} and Cl^-, which are no easily metabolized thus concentrate in the cell via dehydration (Kramer and Boyer, 1995). High levels of certain ions will disrupt enzyme activity in the plant cells (Kramer and Boyer, 1995) preventing plants from completing important processes for survival such as the opening of the stomata (Madhusudana et al., 1982). High concentrations of NaCl will inhibit enzymes (Kramer and Boyer, 1995). Kowles (2010) reports that farmers may often use too much fertiliser causing a dehydration effect. The solute concentration becomes higher in the soil compared to the plant cells due to the excess fertiliser which may cause burning as water is lost from the cells and solutes are concentrated in the cells.

2.8 Solutions to pasture burning

Ayers & Westcot (1994) concluded that irrigating at night is effective in reducing toxicities, in particular sodium and chloride. At night temperature and wind speed decrease and humidity increases, reducing evaporation of water and therefore reducing the concentration of ions on the leaf surface (Ayers & Westcot, 1994). Avoiding periods of hot dry wind will reduce ion build up on leaves, especially when overhead sprinkler systems are used for irrigation (Ayers & Westcot, 1994). If irrigators move, they should move downwind so that sodium that is dried on the leaves are removed via wind and the sodium is not spread to pasture that has already been irrigated (Ayers & Westcot, 1994). Increasing the droplet size will enable the leaves to stay wet for longer between irrigation cycles reducing drying out of leaves and absorption (Ayers & Westcot, 1994). Leaching the soil by flushing it out with large quantities of water will remove the chloride build up in the root zone, reducing toxicity, but in turn may prevent drainage of the soil and aeration (Ayers & Westcot, 1994). Overhead irrigation may enhance toxicity in plants where the ions are directly absorbed by leaves, unlike surface irrigation methods (Ayers & Westcot, 1994).

Rotating sprinkler head systems may allow water to evaporate between each rotation, allowing ions to concentrate on the leaves. Ayers & Westcot (1994) suggest increasing the number of revolutions of a rotating sprinkler head to more than 1 revolution per minute to prevent alternating wet and dry conditions.

2.9 Best practice for irrigation of pasture

When irrigating pasture, ensuring the soil is not water logged is key to preventing ponding (Agriculture Victoria, 2015). Irrigation should only occur for 4-6 hours per event and each paddock should have sufficient drainage to prevent water from standing for longer than 18 hours (Agriculture Victoria, 2015). In New Zealand it is usually considered that effluent irrigation should be at low enough rates to avoid any surface ponding or soil saturation. Fonterra Edgecumbe's resource consent states that a paddock cannot be irrigated again for 14 days after the initial irrigation event to help prevent soil saturation (Sheri Crompton, pers comm, 2016.). Applying irrigation to ryegrass pasture below a soil temperature of 6ºC will be inefficient as ryegrass growth slows below 6ºC (Agriculture Victoria, 2015).

The time of day irrigation occurs is important. For effective foliar absorption of nutrients, the leaf's stomata should be open (Burkhardt et al., 1999 as cited by Fageria et al., 2008). Foliar fertilisation should occur later in the day to ensure the leaf is cold and turgid (Fageria et al., 2008). This will also help prevent leaf burn. Leaf burn has been found to occur when irrigation occurred in the early morning (Woolfolk et al., 2002 as cited by Fageria et al., 2008). To prevent pasture burning, Fageria et al., (2008) suggest that macronutrient concentrations should be less than 2% in solution. Fageria et al., (2008) also states that older plants are less susceptible to high salt concentration damage than young plants.

2.10 Summary of previous investigation into pasture burning at Fonterra Edgecumbe

2.10.1 Investigation of causes of pasture burning by dairy factory effluent

In 2005, J.R Crush, S.N Nichols and M.B O'Connor carried out two experiments to determine potential causes of pasture burning at Fonterra Edgecumbe. They tested four hypotheses:

1) "Osmotic dehydration of plant tissues caused by covering the foliage in effluent with a higher osmotic potential than the plant cell sap."
2) "Applying effluent where the pH exceeds either the upper or lower limit for maintaining the integrity of the plant epidermis. Damage to the plant epidermis would allow desiccation of underlying tissues."
3) "Applying effluent at a temperature that is sufficiently elevated to damage plant enzyme systems."
4) "Applying effluent under bright sunny conditions which would exacerbate the first three factors."

The first experiment consisted of growing a ryegrass clover mixture in pots (samson ryegrass mixed with Kopu II clover) until the plants were ~4.5 months old. A "mixed sward" was also grown which was collected from Alan Barr's farm. To simulate grazing, all plants were trimmed and left to grow for 30 days before treatments were applied.

In the first experiment 4 variables were tested:

1) An upper pH of 9 and lower pH of 4.
2) Effluent temperature of 23^{o}C and 45^{o}C.
3) "Half the pots were shaded to simulate an overcast day."
4) "Two sodium concentrations": 1500 ppm and 750 ppm.
5) "Two potassium concentrations": 1700ppm and 850 ppm.
6) Plants washed down after treatment or left to dry naturally.

The level of burning was based on “visual estimates” on a scale of 1 – 5 where 1 was no burning and 5 was plant desiccation. The level of pasture burning was assessed three times in 14 days following treatment application.

Burning was recorded on the pots that contained “sown ryegrass/clover mixture” and those that were in full sun compared to half sun. Individual pH, effluent temperature, sodium and potassium treatment caused no significant burning. However, combinations of “high sodium/no washdown” treatments caused severe burning of plants in pots filled with sown ryegrass/clover, the only “statistically significant interaction”.

In a second more detailed experiment pots with Samson ryegrass were treated with “6 rates of potassium and sodium (1000, 2000, 4000, 8000, 16000, 32000 ppm).” Each treatment was sprayed in water onto the leaves and each treatment was repeated twice at a rate equivalent to 10mm irrigation. Whey was also applied in concentrations of 5, 10, 20, 40, 80 and 160g/l. None of the treatments had adverse effects on the ryegrass.

As part of the second experiment, pots filled with ryegrass/white clover were also treated but with effluent pH’s of 1.9, 3.2, 5.8, 7.8, 10.1 and 12.0. All pots used in the second experiment were placed in full sunlight in a glasshouse for two weeks. Results showed that only pH 1.9 had an effect on the clover leaves (Figure 2-5). Again, ryegrass was not affected suggesting it is a hardy grass that has a high level of tolerance. White clover however, seemed to be more susceptible to high sodium and low pH.

Figure 2-5. Damage to white clover leaves due to pH of 1.9 (Crush et al., 2005).

Hypotheses two (“Applying effluent where the pH exceeds either the upper or lower limit for maintaining the integrity of the plant epidermis.

Damage to the plant epidermis would allow desiccation of underlying tissues.”) and four (“Applying effluent under bright sunny conditions which would exacerbate the first three factors.”) could be accepted. The recommendations that came from Crush et al., (2005) included reducing high light intensity, avoid irrigating new pasture, do not irrigate effluent with a pH below 2 and samples of the effluent should be collected and frozen for future analysis if needed.

2.10.2 Pasture burning trial – lactic acid

Fonterra undertook a small trial in February of 2016 to determine if lactic acid had an effect on pasture (Bram Beuger, pers comm, 2016.). Lactic acid is found in the effluent due to bacteria converting lactose solution to lactic acid. Copper sulphate has been added to the effluent to inhibit bacterial growth and thus the formation of lactic acid.

Ten 0.25 m^2 plots were mapped out with 0.25 m^2 gaps between each plot. Each plot received 2 L of effluent which replicated 8mm of irrigation. Each plot was treated with a different concentration of lactic acid (Table 2-10). One liter from each solution was removed and stored in a lab bottle in a fridge for future analysis.

Table 2-10. Lactic acid concentration for experiment (Bram Beuger, pers comm, 2016.).

Sample	Effluent litres	Diluted Lactic acid (ml)	Total litres	Lactic acid concentration (g/L)
1	3	0	3	0.00
2	3	5	3.005	0.07
3	3	10	3.01	0.15
4	3	15	3.015	0.22
5	3	20	3.02	0.29
6	3	25	3.025	0.36
7	3	40	3.04	0.58
8	3	60	3.06	0.86
9	3	80	3.08	1.14
10	3	330	3.33	4.36

Results of this experiment concluded that lactic acid may be a potential cause of pasture burning,

2.11 Summary and Conclusion

Pasture burning may also be referred to as "leaf scorch", "leaf burn", "leaf wilt", "sun scorch" or in some cases "phytotoxicity". Relating field observations to researched theories on leaf burn was important but there has been minimal direct research related to burning of pasture from dairy factory effluent. The following conclusions can be made from the research summarised in my literature review:

- It is possible that direct contact of such a high or low pH solution on the leaf surface could damage the plant cells creating dark brown spots. Lactic acid production via fermentation of effluent could lower the pH and thus cause damage to plant leaves. However, the work undertaken by Fonterra did not show evidence of burning due to lactic acid. Crush et al., (2005) observed that burning only occurred when the pH was <1.9, a level considered unlikely to occur even with lactic acid production.
- High temperature effluent, if applied to the soil, may alter the temperature of the soil temporarily reducing oxygen and nutrient up-take. Knowing the temperature of the soil before irrigation is applied is important. Applying hot effluent to cold soil may shock the plant. The effluent temperature should ideally be between 16 ^{o}C and 22^{o}C to prevent potential burning.
- The osmotic potential is a direct measurement of the total amount of solutes in a solution. If the osmotic potential of the solution is more negative than the water potential of the plant water will be lost from the plant cells. High temperatures may enhance dehydration by concentrating the external salt solution and increasing plant water loss by transpiration. The loss of water and the concentration of ions inside and outside the plant cells can cause burning of the leaves.
- Plants respond to UV-A, UV-B and UV-C radiation. Intense UV radiation can reduce the integrity of the epidermis causing the plant to become more susceptible to environmental stressors. If the epidermis is damaged, effluent addition more easily cause leaf burn. As plants have evolved to utilize UV radiation and therefore heal from UV damage, the likelihood of UV radiation causing pasture burning is low.

- The magnification of water droplets from the sun sitting on leaf of a plant has shown to be unlikely because the focal point will sit beneath the leaf surface.
- Nutrients are vital to plant growth. Ensuring the soil contains the key macro and micronutrients is important. If high amounts of nutrients are applied to the soil, via fertilisation, pasture burn may occur. Nitrogen and phosphorus deficiencies are similar in that yellowing of older leaves occurs as well as stunted growth.
- Sodium build-up in leaves is toxic causing die-back of the oldest leaves first. Boron toxicity is like sodium in that the older leaves yellow and the edges of the leaves dry out. Chloride also builds-up in plant leaves which is common in plants that are irrigated by foliar irrigation. Chloride toxicity can cause leaf burn and die-back of the leaf tips.
- Excess sodium can reduce soil structure, thus slowing soil drainage and leading to ponding of irrigation water. Loss of soil structure reduces soil permeability and may cause a crust to form on the surface. The crust may be formed from salt or as a result of degradation of soil structure.
- Potassium is required to maintain water in a plant. Potassium ions are involved in regulation of cell osmotic and membrane potentials. Excess application of potassium may cause imbalances in nutrient transport that lead to nutrient toxicity and burning. The application of fertiliser onto pasture adds soluble salts. Salts can "burn" plant leaves, turning leaves yellow/brown and the veins darken eventually causing the leaves to die back if applied in high concentrations. For example, Cl- should not be applied in concentrations above 350ppm. Fertilisers or nutrient rich effluent may therefore be a contributing cause of pasture burning.
- Overhead irrigation may cause phytotoxicity or a build-up of ions in the leaf due to direct absorption causing dieback of the leaf. Irrigating at night reduces nutrient build-up as the humidity is high reducing transpiration and therefore uptake of water and concentrated ions is less compared to day-time.
- Hot dry windy conditions should be avoided as ions build-up on plant leaves. Droplet size of the irrigated effluent should be large enough so the leaves do not dry out between sprinkler cycles.

- Older plants are more tolerant of high salt concentrations than younger plants.
- Osmotic potential is an integrating measure of the combined effects that may cause pasture burning. The osmotic potential will measure the amount of solutes dissolved in a solution. If the amount of solutes in the soil or on the leaf surface is higher than inside the plant cells, water will move out of the plant causing the solute in the plant cells to concentrate. Dehydration and the concentration of solute in plant cells can cause burning (Kowles, 2010).
- When irrigating, the soil must not be water logged as ponding will occur. Each paddock should also have sufficient drainage to prevent the water from standing for more than 18 hours.

Chapter 3

Fonterra Edgecumbe Dairy Factory effluent production and properties

3.1 Introduction

Chapter Three describes the soils on the farms Fonterra Edgecumbe irrigates, effluent sources and composition, both from Fonterra monitoring and from some measurements undertaken in this study and the consents that control the effluent irrigation process.

3.2 Soil and pasture

The Rangitikei Plains soils were mapped by Pullar (1985) (Appendix 6). Data for the soils of the region are also included in S-map (Landcare Research, 2011-2015). The soils under effluent irrigation on farms near the Edgecumbe dairy factory include five Soil Orders, seven Soil Groups and nine Soil Subgoups. The 9 subgroups are; Acidic Orthic Gley Soil, Buried- pumice Tephric Recent Soil, Typic perch-gley Pumice Soil, Acidic Recent Gley Soil, Acidic Humic Organic Soil, Hummus-pan Pan Podzol, Immature Orthic Pumice Soil, Mottled Tephric Recent Soil, and Mottle Acidic Fluvial Recent Soil. On many of the farms, the soil drainage is poor and there is a high-water table.

The key plant species on the farms receiving effluent from the Edgecumbe dairy factory are white clover and *Lolium perenne* ryegrass (Figure 3-1.).

Figure 3-1. White clover and *Lolium perenne* ryegrass found at experiment site.

3.3 Effluent Composition

Fonterra Edgecumbe produces low strength effluent, medium strength effluent, and high strength effluent. The low strength effluent is made up of clean rinses, low solids DAF effluent, and low strength effluent from floor drains and sumps (Petra Feickert, pers comm, 2017.). The medium strength effluent contains casein wash water, equipment water rinses and cleaning cycles, high solids dissolved air flotation (DAF) clarifier effluent and effluent from floor drains and sumps (Petra Feickert, pers comm, 2017.). The high strength effluent is made up of permeates, whey derivatives, and product waste (Petra Feickert, pers comm, 2017.). The effluent this project is concerned with is the high strength effluent of which ~500 to 1000m^3 of high strength effluent is sent to Awaroa daily. ~1000 to 1600m^3 of medium strength effluent and ~500 to 700m^3 of high strength waste water are sent to Omehue daily. With ~4 to 7000 m^3 of low strength effluent is discharged directly to the Rangitikei river daily. Fonterra Edgecumbe’s high strength effluent contains nutrients of potential fertiliser value (Table 3-1.). The effluent composition varies from year to year (Tables 3-1, 3-2, 3-3, 3-4 and 3-5).

The high strength effluent has a strong fermentation odour and is light yellow in colour. The pH ranges from 4 to 10 depending on site processes. Many of the minerals and ions originate from the milk but some ions are added from cleaning products during milk processing. Each processing plant on site has an effluent stream that contributes to the effluent (Figure 3-2; 3-3.). The effluent is then sent to the Awaroa holding tanks (Figure 3-2; 3-3.). From the holding tanks, the effluent travels through pipelines into paddocks and is irrigated (Bram Berger, pers comm, 2016).

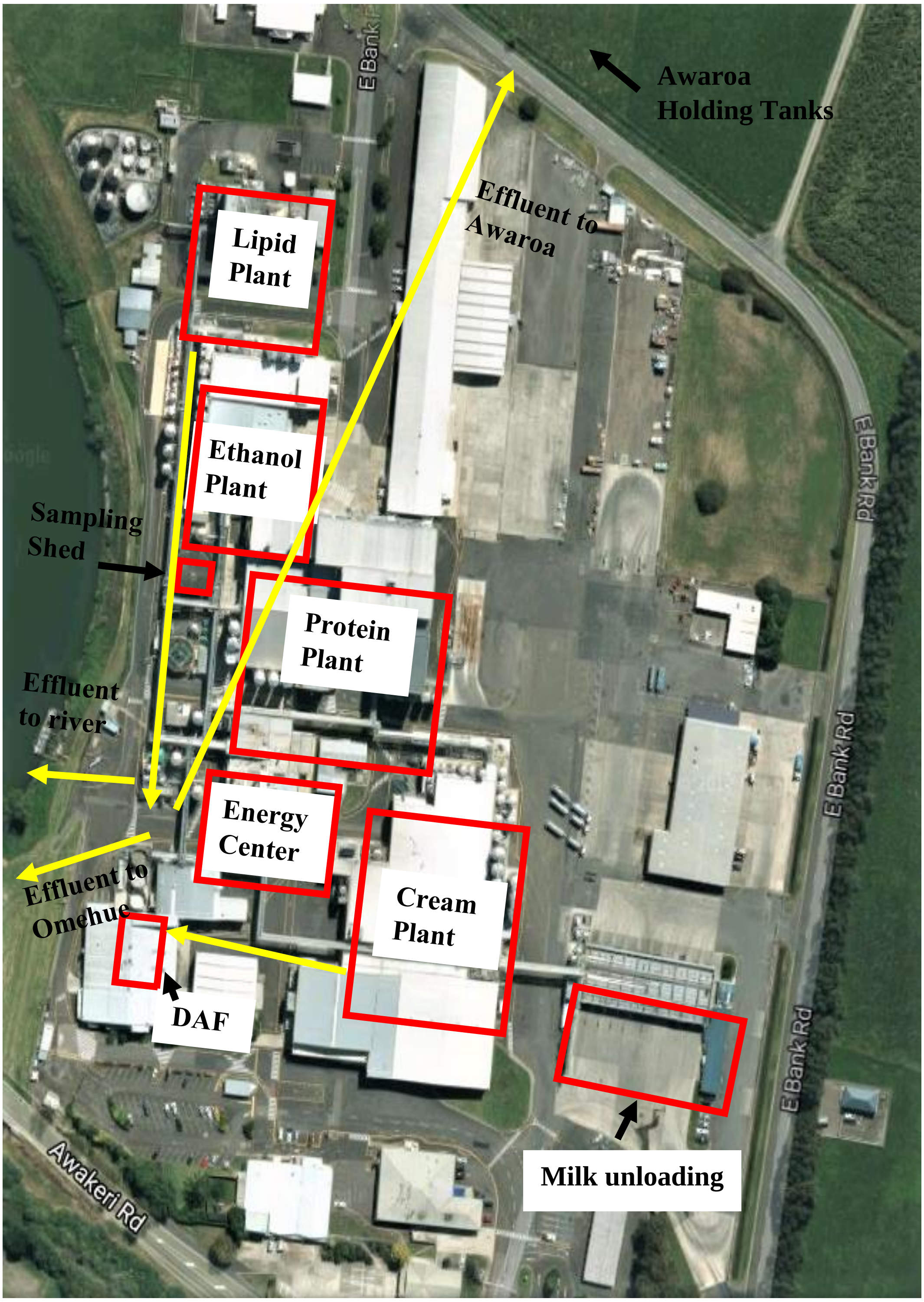
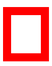


Figure 3-2. Key processing plants and effluent lines at Fonterra Edgecumbe.

 = Effluent lines  = Key processing plants at Fonterra Edgecumbe

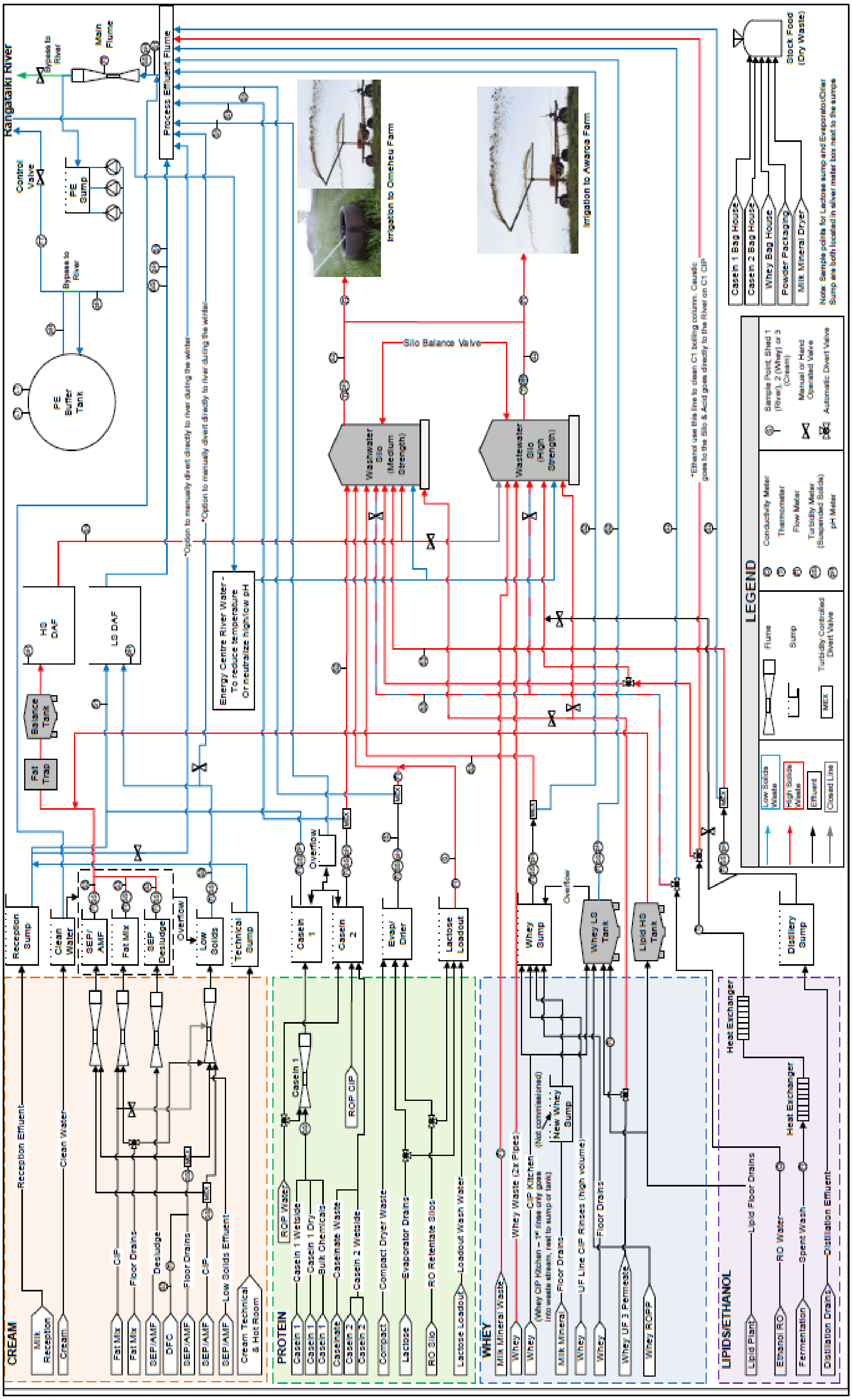


Figure 3-3. Fonterra Edgecumbe effluent flow overview diagram.

The mean Total Nitrogen (g/m^3), mean TKN (g/m^3) and mean Nitrate-Nitrogen (g/m^3) present in the high strength effluent has increased from season 15 (1st August 2014 – 31st March 2015) to season 17 (1st August 2016 – 31st March 2017, Table 3-1). The mean Nitrite-Nitrogen (g/m^3) was high at the start of each season but decreased as the season progressed. Nitrate-N + Nitrite-N (g/m^3) overall, has increased significantly from season 15 to season 17.

Table 3-1. Total Nitrogen (g/m^3), TKN (g/m^3), Nitrate – Nitrogen (NO3-N) (g/m^3), Nitrite – Nitrogen (NO2-N) (g/m^3) and Nitrate-N + Nitrite-N (g/m^3) levels in the high strength effluent from Fonterra Edgecumbe for season 15, 16 and 17; mean of 30 or 31 daily measurements for the months of March, August, November and January (Orange = season 15; Pink = season 16; Green = season 17) (Sheri Crompton, pers comm, 2017).

Effluent Properties	Total Nitrogen (g/m^3)			TKN (g/m^3)			Nitrate – Nitrogen (NO_3-N) (g/m^3)			Nitrite – Nitrogen (NO_2-N) (g/m^3)			Nitrate-N + Nitrite-N (g/m^3)		
	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max
1st – 31st August 2014	192	85	280	189	79	280	3.14	0.05	11.7	0.42	0.02	2.3	2.3	0.92	3.5
1st – 30st November 2014	188	124	220	188	124	220	3	0.51	5.9	0.11	0.02	0.27	3.15	0.52	5.9
1st – 31st January 2015	229.8	174	290	226	174	280	4.09	0.14	20	0.16	0.1	0.19	3.96	0.11	20
1st – 31st March 2015	194	108	280	190	105	270	3.87	0.21	53	0.527	0.095	1.77	3.97	0.25	53
1st – 31st August 2015	214	81	340	214	59	330	9.7	0.1	55	0.93	0.1	2.2	10.1	1.33	55
1st – 30st November 2015	240.1	140	290	237	164	280	3.94	0.35	14.8	0.13	0.11	0.19	3.99	0.45	14.8
1st – 31st January 2016	271.6	200	340	264	199	310	7.14	2.7	37	<0.10	<0.10	<0.10	7.16	2.7	37
1st – 31st March 2016	320.3	250	420	315	240	410	5.6	2.2	23	0.1	0.1	0.1	5.6	2.2	23
1st – 31st August 2016	215	95	510	210	95	500	5.4	0.4	13.1	5.4	0.18	5.6	5.1	0.4	13.3
1st – 30st November 2016	262.5	130	480	245.7	130	470	6.89	2.6	46	0.145	0.14	0.15	6.91	2.6	46
1st – 31st January 2017	255.41	158	340	254.3	155	410	6.8	1.4	27	0.29	0.13	0.58	6.85	1.9	27
1st – 31st March 2017	265.11	183	360	259	175	360	6.94	1.57	15.3	<0.10	<0.10	<0.10	6.96	1.61	15.4

Total Solids (g/m^3), Total Volatile Solids (g/m^3) and the Chemical Oxygen Demand (g O_2/m^3) for seasons 15, 16 and 17 are discussed using data from key months during the dairying season (Table 3-2.). Over seasons 15 to 17, the mean Total Solids (g/m^3) and mean Total Volatile Solids (g/m^3) remained stable. However, during the key processing months of November and January the mean Total Solids (g/m^3) and mean Total Volatile Solids (g/m^3) increased slightly. The mean Chemical Oxygen Demand (g O_2/m^3) fluctuated slightly from season 15 to 17, however remained relatively stable.

Table 3-2. Total Solids (TS) (g/m^3), Total Volatile Solids (g/m^3) and Chemical Oxygen Demand g O^2/m^3 levels in the high strength effluent from Fonterra Edgecumbe for season 15, 16 and 17; mean of 30 or 31 daily measurements for the months of March, August, November and January (Sheri Crompton, pers comm, 2017).

Effluent Properties	*Total Solids (TS) (g/m^3)*			*Total Volatile Solids (g/m^3)*			*Chemical Oxygen Demand g O_2/m^3*		
	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max
1st – 31st August 2014	19709	550	29000	13113	550	24000	15800[1]	-	-
1st – 30st November 2014	18857	14800	24000	10787	7100	15600	14200[1]	-	-
1st – 31st January 2015	20823	17700	26000	13200	8000	17700	16800[1]	-	-
1st – 31st March 2015	12665	8400	19200	6174	3800	10700	11600[1]	-	-
1st – 31st August 2015	17606	2300	34000	9181	1330	25000	12400[3]	11600[3]	13200[3]
1st – 30st November 2015	24167	20000	30000	13590	9800	20000	17400[1]	-	-
1st – 31st January 2016	21881	16600	30000	11258	6900	19000	19083.8	12900	41000
1st – 31st March 2016	23629	17100	30000	12019	7700	18000	17912	12000	23000
1st – 31st August 2016	17440	10000	28000	9248	5600	22000	16259	6900	117000
1st – 30st November 2016	21085.7	15600	27000	10310.3	6600	16100	14965.5	10200	21000
1st – 31st January 2017	20133.3	16200	25000	9630	7100	15100	14730	10500	19400
1st – 31st March 2017	17850	15100	22000	8121	6100	12000	16100[1]	-	-

[1] Only one measurement was taken for the month thus values are the same.
[3] Only two measurements were taken for the month.

The Magnesium (g/m^3), Sodium (g/m^3), Potassium (g/m^3) and Calcium (g/m^3) in the effluent for seasons 15, 16 and 17 are discussed using data from key months during the dairying season (Table 3-3.). The data for Magnesium (g/m^3), Sodium (g/m^3), Potassium (g/m^3) and Calcium (g/m^3) was only tested for once a month thus is not an accurate representation of the effluent. However, all ions measured peak in November and January meaning the strength of the effluent increases during peak processing and then decreases again towards the end of the season.

Table 3-3. Magnesium (g/m^3), Sodium (g/m^3), Potassium (g/m^3) and Calcium (g/m^3) in the high strength effluent composition from Fonterra Edgecumbe for season 15, 16, and 17; mean of 30 or 31 daily measurements for the months of March, August, November and January (Sheri Crompton, pers comm, 2017).

Effluent Properties	Magnesium (g/m^3)			Sodium (g/m^3)			Potassium (g/m^3)			Calcium (g/m^3)		
	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max
1st – 31st August 2014	71[1]	-	-	710[1]	-	-	960[1]	-	-	1170[1]	-	-
1st – 30st November 2014	86[1]	-	-	990[1]	-	-	1160[1]	-	-	800[1]	-	-
1st – 31st January 2015	89[1]	-	-	970[1]	-	-	1200[1]	-	-	870[1]	-	-
1st – 31st March 2015	88[1]	-	-	1150[1]	-	-	1120[1]	-	-	420[1]	-	-
1st – 31st August 2015	87.5[3]	85[3]	90[3]	1210[3]	1190[3]	1230[3]	1340[3]	1270[3]	1410[3]	735[3]	670[3]	800[3]
1st – 30st November 2015	98[1]	-	-	1250[1]	-	-	1450[1]	-	-	1390[1]	-	-
1st – 31st January 2016	114[1]	-	-	1430[1]	-	-	1660[1]	-	-	950[1]	-	-
1st – 31st March 2016	104[1]	-	-	1270[1]	-	-	1280[1]	-	-	810[1]	-	-
1st – 31st August 2016	90[1]	-	-	1050[1]	-	-	1270[1]	-	-	1360[1]	-	-
1st – 30st November 2016	113[1]	-	-	1430[1]	-	-	1690[1]	-	-	1460[1]	-	-
1st – 31st January 2017	105[1]	-	-	1260[1]	-	-	1130[1]	-	-	1320[1]	-	-
1st – 31st March 2017	113[1]	-	-	1180[1]	-	-	1220[1]	-	-	1070[1]	-	-

[1] Only one measurement was taken for the month thus values are the same.
[3] Only two measurements were taken for the month.

Conductivity (mS/m), Chloride (g/m^3), Lactic Acid (g/m^3) and Total Phosphorus (g/m^3) in the effluent for seasons 15, 16 and 17 are discussed using data from key months during the dairying season (Table 3-4.). As in table 3-3, the ion content of the effluent increased during the peak processing months (November and January) which is reflected in the conductivity measurements which increases in these months also. The lactic acid measurements were undertaken as a trial during season 17 thus there is no data from season 15 or 16. The amount of lactic acid present increased over season 17 reaching its peak in January with a mean of 1995.1 g/m^3. The amount of total phosphorus present in the effluent has increased from season 15 to season 17 reaching a maximum of 1170 g/m^3 in season 17.

Table 3-4. Conductivity (mS/m), Chloride (g/m^3), Lactic Acid (g/m^3) and Total Phosphorus (g/m^3) in the high strength effluent composition from Fonterra Edgecumbe for season 15, 16, and 17; mean of 30 or 31 daily measurements for the months of March, August, November and January (Sheri Crompton, pers comm, 2017).

Effluent Properties	Conductivity (mS/m)			Chloride (g/m^3)			Lactic Acid (g/m^3)			Total Phosphorus (g/m^3)		
	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max
1st – 31st August 2014	746	273	1090	510[1]	-	-	-	-	-	499	190	680
1st – 30st November 2014	905.1	844	987	600[1]	-	-	-	-	-	464	360	570
1st – 31st January 2015	928.1	863	1057	630[1]	-	-	-	-	-	394.8	240	480
1st – 31st March 2015	795	380	1135	750[1]	-	-	-	-	-	252	84	560
1st – 31st August 2015	862	158.8	1133	620	570	670	-	-	-	465	56	760[3]
1st – 30st November 2015	1088.6	8.6	1221	680[1]	680[1]	680[1]	-	-	-	643	530	910
1st – 31st January 2016	1131.5	1006	1223	728.3	240	880	-	-	-	573.5	430	750
1st – 31st March 2016	1197	1026	1327	926	790	1080	-	-	-	588	360	800
1st – 31st August 2016	772	146.7	1047	479	125	690	1097	149	2400	700	470	1250
1st – 30st November 2016	1148.5	889	1990	692.4	450	890	1563.14	910	2300	610.3	380	860
1st – 31st January 2017	1051.2	816	1238	660	470	940	1995.1	1060	3900	640.6	450	1170
1st – 31st March 2017	1071	915	1210	760[1]	-	-	-	-	-	488.6	350	750

[1] Only one measurement was taken for the month thus values are the same.

The pH, DRP (NO_4-N) (g/m^3), $CBOD_5$ g O_2/m^3, $tBOD_5$ (O_2/m^3) and Ash (g/m^3) is also measured in the effluent (Table 3-5). pH, DRP, $CBOD_5$ and $tBOD_5$ are only measured once per month thus the results are not an accurate representation of the effluent. The effluent has remained between a pH of 4.2 and 5.5 through seasons 15 to 17 based on the monthly data presented. DRP has not increased significantly over the three seasons but is slightly higher in season 17. $CBOD_5$ data shows no significant outliers between season 15 and season 17. The effluent $CBOD_5$ ranges between 3400 g O_2/m^3 and 15300 g O2/m3 which is a large difference but over three seasons the $CBOD_5$ does not move outside this range according to the data provided. The $tBOD_5$ in the effluent decreased overall in season 16 and 17, again however the data provided is a monthly recording and does not provide evidence for variance in the effluent. The amount of ash present in the effluent was measured daily giving a more accurate picture of the amount present. In season 15 ash levels present in the effluent peaked at the beginning of the season and at the end of the season based on the maximum. In season 16 and 17 ash levels peaked in November and January, however levels were very similar throughout the whole season.

Table 3-5. pH, DRP (NO_4-N) (g/m^3), $CBOD_5$ (g/m^3), $tBOD_5$ (g/m^3) and Ash (g/m^3) in the high strength effluent composition from Fonterra Edgecumbe for season 15, 16, and 17; mean of 30 or 31 daily measurements for the months of March, August, November and January (Sheri Crompton, pers comm, 2017).

Effluent Properties	pH			DRP (NO_4-N) (g/m^3)			$CBOD_5$ g O_2/m^3			$tBOD_5$ (O_2/m^3)			Ash (g/m^3)		
	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max
1st – 31st August 2014	5.4[1]	-	-	410[1]	-	-	10300[1]	-	-	410[1]	-	-	6614	360	10500
1st – 30st November 2014	5[1]	-	-	340[1]	-	-	12800[1]	-	-	7200[1]	-	-	8037	7400	9200
1st – 31st January 2015	4.4[1]	-	-	390[1]	-	-	12200[1]	-	-	11200[1]	-	-	10174	7000	79000
1st – 31st March 2015	4.2[1]	-	-	131[1]	-	-	7400[1]	-	-	4400[1]	-	-	6532	2800	10100
1st – 31st August 2015	5.04[3]	-	-	310[3]	-	-	7150[3]	-	-	310[3]	-	-	8004	1010	11200
1st – 30st November 2015	5[1]	-	-	410[1]	-	-	11600[1]	-	-	8200[1]	-	-	10613	9300	11900
1st – 31st January 2016	4.7[1]	-	-	320[1]	-	-	15300[1]	-	-	7400[1]	-	-	10771	9100	16600
1st – 31st March 2016	5.2[1]	-	-	300[1]	-	-	3400[1]	-	-	300[1]	-	-	11213	116	12900
1st – 31st August 2016	5.5[1]	-	-	410[1]	-	-	8400[1]	-	-	410[1]	-	-	7898[1]	860[1]	10100
1st – 30st November 2016	5.3[1]	-	-	400[1]	-	-	11100[1]	-	-	8800[1]	-	-	10689.6	8400	13200
1st – 31st January 2017	5.3[1]	-	-	520[1]	-	-	8000[1]	-	-	5100[1]	-	-	10516.6	8700	13000
1st – 31st March 2017	5[1]	-	-	-	-	-	-	-	-	9300[1]	-	-	9711	8400	11400

[1] Only one measurement was taken for the month thus values are the same.

3.3.1 Effluent pH, temperature and conductivity from the sampling shed, short term variability and regular monitoring

3.3.1.1 Introduction

Continuous monitoring of the pH, temperature and conductivity of the effluent in the Awaroa and Awakeri effluent line was undertaken to determine the short-term variability of the effluent being irrigated.

3.3.1.2 Methods

Electrical conductivity, temperature and pH data were collected from the Awaroa effluent line on site at Edgecumbe Fonterra from the 6th to the 21st of December 2016. The data were collected to determine if there was much short-term variability in the effluent. Three probes were used to collect the data; a HACH HQ40D multi meter probe and two YSI Professional Plus (Pro Plus) Multiparameter Instruments (Figure 3-3; 3-4).

The first YSI Professional Plus (Pro Plus) Multiparameter Instrument was supplied by Fonterra Edgecumbe. The second YSI Professional Plus (Pro Plus) Multiparameter Instrument was supplied by the Bay of Plenty Regional Council.

Figure 3-4. YSI Professional Plus (Pro Plus) Multiparameter Instrument (Fondriest Environmental, Inc (2017).

Figure 3-5. HACH HQ40D multi meter probe (Bryant, 2015.).

The YSI Professional Plus (Pro Plus) Multiparameter Instruments were calibrated following the calibration process described in the YSI Professional Plus User Manual on pages 32 – 48.

The YSI probe setup and calibration process was;

1) Plug the pH and conductivity probe attachment into the bottom of the YSI Professional Plus (Pro Plus) Multiparameter Instrument,
2) Select the Calibration button,
3) Highlight "pH" and press enter,
4) Place probe into pH buffer solution 4 and wait until calibration is complete,
5) Repeat step 4) using pH buffer solution 7 and then 10, and
6) Complete steps 2) to 5) again to calibrate the conductivity probe.

The HACH HQ40D multi meter probe was calibrated following the calibration process described in the Conductivity Probe: DC40101, CDC40103, CDC40105, CDC40110, CDC40115 or CDC40130 User Manual on page 3.

The HACH probe setup and calibration process was;

1) Plug the pH and conductivity probe attachments into the top of the HACH HQ40D multi meter probe,
2) Select "CALIBRATE",
3) Place conductivity standard solution into a beaker,
4) Wash the probe with deionized water,
5) Place probe in the beakers containing the conductivity standard solution ensuring the sensor is completely submerged,
6) Push "READ" and the screen will show "Stabilizing" as a progress bar fills.
7) Once the progress bar is full calibration is complete, and
8) Push "STORE" to accept the calibration and return to measurement mode.

The HACH HQ40D multi meter probe and two YSI Professional Plus (Pro Plus) Multiparameter Instruments were used to collect the data to ensure each probe was working correctly. The Fonterra YSI Professional Plus (Pro Plus) Multiparameter Instrument was screwed into the line in the sampling shed directly measuring effluent as it moved past from the 6th – 7th December 2016 and from the 12th – 22nd December 2016 (Figure 3-6).

Figure 3-6. YSI Professional Plus (Pro Plus) Multiparameter Instrument screwed directly into the Awaroa effluent line.

The Bay of Plenty regional council YSI Professional Plus (Pro Plus) Multiparameter Instrument was also screwed into the line in the sampling shed directly measuring effluent as it moved past from the 7th – 9th December 2016.

The HACH HQ40D multi meter probe was placed inside an over flow bucket where the hose that was placed in the overflow bucket was connected directly to an outlet on the Awaroa line in the sampling shed. The pump in the sampling shed that sends the effluent from the high strength effluent storage tank to the Awaroa holding tanks turns on when the levels are high enough, this means the probe was only reading fresh effluent every ~30 minutes to ~1 hour.

3.3.2 Results

The conductivity recorded from the sampling shed on site showed a large spike on the 7th of December 2016 reaching 5000 mS/cm (Figure 3-7). There were small spikes ranging from 49 to 151 mS/cm on the 12th to 21st of December 2016. The second YSI Professional Plus (Pro Plus) Multiparameter Instrument (council probe) conductivity did not work as the probe was broken which is shown as the green highlight (Figure 3-7). Individually, the pH and temperature from the 6th to 21st of December 2016 showed varying spikes. pH spiked between 5 and 12 (Figure 3-8). Temperautre showed a random varied pattern over time moving between 20 °C and 60°C (Figure 3-9).

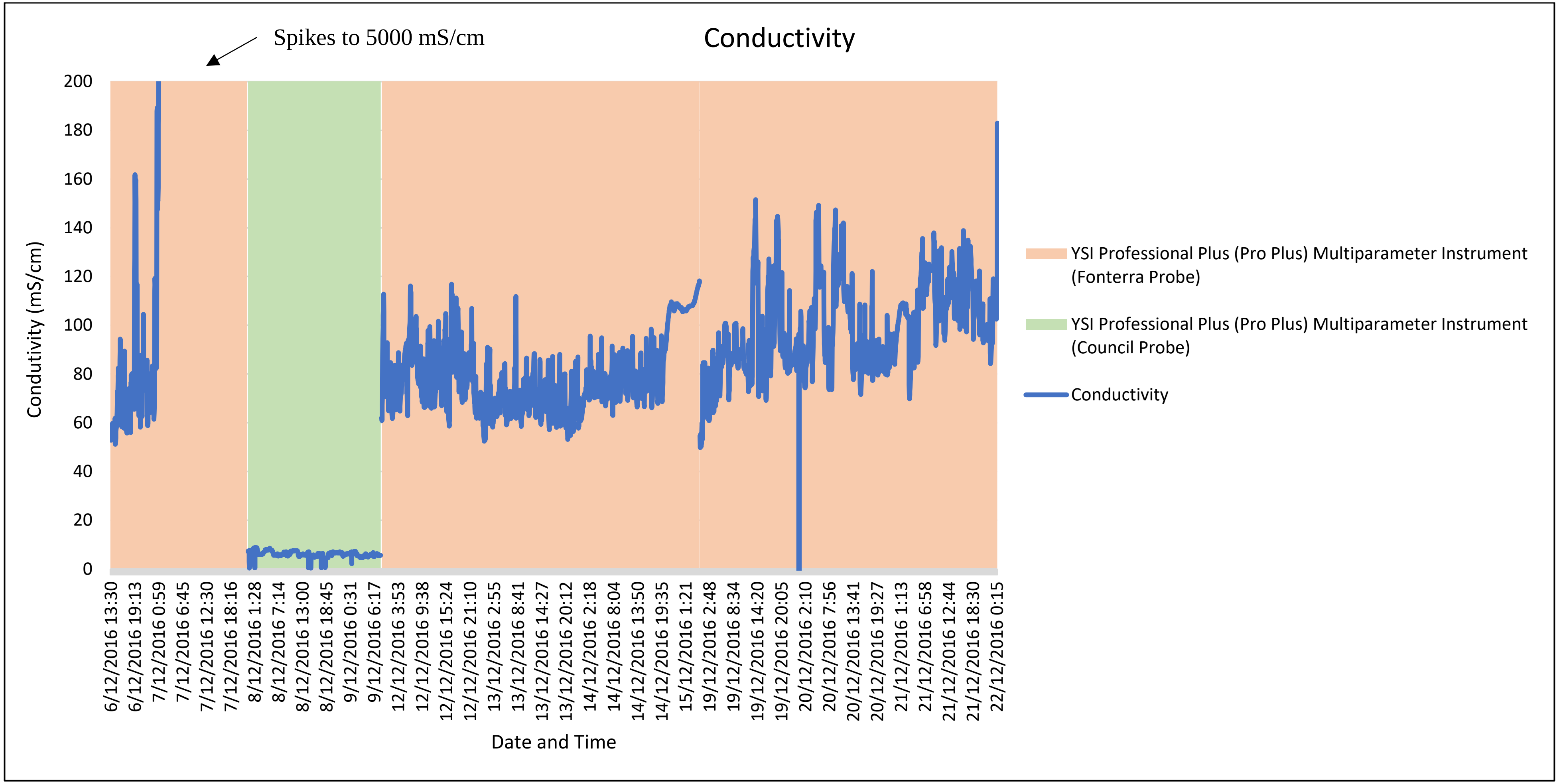


Figure 3-7. Conductivity of effluent in sampling shed.

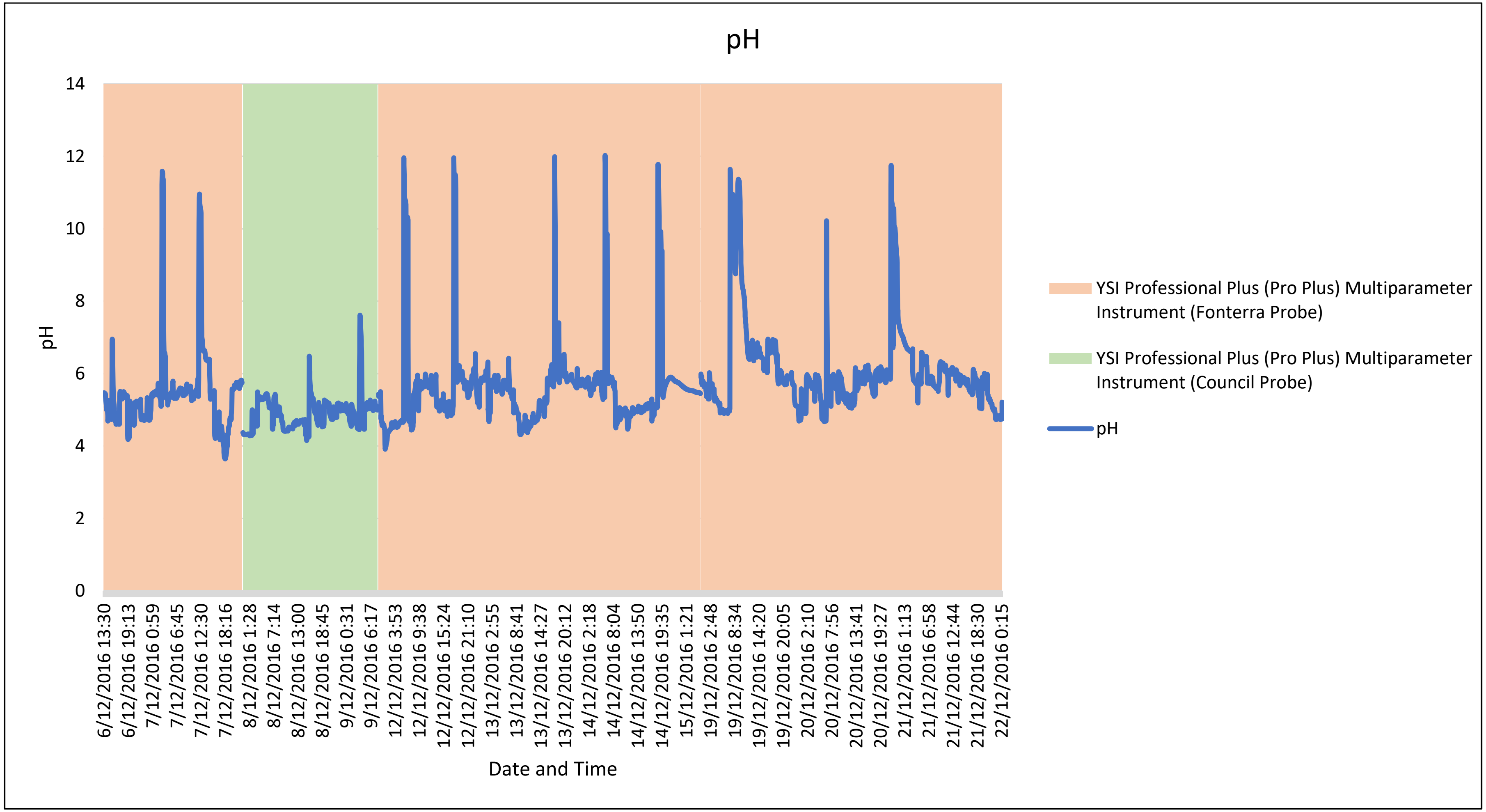


Figure 3-8. pH of effluent in sampling shed.

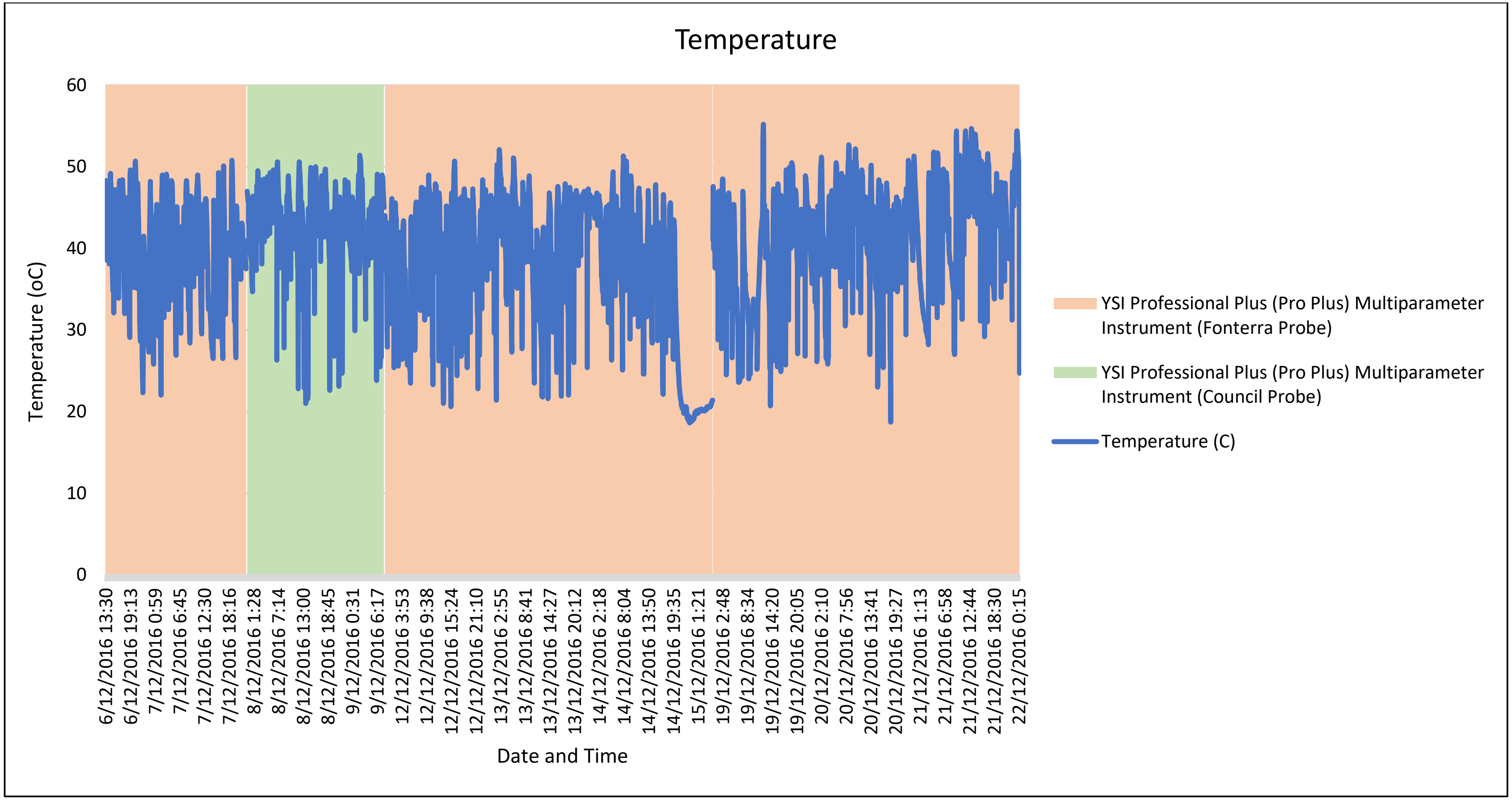


Figure 3-9. Temperature of effluent in sampling shed.

3.3.3 Probe data collection of continuous pH, temperature and conductivity from the Awakeri line at the Awaroa tanks

3.3.3.1 Methods

Conductivity, temperature and pH data were also collected from the Awakeri line at the Awaroa tanks over 3 days. A hose was connected to the Awakeri effluent line (Figure 3-10). The hose ran into the holding tank where it was placed into a small overflow container (Figure 3-11). The HACH HQ40D multi meter probe was placed in the overflow container and set to record continuously. The data on the probe was collected and uploaded onto a USB stick every 24 hours.

Figure 3-10. Hose connected to Awakeri effluent line.

Figure 3-11. Hose running into holding tank.

3.3.4 Results

The HACH HQ40D multi meter probe measured conductivity and temperature for three days. The data presented below shows that the conductivity of the effluent varies daily ranging between ~40 mS/cm to ~85 mS/cm (Figure 3-12). Temperature varies between ~35^{o}C and ~55^{o}C. However, the graph also shows large drops in temperature which correlates to night time. pH was not measured as the pH probe was broken.

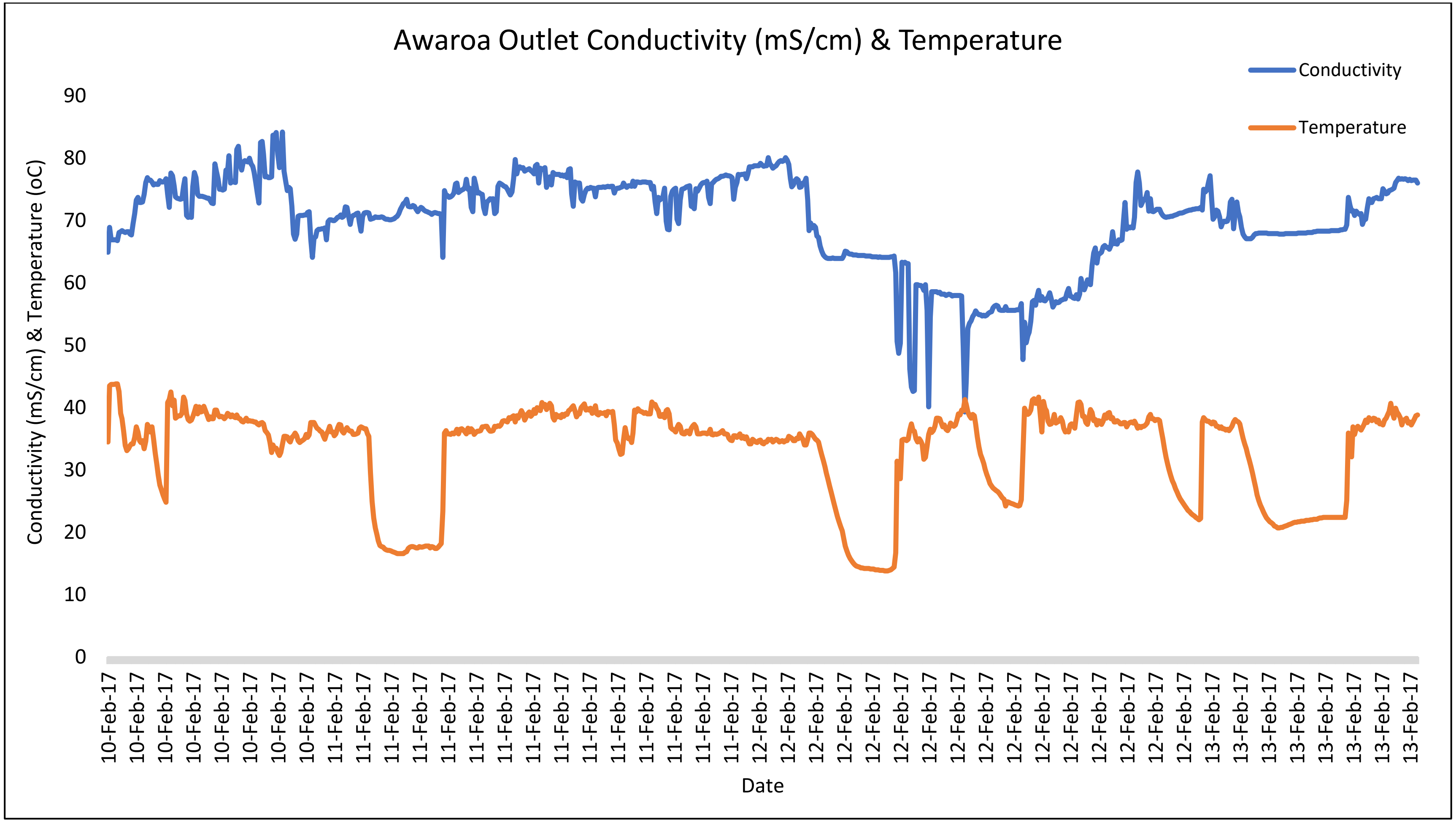


Figure 3-12. Conductivity and temperature data from Awakeri line at Awaroa tanks over 3 days.

3.4 Fonterra Edgecumbe resource consents

The Fonterra Edgecumbe dairy factory currently holds 10 resource consents, one of which relates to effluent discharge to land (Table 3-6). Many of the resource consents allow Fonterra Edgecumbe to discharge various materials to water-ways, land, and air.

Table 3-6. Fonterra Edgecumbe resource consents (Sheri Crompton, pers comm, 2017).

Consent	Purpose
64482	To authorise activities associated with the removal of accumulated sediment from the bed of the Rangitaiki River adjacent to the Fonterra water intake structure.
27	Consent to discharge trade waste to the public sewer.
67242	Discharging dissolved air flotation (DAF) and dairy effluent silo solids to land from the consent holder's operation at Edgecumbe and its associated silo compound areas onto various farms within the Whakatane District.
65800-AP	Discharge treated dairy manufacturing effluent to land and the associated discharge of contaminates to air.
02 4211	For the purpose of discharging cooling water, effluent and water treatment sedimentation solids from the consent holder's dairy factory and from the New Zealand Distillery Company Limited, distillery at Edgecumbe, to the Rangitaiki River.
02 4212	Discharging stormwater into the Rangitaiki River and the Eastbank Road Drain.
02 4606	Discharge of cooling water into the Rangitaiki River.
61734	Discharge of untreated farm dairy effluent to pasture irrigation at Eastbank Road, Edgecumbe.
62000	Taking water for dairy processing, cooling and cleaning.
65013	Discharge of particulate matter from the tempering, blending, milling and packing system, waste gases from laboratory and miscellaneous other processes at the dairy processing facility.

Resource consent 65800-AP was granted to "undertake a discretionary activity to discharge treated dairy manufacturing effluent to land and undertake the associated discharge of contaminants to air" (Appendix 1) Resource consent 65800-AP is of interest to this project as it allows Fonterra Edgecumbe to apply effluent to surrounding farms which, in turn can cause pasture burning. The conditions applied to this resource consent state that medium strength effluent may only be applied to seven farms (Table 3-7).

Table 3-7. Farms irrigated by Fonterra Edgecumbe's medium strength effluent.

Omehue farm	Mulins PJ & KJ
Brophy Block	AB & MI McLean
Mclean FA and Searle GG	Gow Family Trust
Shakes Woods BH & JF "Dreamfields Family Trust"	

Resource consent 65800-AP states that high strength effluent may only be applied to 21 farms in the Edgecumbe area (Table 3-8).

Table 3-8. Farms irrigated by Fonterra Edgecumbe's high strength effluent.

By De Lay	Zink	Watkins
Orini dairies limited	Ngati Awa Farms	Mullins
Langdon	Virbickas	LeLievre
MacDonald	Awaroa	Sullivan
Carter-Brain	Gow	Bradley
Barr	Steiner	Olsen
Campbell	Reeves	Haultain

The resource consent 65800-AP outlines the consent conditions Fonterra Edgecumbe must follow in regards to the application of effluent to land and the associated discharge of contaminates to air.

- The medium strength effluent applied using centre pivot irrigation systems must not exceed 15mm per pass.
- If medium strength effluent is applied using in-ground sprinkler, pod irrigation systems or long lateral irrigation systems must not exceed 60 cubic meters per hectare per hour.
- Any irrigation event must not exceed 50mm.
- Farms receiving medium strength effluent shall not exceed nitrogen limits of 550kgN/ha/year from 1 July 2010 to 30 June 2018.
- High strength effluent is applied via travelling irrigations and shall not exceed 16mm per irrigation event.
- Farms receiving high strength effluent shall not exceed nitrogen limits of 150kgN/ha/year.
- Effluent may also be spread via trucks of either high strength or medium strength on farmland in the Rangitaiki Plains.
- Effluent disposal via trucks must not exceed 50 m^3 per hectare per application.

- There must be a 10-day or longer rest period before the next irrigation event by trucking on every area where truck spreading is carried out unless agreed upon by Chief Executive of the Bay of Plenty Regional council or delegate.
- Any area receiving effluent via irrigation must have a at least 14 days between each irrigation event.
- Farms receiving high strength effluent via truck spreading shall not exceed nitrogen limits of 150kgN/ha/year and phosphorus limits of 200kgP/ha/year.
- Effluent must not be applied within 10m of any stream or drain, or property boundary. Also, effluent must not be applied within 45m of any residential dwelling.
- To prevent odour, irrigation will be operated in such a way that ensures there is no offensive odour beyond the irrigation property's boundaries. To help with odour, all irrigation lines need to be flushed with clean water at the end of each season and irrigation silos must be cleaned on a regular basis.
- The nature of the effluent shall be characterised and a weather station at Omeheu must record rainfall daily.
- The volume of effluent discharged each day, the area irrigated and paddock number must be recorded.
- The equivalent depth of effluent applied shall be recorded once every three months.
- The quantity of effluent discharged by truck each day, area irrigated and properties and paddock number must be recorded.
- Ground water and surface water quality monitoring shall be carried out to determine any effects from the irrigation.
- oil monitoring must be carried out once every two years.
- A register of all complaints and incidents must be kept and given to the council on request.
- Fencing will be installed to prevent all stock from accessing water bodies. In conjunction with the landowner, riparian planting management plans for water bodies immediately adjacent to irrigation areas can be created with the landowner's consent.

3.5 Discussion and Conclusion

The soil present on the farms that are irrigated are poorly drained and many of the farms have a high water table which may contribute to pasture burning.

Overall, the strength of high strength effluent did increase between season 15 to season 17 in regards to Total nitrogen, TKN, Nitrate-Nitrogen, Nitrate-Nitrite, and DRP. Magnesium, Sodium, Calcium, Potassium, Phosphorus and the conductivity of the high strength effluent peaked during key processing months (November – January) of each season. The high strength effluent has high fertilizer properties in regard to Nitrogen and Phosphorus. If Fonterra applied 15mm of effluent, as per their resource consent, 30 $kgha^{-1}$ of nitrogen and 75 $kgha^{-1}$ of phosphorus would be applied per irrigation event. As the effluent has a high Total Solids, Total Volatile Solids, and BOD allowing time between each irrigation event would ensure all solids would biodegrade.

The average conductivity of the effluent ranged between 49 mS/cm to 151 mS/cm which was confirmed by the data collected via the YSI and HACH probes. The large spike in conductivity recorded then confirmed the effluent does spike and change in composition over a few hours. Only one large spike was recorded during the monitoring undertaken (section 3.4.1). Such "spikes" in the effluent may not be evident in the regular 24-hour composite sampler data collected by Fonterra daily. The data collected from the sampling shed using the YSI probe may have been a magnitude lower than the 24-hour composite sampler data analysed by Hills Laboratory. The increase in conductivity may have been a contributor to pasture burning in the following days after the effluent passed through the system and was irrigated on the surrounding farms.

The pH recorded by the Fonterra Edgecumbe YSI Professional Plus (Pro Plus) Multiparameter Instrument and the Bay of Plenty regional council YSI Professional Plus (Pro Plus) Multiparameter Instrument showed an average pH of ~5 but spiked to pH 12 regularly due to the CIP's (cleaning in progress) occurring in the processing plants on site.

The pH collected by the 24-hour sampler was only recorded once or twice during each month thus was not an accurate representation and spikes in pH was not recorded. However, the 24-hour sampler data showed that during the months of March and August through seasons 15 to 17, the pH ranged from pH 4.2 to 5.5 which is similar to average pH recorded by the Fonterra Edgecumbe YSI Professional Plus (Pro Plus) Multiparameter Instrument.

The 24-hour sampler data collected from the sampling shed on site was not analysed for temperature. However, the Fonterra Edgecumbe YSI Professional Plus (Pro Plus) Multiparameter Instrument and the Bay of Plenty regional council YSI Professional Plus (Pro Plus) Multiparameter Instrument did measure temperature which showed a varying pattern between the 6th to the 22nd of December 2016 ranging between 20^{o}C and 60^{o}C. When the temperature of the effluent fell to ~20^{o}C the pumps moving the effluent turned off allowing the effluent in the overflow bucket to cool. The temperature or the effluent, based on the data collected does not spike abnormally.

Chapter 4

Preliminary observations

4.1 Introduction

Chapter Four reports the initial observations from pasture burning events, farm observations, effluent, soil and plant composition data, as well as weather data and plant osmolality data. All preliminary data were gathered from October 2016 – February 2017. Weather data from September through to December 2016 is discussed in relation to pasture burning events. The cell osmolality of the white clover and perennial ryegrass collected from Omehue farm and Rowlands farm were determined.

This chapter is partly descriptive as the initial observations were limited by resources and access therefore some information presented is anecdotal.

4.2 Objectives

The overall aim of chapter four is to investigate the occurrence of pasture burning on the surrounding farms that are irrigated by the Edgecumbe Dairy Factory, in the Bay of Plenty.

Specific objective are to:

- Record all pasture burning events to determine any patterns that would help identify causes,
- collect weather data during the key burning season to investigate any relationship between temperature and/or rainfall and pasture burning events,
- collect effluent at the paddock during irrigation to endeavour to capture effluent that causes burning,
- determine soil and pasture properties, and
- determine the osmolality of clover and ryegrass.

4.3 Description of Pasture Burning events

4.3.1 Methods

Pasture burning record sheets were developed for the irrigation workers to fill out every time they witnessed pasture burning in the field (Appendix 2). The information collected about each pasture burning event included farm name, operator who placed the irrigator in the paddock that burned, date damage to pasture was observed and description of the burning, paddock number, irrigator number, run number, time of the run, where burning occurred on the run, and the line that the effluent came from (Table 4-1). Photographs were also taken to capture the event.

4.3.2 Results

The main pasture burning observed was classed as "tip burn"; however severe burning was also observed which caused desiccation of all leaves on the plant. Ponding was also a cause of pasture dieback in low lying areas where saturated conditions prevailed for extend periods of time.

Thirty-eight pasture burning events were captured between September and December 2016 (Table 4-1). A detailed description of each pasture burning is event is listed in Appendix 3.

Table 4-1. Pasture burning event record

	Farm	Date pasture burning observed	Date of irrigation	Paddock number	Run that burnt	Time and date of run	Type of burn and location on run?	Line
1	Barr	14/09/2016	-	3	-	-	Ponding	Awakeri
2	McDonalds (A)	14/09/2016	12/09/2016	3	-	-	Tip burn	Angle road
3	McDonalds	20/09/2016	18/09/2016	77	1 2 3	1 = 18/09/2016 → 7.30am - late 2 = 18/09/2016 →2.40pm - late 3 = 19/09/2016 → 8.12am - late	Tip burn	Angle road
4	McDonalds	20/09/2016	17/09/2016 or 18/09/2016	22A	1 2 3	1 = 17/09/2016 → 4.20pm-late 2 = 18/09/2016 → 7.50am-late 3 = 19/09/2016 → 8.30am - late	Ponding	Angle road
5	Ngakauroa	21/09/2016	15th →19/09/2016	48	1 2 3 4 5 6	1= 15/09/2016 → 4.50pm - late 2 = 16/09/2016 →2.19pm - late 3 = 17/09/2016 → 9.00am - late 4 = 17/09/2016 → 7.40pm - late 5 = 18/09/2016 →9.43am - late 6 = 18/09/2016 →8.50pm - late	Tip Burn	Awaroa
6	Rowlands	21/09/2016	17th → 19/09/2016	28	2 3	2 = 17/09/2016 → 8.14am-1pm 3 = 18/09/2016 → 4.35pm – late 3 = 18/09/2016 → 9.20am - late	Tip Burn	Angle road
7	McDonalds	25/09/2016	25/09/2016	71	3	3 = 25/09/2016 → 12pm- 8pm	Tip Burn	Angle
8	Barr	28/10/2016	24/10/2016	16		-	Tip burn; End of run	Awakeri
9	Rowlands	28/10/2016	24/10/2016	3		-	Tip burn	Angle road
10	Rowlands	28/10/2016	24/10/2016	4		-	Tip burn	Angle road
11	Rowlands	28/10/2016	24/10/2016	15		-	Tip burn	Angle road

Table 4-1. Pasture burning event record continued.

	Farm	Date pasture burning observed	Date of irrigation	Paddock number	Run that burnt	Time and date of run	Type of burn and location on run?	Line
12	McDonalds (B)	7/11/2016	6/11/2016	75	2	1 = 6/11/2016 → 9.50am - 1pm 3 = 6/11/2016 →1.35pm - 6pm	Tip burn; Start of run	Angle road
13	Campbell	9/11/2016	6 th → 7/11/2016	95	2 3 4	2 = 6/11/2016 → 7.00am - 3pm 3 = 6/11/2016 → 4.05pm - late 4 = 7/11/2016 →7.30am -3.30pm	Tip burn	Awakeri
14	Ngakauroa	9/11/2016	8/11/2016	40	6	6 = 8/11/2016 → 8.45am - late	Tip burn; Middle of run	Awakeri
15	Awaroa	9/11/2016	5 th → 6/11/2016	33	1 2 3 4 6 7	1 = 3/11/2016 →2:14pm -6.30pm 2 = 4/11/2016 → 6.50am - 1pm 3 = 4/11/2016 → 12.15pm- 5pm 4 = 5/11/2016 →7pm - late 5 = 5/11/2016 → 6.41am – 12pm 6 = 5/11/2016 →1.30pm - late 7 = 6/11/2016 → 6.45am - 12.45pm	Tip burn	Putiki
16	Law	9/11/2016	7/11/2016	19	1 2	1 = 7/11/2016 →9.30am - 2pm 2 = 7/11/2016 →2.45pm - late	Tip burn; middle to end of run	Angle Road
17	McDonalds (C)	10/11/2016	9/11/2016	9	1	1 = 9/11/2016 → 8.50am - 5pm	Tip burn; middle of run	Angle road
18	Barr	15/11/2016	13/11/2016	-	4	4 = 13/11/2016 → 1pm	Tip burn	Awakeri
19	Ngakauroa	14/11/2016	10/11/216	6	3	3 = 10/11/2016 → 6.47am - 1pm	Tip burn	Awaroa
20	Awaroa	14/11/2016	12/11/2016	15	2 4	2= 12/11/2016 → 9.15am - 4pm 4 = 13/11/2016 → 6.30am - 4pm	Tip burn; parts of run	Putiki
21	Laws	14/11/2016	11/11/2016	33	1	1 = 11/11/2016 → 8.50am - late	Tip burn; most of run 1	Angle road
22	Awaroa	13/11/2016	10/11/2016	14	3 6	3= 10/11/2016 → 8.50am - 5pm 6 = 10/11/2016 → 7.50am - 5pm	Tip burn; most of run	Angle Road
23	Awaroa	13/11/2016	-	15	-	-	Tip burn	Putiki
24	Awaroa	13/11/2017	-	16	-	-	Tip burn	Putiki

Table 4-1. Pasture burning event record continued.

	Farm	Date pasture burning observed	Date of irrigation	Paddock number	Run that burnt	Time and date of run	Type of burn and location on run?	Line
25	Sullivan	-	-	24	-	-	Severe burn	Awakeri
26	Barr	24/11/2016	13/14/15/16th/11/2016	29	1		Ponding; most of run	Awakeri
27	McDonalds	25/11/2016	23/11/2016	45	1 2	1 = 23/11/2016 → 8.10am - 4.10pm 2 = 23/11/2016 → 5pm - late	Tip burn; Whole left side of the paddock	Angle Road
28	Rowlands	8/12/2016	4th → 5/12/2016	3	Most of paddock	All runs	Tip burn; whole paddock (multiple runs)	Angle Road
29	Rowlands	8/12/2016	6/12/2016	4	1	1 = 6/12/2016 → ?	Tip burn; most of run	Angle Road
30	Ngakauroa	7/12/2016	3rd →6/12/2016	15	1 5 6 7	1 = 3/12/2016 5 = 3/12/2016 6= 6/12/2016 7= 6/12/2016	Severe tip burn; Strips	Awaroa
31	Kokshaun	7/12/2016	4th → 7/12/2016	25	1 2	1 =? → 7.13am - 11.30am 2 =? → 11.30am - 2pm	Tip burn; Patchy / Strips	Awakeri
32	Kokshaun	7/12/2016	4th → 7/12/2016	29	1 2 3	1 =? → 1.30pm - 4.30pm 2 =? → 1.30pm - 4.320pm 3=? → 6.50am - 11am	Tip burn; Patchy / Strips	Awakeri
33	Kokshaun	7/12/2016	4th → 7/12/2016	30	1 2 3	1 =? → 8pm - late	Tip burn; Patchy / Strips	Awakeri
34	Reeves	9/12/2016	6/12/2016	19	2	2 = 6/12/2016 → 7.25am - 4pm	Tip burn; Patchy / Strips	Awakeri
35	Rowlands	10/12/2016	7/12/2016	16	1	1 = 7/12/2016 →12.40pm-6pm	Tip burn; whole run	Angle road
36	BDL East	10/12/2016	7/12/2016	14	1	1 = 7/12/2016 → 9.10am	Tip burn; most of run	Putiki road
37	BDL East	10/12/2016	8th →9/12/2016	15	1 2	1 = 8/12/2016 → 5.50pm - late 2= 9/12/2016 →11.45am	Tip burn; most of run 1 & 2	Putiki road
38	Rowlands	10/12/2016	9/12/2016	15	1	1 = 9/12/2016 →9.30am	Tip burn; Most of 1st run	Angle road

The pasture burning record shows that pasture burning mostly occurred on Barr, McDonalds and Rowlands farm (Table 4-1). However, burning also occurred on Ngakauroa, Campbell, Law, Sullivan, Kokshaun and BDL east farm (Table 4-1). The majority of burning events occurred on runs 1, 2 and 3 (Table 4-1). The key type of pasture burning was tip burning where some was severe or occurred in patches or in strips along each run (Table 4-1). Ponding also occurred on the Barr farm in September and November (Table 4-1).

The first example of burning observed during this project was on Barr's farm (Figure 4-1, 4-2). Burning was noticed on the 14th of September 2016 in paddock 3 (Table 4-1). The burning was in dips and hollows suggesting the type of pasture burning was due to ponding creating anoxic conditions for the pasture thus causing the pasture to die off.

Figure 4-1. Ponding and pasture die back in paddock 3 occurred in low points in the paddock.

Figure 4-2. Ponding in paddock 3 occurred in low points in paddock 3 along with large brown patches of pasture.

The second, and more common type, of pasture burning was tip burn. Tip burn was observed on the 14th of September 2016 on McDonalds farm in paddock 3 (Table 4-1). Paddock three was irrigated on the 12th of September 2016. The tip burn occurred in strips creating a light brown path behind where the irrigator ran (Figure 4-3). The tip of the clover leaves, ryegrass and dock were burned (Figure 4-4).

Figure 4-3. McDonalds farm, paddock 3 – strip burning.

Figure 4-4. McDonalds farm, paddock 3 – tip burning.

4.4 Weather data

4.4.1 Methods

Air temperature, rainfall, wind direction, and wind speed for Edgecumbe were downloaded off the Bay of Plenty Regional Council website from the Edgecumbe township weather station. The weather data station in Edgecumbe is located in the town of Edgecumbe on a 10m high mast (grid reference: V15: 456 509) (http://monitoring.boprc.govt.nz/MonitoredSites/cgi-bin/hydwebserver.cgi/distict/details?district=3). Relative humidity and solar radiation weather data were downloaded from the weather station on the Rangitaiki plains. The Rangitaiki plains weather station is located at 147B Flax Road 26m above ground. The data were collected for the months of September 2016 through to December 2016 to determine if there was a pattern of burning connected to the weather (Appendix 4). Each pasture burning event was overlaid on graphs of the weather data.

4.4.2 Results

No pattern was evident when air temperature, humidity, rainfall, wind speed, wind direction, or solar radiation were compared to pasture burning events (Figure 4-5).

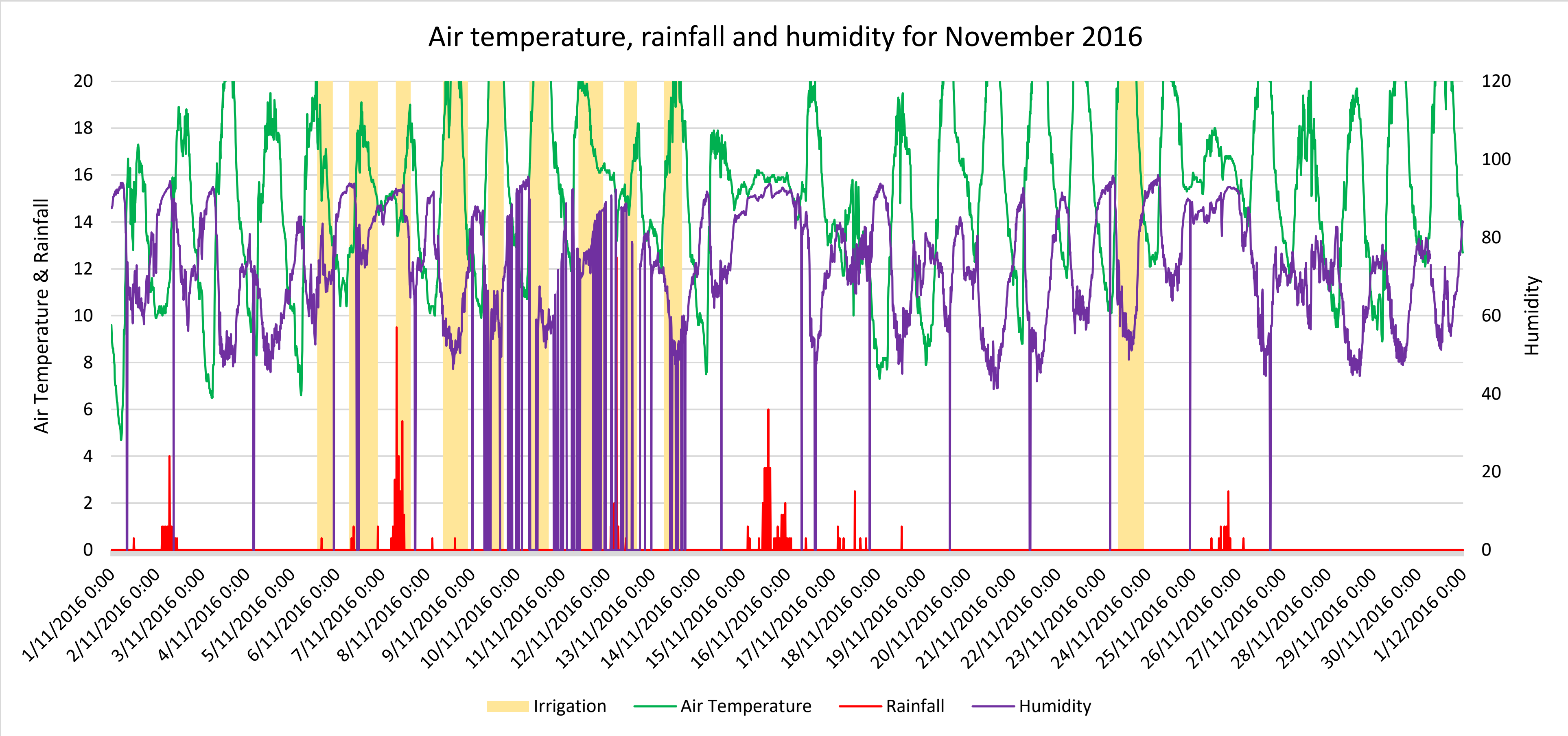


Figure 4-5. Weather data for November 2016.

4.5 Effluent collection from irrigation paddock hydrants to catch pasture burning

4.5.1 Methods

Effluent samples were collected directly from the hydrant in paddocks where pasture burning had previously occurred on Rowlands, Awaroa and McDonalds farm. Samples were collected in November – December 2016. The effluent samples were collected in one 1L unpreserved blue hills laboratory bottle and one 250ml preserved green hills laboratory bottle per hydrant before the irrigator was turned on at the start, middle, and end of each run. Each bottle was labelled with the farm name, paddock number, run number and date. The bottles were taken to the freezer at Omehue to be stored. If a paddock had burned after irrigation the sample, along with some adjacent non-burning samples, would have been sent away to Hills Laboratory for analysis. However, there were no burning events associated with the samples taken. Eleven samples from Rowlands, Awaroa and McDonalds farm were sent for analysis to determine a baseline effluent composition in the field.

4.5.2 Results

The samples taken on the 28th of November on Rowlands farm in paddock seven and paddock eight have different effluent compositions despite irrigation occurring on the same day (Table 4-2). The composition of the effluent taken from Rowlands paddock 7 was also very different to the 24hr sampler data proving the composition can change in the field (Table 4-2). As irrigation occurred on the same day, the effluent sampled was expected to have a similar composition (Table 4-2). All effluent properties tested in the sample taken in paddock seven were higher than the samples taken in paddock eight (Table 4-2). As there is such a large pipe network, the effluent can reach a paddock via different paths depending on what irrigators are on throughout the scheme at the time. As each paddock has its own hydrant, the effluent may have travelled through different pipes to reach these paddocks allowing for effluent that is left in the pipes to be picked up as it travels to the paddock.

Despite irrigation occurring on different farms, the effluent composition for samples taken from Rowlands farm and Awaroa farm were mostly similar (Table 4-2).

The pH of Awaroa paddock 27 spiked to 4.7 and the total calcium was slightly higher than the other three samples (Table 4-2). The sample taken from Awaroa paddock 27 - run five contained 19,600 g/m^3 of total dissolved solids which was similar to the sample taken from Rowlands farm paddock eight (20,000 g/m^3) (Table 4-2).

The samples from Rowlands farm paddock eight - run one, Rowlands farm paddock eight - run two and Rowlands farm paddock eight - run eight had similar effluent compositions and were all sampled on the same day (Table 4-2). The effluent samples from McDonalds farm paddock 47 showed some variability even though they were taken from the same paddock and hydrant. Both samples, however, had a similar range in their effluent properties as the samples taken from Rowlands farm on the 1st of December 2016 (Table 4-3).

The effluents analysed from Awaroa, Rowlands and McDonalds farm was mostly similar to the effluent that was analysed daily from the 24-hour sampler (Table 4-2; 4-3). However, the sample taken from Rowlands paddock seven had a far lower amount of all properties present. Samples taken from McDonalds paddock 47 run one and Awaroa paddock 27 run three had a lower amount of total dissolved solids and total calcium compared to all other samples (Table 4-3). There was slightly more total dissolved solids and total calcium present in the 24-hour sampler data overall.

Table 4-2. Analysis of effluent taken from Rowlands farm undertaken in November/December 2016 compared with 24hr sampler data.

Effluent Properties	28/11			30/11			01/12			
	Row – P7; run 3	**Row - P8; run 3**	**24 hr sampler**	**Row – P7; run 1**	**Row – P7; run 3**	**24 hr sampler**	**Row – P8; run 1**	**Row – P8; run 2**	**Row – P8; run 8**	**24 hr sampler**
pH	4.9	4.3	5.3[1]	4.1	4	5.3[1]	4.1	4	4.4	5[1]
Electrical Conductivity (mS/m)	691	1,275	1,091	1,064	981	1,268	1,172	1,046	1,295	1,028.9
Total Dissolved Solids (g/m^3)	6,600	20,000	19,800	14,500	14,700	>20,000	17,300	13,900	16,100	19,720
Total Calcium (g/m^3)	540	1,040	1,460[1]	800	740	1,460[1]	820	630	730	980[1]
Total Magnesium (g/m^3)	56	123	113[1]	116	102	133[1]	109	97	113	108[1]
Total Potassium (g/m^3)	690	1,750	1,690[1]	1,440	1,250	1,690[1]	1,570	1,410	1,550	1,570[1]
Sodium absorption ratio	7.7	12.4	-	12.9	11.7	-	12.9	12.8	13	-
Total sodium (g/m^3)	700	1,590	1,430[1]	1,470	1,280	1,430[1]	1,480	1,310	1,430	1,400[1]
Total sulphur (g/m^3)	430	1,490	-	1,220	1,110	-	1,290	1,130	1,270	-
Chloride (g/m^3)	540	850	610	640	580	850	700	630	730	622
Total nitrogen (g/m^3)	95	260	240	250	150	230	240	230	280	225
Nitrite-N (g/m^3)	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	0.55
Nitrate-N (g/m^3)	0.13	5.4	7.8	4.4	5.4	2.6	4.1	4	2.6	6.15
Nitrate-N + Nitrite-N (g/m^3)	0.16	5.5	7.8	4.4	5.5	2.6	4.2	4.1	2.6	6.2
Total Kjeldahl Nitrogen (g/m^3)	95	144	240	240	144	230	240	230	260	225
Dissolved reactive phosphorus (g/m^3)	22	360	400[1]	420	360	400[1]	350	320	420	440[1]
Sulphate (g/m^3)	1,140	2,900	-	3,200	2,900	-	3,800	3,100	3,400	-

*Row = Rowlands farm; * [1] = only one sample taken that month thus is an average.

Table 4-3. Analysis of effluent taken from Awaroa farm and McDonalds farm in November/December 2016.

Effluent Properties	29/11		01/12		30/11		
	McD P47 – run 1	24 hr sampler	McD P47 – run 3	24 hr sampler	Awa P27 – run 5	Awa P27 – run 3	24 hr sampler
pH	4	5.3	4	5[1]	4.4	4.7	5.3[1]
Electrical Conductivity (mS/m)	1,012	1,109	1,141	1,253	1,253	1,165	1,268
Total Dissolved Solids (g/m^3)	14,300	21,085	16,100	23,000	19,600	14,500	>20,000
Total Calcium (g/m^3)	590	1,460[1]	730	980[1]	760	870	1,460[1]
Total Magnesium (g/m^3)	100	113[1]	113	108[1]	105	103	133[1]
Total Potassium (g/m^3)	1,330	1,690[1]	1,550	1,570[1]	1,570	1,530	1,690[1]
Sodium absorption ratio	13.3	-	13	-	12.7	12.5	-
Total sodium (g/m^3)	1,320	1,430[1]	1,430	1,400[1]	1,410	1,460	1,430[1]
Total sulphur (g/m^3)	1,220	-	1,270	-	1,550	1,390	-
Chloride (g/m^3)	540	692	730	820	860	720	850
Total nitrogen (g/m^3)	230	210	280	420	320	250	230
Nitrite-N (g/m^3)	<0.10	0.15	<0.10	<0.10	<0.10	<0.10	<0.10
Nitrate-N (g/m^3)	5.9	2.8	5.2	2.1	5.5	5.6	2.6
Nitrate-N + Nitrite-N (g/m^3)	5.9	3	5.2	2.1	5.6	5.6	2.6
Total Kjeldahl Nitrogen (g/m^3)	280	210	280	420	310	240	230
Dissolved reactive phosphorus (g/m^3)	390	400[1]	370	440[1]	370	370	400[1]
Sulphate (g/m^3)	2,800	-	3,400	-	4,700	3,700	-

*McD = McDonalds farm; *Awa = Awaroa farm; * [1] = only one sample taken that month thus is an average.

4.6 Reeves farm: soil and pasture sampling

4.6.1 Methods

Soil and pasture samples were taken using a 15cm auger from Reeves farm, paddocks 47 and 48 for analysis to determine levels of nutrients at a farm that has had previous pasture burning (Appendix 3). The soil was tested for pH, Olsen phosphorus, potassium, calcium, magnesium, sodium, cation exchange capacity (CEC), total base saturation, volume weight, sulphate sulphur, soluble salts, electrical conductivity (EC), organic matter, total carbon, total nitrogen, calcium, magnesium, sodium, sodium absorption ratio (SAR) and total copper.

4.6.2 Results

According to the Hills Laboratory scale, the soil in paddock 47 on Reeves farm had a medium to high pH and a high Olsen phosphorous, potassium, calcium, magnesium and total nitrogen (Table 4-4). Paddock 48 on Reeves farm had a high Olsen phosphorous, calcium, magnesium, sodium, sulphate sulphur content.

Table 4-4. Soil analysis - Reeves Farm, paddock 47 and 48.

Analysis	Level (P47)	Range (P47)	Level (P48)	Range (P48)
pH	6.2	Medium → High	6.1	Medium
Olsen Phosphorus (mg/L)	147	High	134	High
Potassium (me/100g)	1.44	High	2.14	High
Calcium (me/100g)	12.5	High	13	High
Magnesium (me/100g)	2.14	High	2.84	High
Sodium (me/100g)	0.19	Low	0.85	High
CEC (me/100g)	24	Medium	25	Medium → High
Total Base Saturation (%)	69	Medium	74	Medium
Volume Weight (g/mL)	0.78	Medium	0.76	Medium
Sulphate Sulphur (mg/kg)	10	Low	183	High
Soluble salts (%)	<0.05	-	0.13	Medium
EC (mS/cm)	0.09	-	0.37	-
Organic Matter (%)	11.7	Medium	13.6	Medium
Total Carbon (%)	6.8	-	7.9	-
Total Nitrogen (%)	0.66	High	0.73	Medium
Calcium (mg/L)	27	-	84	-
Magnesium (mg/L)	7	-	25	-
Sodium (mg/L)	13	-	91	-
Sodium Absorption Ratio	0.6	-	2.2	-
Total Copper (mg/kg)	25	-	21	-

In paddock 47, the pasture was high in potassium, zinc and molybdenum (Table 4-5). In paddock 48 the pasture contained high levels of potassium, sulphur, sodium and copper (Table 4-5).

Table 4-5. Pasture analysis - Reeves Farm, paddock 47 and 48.

Analysis	Level (P47)	Range (P47)	Level (P48)	Range (P48)
Nitrogen (%)	3.4	Low	3.6	Low
Phosphorus (%)	0.38	Low	0.44	Medium
Potassium (%)	3.3	High	3.6	High
Sulphur (%)	0.30	Low → Medium	0.54	High
Calcium (%)	0.61	Low → Medium	0.60	Low → Medium
Magnesium (%)	0.22	Medium	0.20	Low → Medium
Sodium (%)	0.085	Low	0.342	Medium → High
Iron (mg/kg)	121	Medium	116	Medium
Manganese (mg/kg)	36	Low	35	Low
Zinc (mg/kg)	58	High	32	Medium
Copper (mg/kg)	8	Low	23	High
Boron (mg/kg)	13	-	12	-
Molybdenum (mg/kg)	1.27	Medium → High	1.11	Medium
Chloride (%)	1.10	Medium	1.12	Medium
Nitrate – N (mg/kg)	353	-	289	-

4.7 Osmolality of clover/ryegrass and effluent

4.7.1 Introduction

The osmolality of fresh and burned clover and ryegrass were measured to determine a base line osmolality for the pasture which could then be compared with the osmolality of Fonterra Edgecumbe's effluent.

4.7.2 Methods

Clover and ryegrass samples were collected from the Omehue irrigation farm next to the inground operator shed to determine the osmolality of fresh clover and ryegrass (Figure 4-6). Effluent samples were collected from the Awaroa effluent line.

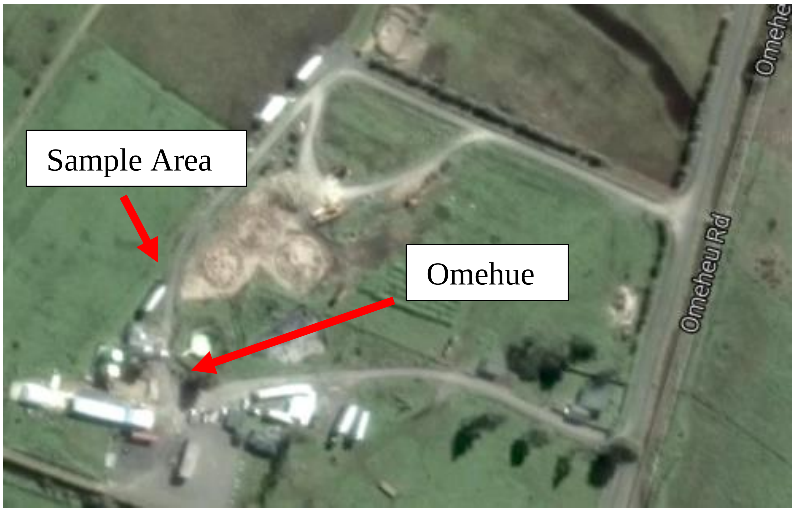


Figure 4-6. Map of Omehue irrigation farm showing collection area of fresh clover and ryegrass.

Clover and ryegrass were also collected from Rowlands farm where burning occurred 2 days before collection. The clover and ryegrass samples were frozen overnight to preserve the sap after being picked and to rupture the cell membranes for sap extraction. The pasture was removed from the freezer the next morning and placed in a tray. Tissue paper was lightly placed on the pasture to remove any excess liquid while defrosting. Five clover leaves were then cut from the steam using a blade. Five clover leaves and five ryegrass leaves were separated into two trays. The five leaves were placed into a plastic 10ml syringe and squeezed to remove the sap. The sap was squeezed into a 1.5ml microcentrifuge tube.

The sap was then tested using a VAPRO Vapor Pressure Osmometer to determine the symplasmic osmolality of the cell sap. Three replicates were carried out to get a mean osmolality for both clover and ryegrass. The VAPRO Vapor Pressure Osmometer measures the osmolality in milliosmoles (mmol/kg). Milliosmoles was converted into solute potential in pressure units (MPa) as the literature refers to plant cell sap symplasmic osmotic potential in MPa. To convert milliosmoles to MPa the following process was followed:

1) Read the osmolality in milliosmoles using the VAPRO Vapor Pressure Osmometer of either clover or ryegrass.
2) Multiply the milliosmoles by 0.002437; this give the MPa (osmotic potential) of the cell sap.

The number "0.002437249" represents the RT (R = gas constant; T = temperature) which is based on room temperature and was calculated from the Van't Hoff relationship (Nobel, 1999):

$$\Psi_s = -RT\sum_j c_j$$

Where: $\sum_j c_j$ is the osmolality in mmol kg^{-1}

Ψs = solute water potential (MPa)

R = gas constant (m^3 MPa mol^{-1} K^{-1})

T = temperature (K^o)

c = molar concentration of solute particles (mmol kg^{-1})

4.7.3 Results

The mean symplasmic osmolality of cell sap expressed from fresh clover at Omehue was 409 mmol/kg and the mean symplasmic osmolality of ryegrass cell sap was 593 mmol/kg (Table 4-6). Burned clover from Rowlands farm had an osmolality of 480 mmol/kg compared to 430 mmol/kg of fresh clover meaning that the burned clover had more solutes presents in the leaf sap. Burnt ryegrass had a higher mean osmolality of 556 mmol/kg compared to fresh ryegrass with a mean osmolality of 535 mmol/kg although the difference was not as substantial as clover (Table 4-7).

Table 4-6. Fresh clover and ryegrass from Omehue farm.

Omehue Farm		Omehue Farm	
Clover Fresh (mmol/kg)	Mpa	Ryegrass Fresh (mmol/kg)	Mpa
407	0.992	594	1.448
402	0.980	593	1.4458
420	1.024	594	1.448

Table 4-7. Fresh and burnt clover and ryegrass from Rowlands farm which recently experienced pasture burning.

Rowlands Farm				Rowlands Farm			
Clover Fresh (mmol/kg)	Mpa	Ryegrass Fresh (mmol/kg)	Mpa	Clover Burnt (mmol/kg)	Mpa	Ryegrass Burnt (mmol/kg)	Mpa
393	0.958	535	1.304	475	1.158	554	1.350
416	1.0138	538	1.311	470	1.145	554	1.350
437	1.065	532	1.296	490	1.194	560	1.365

The osmolality of the effluent from the Awaroa effluent line ranged between 202 mmol/kg, 216 mmol/kg and 233 mmol/kg.

4.8 Discussion

4.8.1 Pasture burning event record

By recording each pasture burning event as record was created. However, a pattern based on date of irrigation, time of irrigation, irrigator used, paddock number and farm was not evident. The type of burning and severity was determined using the pasture burning record. The two major types of pasture burning include tip burning and severe burning. Ponding was also recognised as a mechanism for pasture burning. As the severity of burning changed between irrigation officers, narrower limits placed around what was severe burning and what was light burning needed to be better defined. Most burning events occurred on Barr's, McDonalds and Rowlands farm however, Barr's farm is irrigated from the Awakeri line and McDonalds and Rowlands farm is irrigated from the Angle road line. As the pipe network is large, and there are many routes for the effluent to take, changes in the effluent composition may alter if old effluent is picked up along the way. The old effluent may contain high levels of lactic acid which could burn the pasture. The majority of burning events occurred on runs one, two and three however the time of these run vary throughout the day therefore a pattern cannot be recognised. After many pasture burning events, the Fonterra Edgecumbe irrigation team concluded that the pasture seems to grow back faster compared to when the pasture does not burn (Fonterra Edgecumbe Irrigation team, pers comm, 2017).

4.8.2 Weather data

The weather data download from the Bay of Plenty Regional council live monitoring site was matched with the pasture burning events. No pattern stood out when temperature, rainfall, humidity, wind speed, wind direction and solar radiation were compared with pasture burning events. The weather is known to have effects on pasture growth and susceptibility to injury (Sparks, 2017). Hot temperatures will increase the plants need for water thus if the pasture is irrigated, the pasture may absorb too much effluent increasing the concentration of effluent in the plant. Increased rainfall, after irrigation, could dilute or wash off the effluent from the leaves of the pasture reducing the concentration of ions being absorbed which may prevent burning.

The humidity of the atmosphere plays a role by influencing whether the ions in the effluent will crystallise on the leaf surface or dissolve into a solution (Fallahi & Eichert, 2013). If the ion is able to dissolve into a solution due to the humidity, the plant may absorb too much creating a toxic effect and burning the plant. Wind speed, if fast enough can injure the plant (Sturrock, n.d). Solar radiation can damage the epidermis of a plant however, the plants ability to repair damaged cells is high thus no extreme damage can be done via radiation (Jenkins, 2009).

4.8.3 Effluent solutions compared to 24hour sampler data

Effluent samples that were collected during November and December 2016, where pasture burning has happened previously did not correlate with any burning events. A baseline effluent composition in the field was determined. Many of the samples had a similar composition where the pH was around 4 and the amount of total dissolved solids was between 14,000 and 17,000 g/m^3. However, two samples taken from Rowlands farm on the 28th of November 2016 had contrasting compositions. The amount of total dissolved solids present on one samples was 20,000 g/m^3 which was high. However, another samples from Rowlands contained only 6,600 g/m^3 of total dissolved solids. The difference in compositions highlighted the fact that the effluent composition can change within hours in the field. The samples that were taken in the field had somewhat different effluent compositions to the 24-hour sampler effluent. The total dissolved solids varied between the 24-hr sampler data and the effluent samples however the electrical conductivity remained similar. Large variabilities in effluent composition are possible based on the difference in the effluent compositions seen in the field.

4.8.4 Soil and pasture analysis

Reeves farm soil has a pH of 6 means the soil is slightly acidic. At a pH of 6, the amount of phosphorus, sulphur, calcium, and magnesium available for plant use decreases (Potash Development Association, 2011 adapted from Truog, 1946). However, as the soil samples taken from Reeves farm have high levels of potassium, olsen phosphorus, calcium, magnesium, sodium, sulphate sulphur, total nitrogen as well as a high CEC, a pH 6 should not reduce plant growth.

The pasture samples from paddock 47 and paddock 48 are similar to an average pasture with legumes (Muller, n.d.). Paddock 47, however had a high potassium, zinc and molybdenum content (Hills Laboratory, 2017, Muller, n.d.). But had low levels of nitrogen, phosphorus, sodium, manganese and copper. Paddock 48 also had high potassium however, sulphur, sodium, and copper was also high (Hills Laboratory, 2017). However, there were low levels of calcium, magnesium and manganese.

High levels of potassium in a plant will affect stomatal regulation (Van Brunt, 1998) which may lead to a loss of water via transpiration thus dehydrating the plant (Sterling, 2004). Excess zinc present in ryegrass can reduce growth (Tsonev and Lidon, 2015). Zinc can also interfere with photosynthesis where stomata opening can be affected thus photosynthesis (Tsonev and Lidon, 2015). Low levels of nitrogen may cause older leaves to yellow and the plant will have stunted growth (Broome, n.d.). Low levels of phosphorous can also stunt the growth of the plant (Broome, n.d.). Low sodium levels in conjunction with low potassium levels are ideal for a plants survival as sodium and potassium can interchange and complete some of the same functions in a plant (Maathuis, 2013). However, low sodium levels are very beneficial as many plants cannot cope with high levels (Maathuis, 2013). High levels of sodium can induce osmotic stress which can have negative affects on a celluar level (Maathuis, 2013). Manganese and copper are micronutrients thus too little of each may affect pasture growth they are required in small amounts (Graham and Stangoulis, 2003).

4.8.5 Osmolality: clover, ryegrass and high strength effluent

On average, cell sap from the non-burned clover and ryegrass collected from Rowlands farm had a lower symplasmic osmolality (415 mmol/kg and 535 mmol/kg) than burned clover and ryegrass (478 mmol/kg and 556 mmol/kg). It is possible that the burned pasture had a higher solute content. The effluent had a mean osmolality of 217 mmol/kg which is lower than the osmolality of the clover and ryegrass cell sap. However, the effluent is known to vary daily (Table 4-2, 4-3) thus the osmolality of the effluent may at times exceed that of the clover and ryegrass cells.

If the osmolality of the effluent exceeds that of the pasture, a dehydration affect could occur within the pasture (Nabors, 1973, Kowles, 2010). As the effluent does vary daily (Table 4-2), measuring the osmolality of the effluent daily would be a good indicator of a potential dehydration affect.

4.9 Conclusion

Thirty-eight pasture burning events were recorded. Many of the pasture burning events showed light tip burning, however, severe pasture burning events also occurred. Ponding due to poor drainage was recognised as another cause of pasture burning. Pasture burning is most likely occurring due to many different variables including changes in the weather, effluent composition and the osmolality of the pasture and the effluent. The effluent composition does change in the field after it leaves the factory. Changes in the effluent composition may be a key cause in pasture burning as all other variables discussed do no cause pasture burning individually. The soil analysis completed showed high levels of potassium, olsen phosphorus, calcium, magnesium, sodium, sulphate sulphur and total nitrogen however, due to the pH, the ability for the plants to uptake such nutrients is possible. The pasture analysis completed had high levels of potassium, zinc, molybdenum sulphur, sodium, and copper. High potassium levels are most concerning as due to the loss of water via stomatal opening and therefore dehydration of the plant. A further in detailed analysis of the soil and pasture in the Edgecumbe area needs to be completed. The osmolality of the pasture was higher than the average effluent osmolality which suggests that unless the effluent concentration increases, burning would not occur. However, because there is evidence the effluent composition does change in the field, the osmolality may be a measure for pasture burning.

Chapter 5

Field Experiment Methods & Results

5.1 Introduction

Based on the literature review (Chapter 2) and the preliminary observations (Chapter 4) the following hypotheses were developed:

a) When effluent with a high osmolality is irrigated “pasture burning” occurs,
b) New growth has a lower osmolality thus is more susceptible to pasture burning at lower effluent osmolality. Mature pasture has a higher osmolality therefore will not burn when effluent with a lower osmolality is applied.

Two experiments are described and used to investigate the hypotheses. A pilot trial, and a follow- up field experiment were carried out. The initial pilot trial confirmed that pasture burning occurred following application of effluent with a high osmolality. The main experiment was then undertaken to further investigate the relationship between osmolality and pasture burning, and to test hypothesis b) (the vulnerability of new growth).

The experiments were undertaken on Fonterra’s Awaroa farm in paddock 1 on a clover/ryegrass dominated pasture.

5.2 Methods

5.2.1 Paddock selection and soil description

Awaroa farm was chosen as the site to carry out both experiments as it is irrigated with effluent from the factory and has established pasture growth (Figure 5-1). Thirty-nine plots were measured out in 1m by 1m blocks (Figure 5-1).

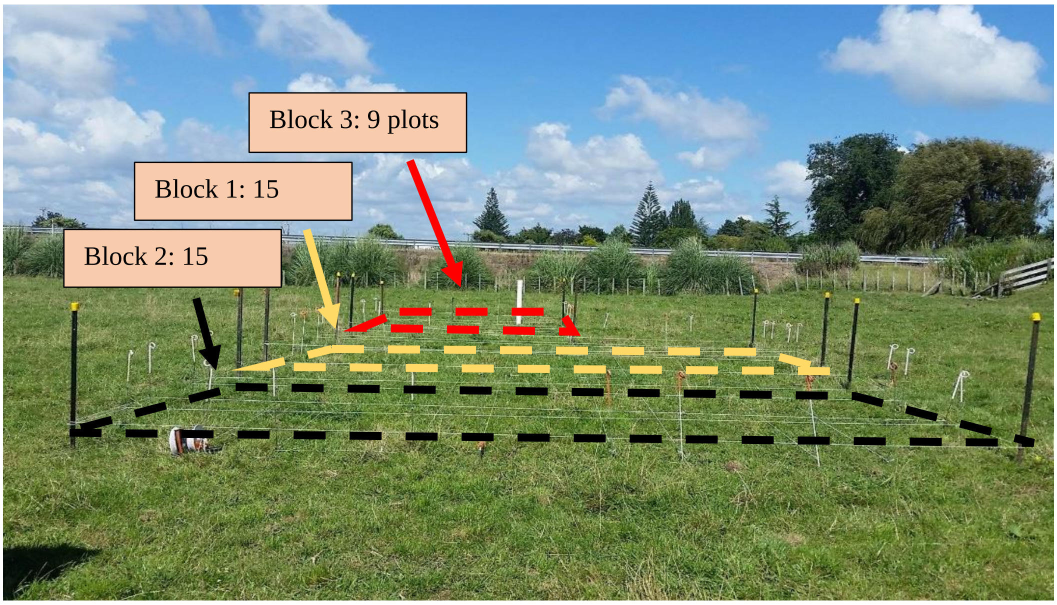


Figure 5-1. Experiment set-up in field showing three blocks – block 1 & 2 = main experiment and block 3 = pilot trial.

Awaroa paddock 1, is predominantly an Acidic Orthic Gley Soil, and is a sandy loam (Landcare Research, 2011-2015). (Figure 5-2; 5-3). The potential depth the plant roots can reach into the soil is classed as unlimited. The soil is poorly drained due to a high-water table as the area is low-lying. The aeration capacity of the root zone in the soil is limited where in some parts of the year anaerobic conditions exist (Landcare Research, 2011-2015). The permeability of the soil is rapid to moderate which is good for soil productivity, drainage, nutrient retention, and effluent adsorption. The water logging vulnerability is high and the leaching of nitrogen is low due to potential for denitrification in the saturated subsoil (Landcare Research, 2011-2015).

Figure 5-2. Top soil in Awaroa paddock 1.

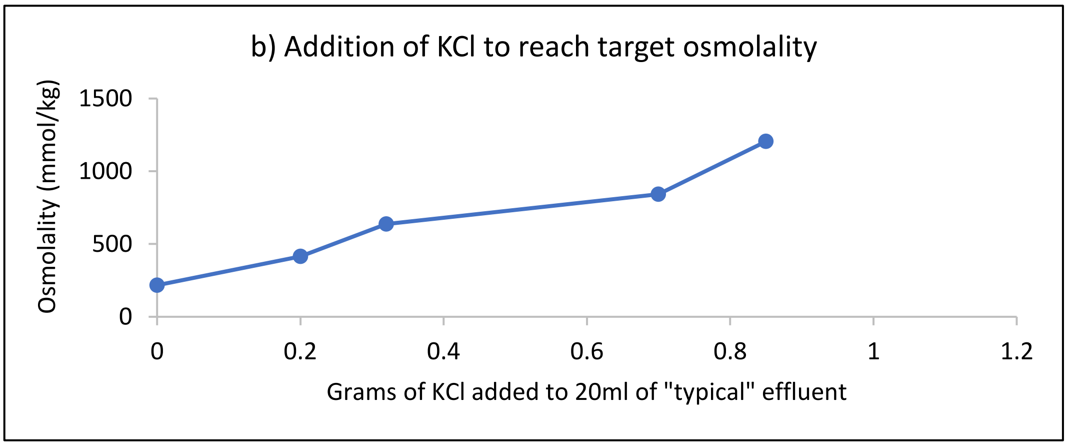
Figure 5-3. Soil from 20-40cm depth in Awaroa paddock 2.

5.2.2 Altering the osmolality of the effluent

Initial measurements were undertaken to determine the osmotic potential of effluent as well as determining how much KCl and lactose solution to add to the effluent to alter osmotic potential. Two 1L containers were filled with effluent from the Awaroa line in the sampling shed. Two 1L containers were filled with lactose solution EP 45 (evaporate permeate 45% solids) which was collected off the evaporator in the protein plant which only operates from 4pm each day. The four containers were transported to the Environmental Laboratory at Fonterra Edgecumbe and stored at 4°C. A Vapor Pressure Osmometer (Vapro 5600, Wescor, Utah) which measures the osmotic potential of solutions was used (Section 4.11, figure 5-4).

Figure 5-4. VAPRO Vapor Pressure Osmometer.

To measure and alter the osmolality of the effluent, 20ml of effluent was added to each beaker. Small amounts of KCL and lactose solution were repeatedly added to 20ml of effluent to determine how much of each was needed to alter the osmolality of the effluent. The osmolality of the initial effluent was about 200 mOsm. The amounts of KCL and lactose solution required to reach the target osmolarities of 400 mOsm, 600 mOsm, 800 mOsm and 1200 mOsm were determined (Figure 5-5). The amount of KCl and lactose solution required in 16L of effluent to reach the target osmolarities were then calculated (Table 5-1).



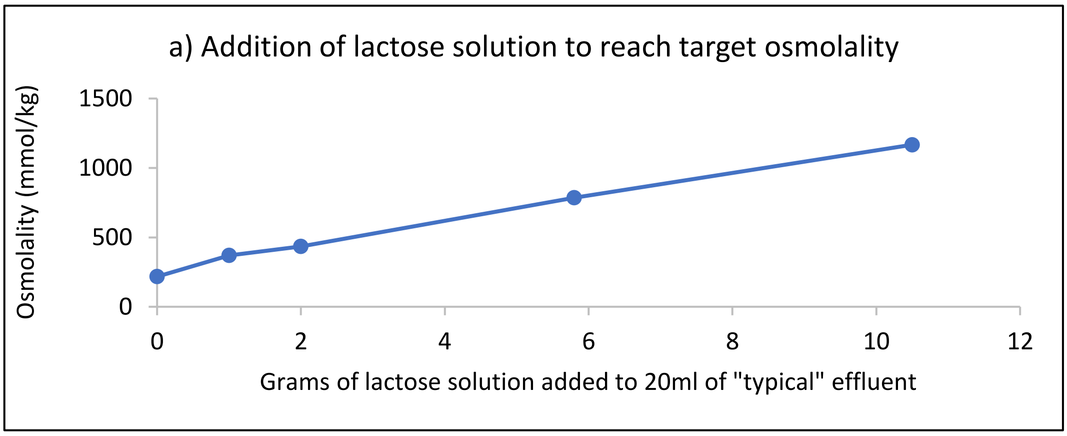


Figure 5-5. Amount of lactose solution solution(a) and KCl (b) needed reach target osmolarities.

Table 5-1. Amount (g) of potassium chloride and lactose solution added to effluent to create each solution.

Target osmolality (mOsm)	Effluent (L)	KCl (g)	Lactose solution (L)
KCl 400	16	160	
KCl 1200	16	680	
Lactose solution 400	15.2		0.8
Lactose solution 1200	7.28		8.720
KCl + lactose solution 400	15.6	80	0.4
KCl + lactose solution 1200	12	320	4

5.2.3 *Experimental design for field experiments*

a) Pilot Trial

First a pilot trial was carried out. The objective of the pilot trial was to determine whether there was any relationship between effluent osmolality and pasture burning. Nine plots were taped off in 1m by 1m squares with a 0.5m gap between each square in Awaroa paddock 1 (Figures 5-6, 5-7). Fifteen litres of lactose solution was collected from the evaporator in the protein plant at 4pm the day before the effluent solutions were applied to the pasture. The lactose solution was stored in the Environmental Laboratory at 17^{o}C overnight. The treatment for each plot was prepared as per Table 5.1.

Effluent+ Lactose solution + KCl 1311	Effluent + Lactose solution + KCl 464	Water Only 51
Effluent + Lactose solution 1406	Effluent + Lactose solution 370	Effluent Only 216
Effluent + KCl 1194	Effluent + KCl 501	Untreated

Figure 5-6. Schematic of pilot trial showing treatment layout. Numbers below treatments is the osmolality of each treatment.

Figure 5-7. Pilot trial layout in Awaroa paddock 1.

b) Main experiment

The main experiment was designed after the pilot trial finished as burning did occur (Section 5.6.1). The main experiment assessed the pasture response at a wider range of osmolarities to determine at what osmolality pasture burning occurred. Two blocks were marked out. Each block had 15 squares that were 1m^2 in size (Figure 5-8.). Each 1m by 1m plot (excluding untreated) was irrigated using a watering can with 14.75L of effluent solution with different osmolarities simulating irrigation (Figure 5-8.). In order to promote new growth so the hypothesis b) could be tested, 225g of urea and 0.3g of progibb (gibberellic acid) was dissolved in 15L of water and applied to block 2 of the main experiment (Figure 5-8).

Matata Road

Block 1: No progibb or urea

Effluent + KCl 818	Effluent + KCl 382	Effluent + Lactose solution 921	Effluent + Lactose solution + KCl 1095	Effluent + KCl 1064
Effluent + Lactose solution + KCl 395	Effluent + Lactose solution + KCl 645	Untreated	Effluent + Lactose solution 803	Effluent + Lactose solution 356
Water Only	Effluent + Lactose solution + KCl 847	Effluent Only	Effluent + Lactose solution 656	Effluent + KCl 570

Block 2: Progibb and urea added

Effluent + KCl 604	Water Only	Effluent + KCl 990	Effluent + Lactose solution + KCl 421	Effluent + KCl 440
Effluent + Lactose solution + KCl 876	Effluent + Lactose solution 768	Effluent + Lactose solution + KCl 993	Effluent + KCl 797	Effluent + Lactose solution 570
Effluent + Lactose solution 365	Untreated	Effluent Only	Effluent + Lactose solution 967	Effluent + Lactose solution + KCl370

Factor →

Figure 5-8 Treatment layout of the main experiment plots.

Figure 5-9. Progibb and urea was applied in the squares causing the pasture to grow faster than the surrounding walkway between each square.

Following application of progibb and urea the site was left for three weeks allow pasture growth (Figure 5-9).

5.3 Pilot trial implementation

Seven 20L buckets were filled with warm effluent collected the morning of the pilot trial from the Awaroa line sampling shed (Figure 5-10). Fifteen liters of lactose solution was obtained for the experiment the day before from the protein factory.

Figure 5-10. Effluent was collected from the sampling shed in buckets for the pilot experiment.

The volume of effluent in each container was calculated before the effluent was collected to ensure that when the lactose solution was added, altogether the volume came to 16L (Table 5-2). The pre-calculated amount of lactose solution and KCl needed to raise the osmolality of the effluent from ~200 to 400 and 1200 (Table 5-2) was measured out and added to the effluent in the buckets to create the different effluent solutions. After the KCl and lactose solution were added, the osmolality of the solution was measured again to confirm the osmolality achieved (Table 5-2). Each bucket was stirred with a metal stick, which was rinsed between buckets, to ensure that the additional lactose solution and potassium chloride dissolved.

Table 5-2. Amount (g) of potassium chloride and lactose solution added to effluent to create a targets osmolality.

Treatment Name	Target osmolality	Osmolality achieved	Effluent volume (L)	KCl (g)	Volume of lactose solution (L)
KCl	400	501	16	160	
KCl	1200	1194	16	680	
Lactose	400	370	15.2		0.8
Lactose	1200	1406	7.28		8.720
Lactose solution + KCl	400	464	15.6	80	0.4
Lactose solution + KCl	1200	1311	12	320	4

Once mixed, 1.25L of each solution was taken from the buckets and poured into a 1L unpreserved polyethylene container and 250ml sulphuric acid polyethylene container from Hills Laboratory (Figure 5-11). The Hills Laboratory containers were frozen in the Omehue workshop freezer.

Figure 5-11. Effluent samples taken from each effluent solution from the pilot trial.

After the effluent solutions were made up, each bucket was transported to Awaroa paddock 1 and placed next to the square where the treatment would be applied (Figure 5-12).

Figure 5-12. Pilot trial showing each effluent solution next to chosen pasture.

Each solution was applied to the allotted square, with 14.75L applied using a watering can. Every day for one week the pasture in both experiments were visually observed and any burning was rated using the visual damage scale (Table 5-3). All observations were recorded. Pre-treatment damage was also observed as leaves may not be in optimal conditions before an experiment begins.

Table 5-3. Visual damage scale describing different degrees of burning.

0: No burning		
1: Slight burning - leaf curl/margins brown (>10% affected in plot)		
2: Moderate burning - brown margins (>10% affected in plot)		
3: Strong burning - half dead leaf (>10% affected in plot)		
4: Very strong burning - leaf dead/fully brown (>50% affected in plot)		Not observed

5.4 Main experiment implementation

Nine buckets were filled from the Awaroa effluent holding tanks along East Bank road (Figure 5-13). The buckets were filled (with a specific amount of hot effluent which was calculated in Table 5-2) from the automatic sampling point that runs off the outgoing Awakeri effluent line. Each bucket was labelled to ensure the correct amount of effluent, KCl and lactose solution was added.

Figure 5-13. Collecting effluent from the Awakeri outline effluent line at the Awaroa holding tanks, East Bank Road, Edgecumbe.

The buckets of effluent were taken to the laboratory on site at Fonterra, Edgecumbe. Each bucket of effluent was labelled with the treatment that would be applied to each plot in the field. Each bucket of effluent was tested for initial electrical conductivity and osmolality and the data was recorded.

The initial osmolality of the effluent in each bucket was measured (Table 5-4), then KCl or lactose solution was added to achieve the target osmolality (Table 5-5).

Table 5-4. Osmolality of the effluent before KCl and lactose solution was added.

Pilot trial		**Block 1**		**Block 2**	
Treatment	**Osmolality (mmol/kg)**	**Treatment**	**Osmolality (mmol/kg))**	**Treatment**	**Osmolality (mmol/kg)**
Effluent Only	216	Effluent Only	233	Effluent Only	202
KCl 400	236	KCl 400	253	KCl 400	207
[redacted]		KCl 600	237	KCl 600	188
[redacted]		KCl 800	200	KCl 800	180
KCl 1200	180	KCl 1000	260	KCl 1000	196
Lactose solution 400	245	Lactose solution 400	259	Lactose solution 400	181
[redacted]		Lactose solution 600	266	Lactose solution 600	181
[redacted]		Lactose solution 800	259	Lactose solution 800	182
Lactose solution 1200	218	Lactose solution 1000	199	Lactose solution 1000	190
Lactose solution + KCl 400	220	Lactose solution + KCl 400	199	Lactose solution + KCl 400	192
[redacted]		Lactose solution + KCl 600	191	Lactose solution + KCl 600	193
[redacted]		Lactose solution + KCl 800	217	Lactose solution + KCl 800	186
Lactose solution + KCl 1200	233	Lactose solution + KCl 1000	219	Lactose solution + KCl 1000	172

Table 5-5. Calculated amount (g) of potassium chloride and lactose solution added to effluent to reach a target osmolality.

Osmolality			Effluent Volume (L)	Lactose solution Volume (L)	KCl (g)
Target	Block 1: Achieved	Block 2: Achieved			
Lactose solution 400	356	365	15.35	0.64	
Lactose solution 600	656	570	14.04	1.95	
Lactose solution 800	803	768	12.85	3.14	
Lactose solution 1000	921	967	11.74	4.25	
KCl 400	382	440	16		160
KCl 600	570	604	16		256
KCl 800	818	797	16		560
KCl 1000	1064	990	16		635
Lactose solution + KCl 400	395	370	15.66	0.33	80
Lactose solution + KCl 600	645	421	15.89	0.110	120
Lactose solution + KCl 800	847	876	13.94	2.06	240
Lactose solution + KCl 1000	1095	993	13.54	2.46	288

Like the pilot trial, once the effluent solution was mixed (using a metal stick), 1.25L of each solution was taken from the buckets and poured into a 1L unpreserved polyethylene container and 250ml sulphuric acid polyethylene container from Hills Laboratory (Figure 5-11). These samples were frozen in the Omehue workshop freezer.

Effluent solutions were mixed and transported to Awaroa paddock 1. The correct bucket was poured into a watering can and the effluent was then applied to the corresponding plot (Figure 5-14.). The watering can was rinsed between each use.

Figure 5-14. Application of effluent on plot.

Treatments were applied to block 1 on the 23rd of March 2017 and block 2 on the 24th of March 2017. Pasture burning was assessed every day for 6 days after the effluent was applied, notes and pictures were taken. After 6 days, notes and pictures were taken every second day for four more days as pasture burning reached its peak after the 3rd or 4th day in the pilot trial.

5.5 Results

5.5.1 Pilot trial

5.5.1.1 Burn Record

Burning results (Table 5-6, Appendix 7) show that clover was much more susceptible to burning than ryegrass. Strong clover burning was evident by day three of the trial (Table 5-6). Clover was moderately burned in all treatments with an osmolality between 370 mmol/kg and 501 mmol/kg and was very strongly burned (level 4) in all treatments with an osmolality of >1194 mmol/kg (Table 5-6). Strong burning of the ryegrass occurred from day five onwards in the plot treated with lactose solution with an osmolality of 1406 mmol/kg (Table 5-6.). All other treatments caused slight to moderate burning (Table 5-6).

Table 5-6. Burning recorded on each day following effluent application of the pilot trial.

Treatments		Day 0	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7
Untreated 0	Clover	0	0	0	0	0	0	0	0
	Ryegrass	0	0	0	0	0	0	0	0
Water only 51	Clover	0	0	0	0	0	0	0	0
	Ryegrass	0	0	0	0	0	0	0	0
Effluent only 216	Clover	0	0	0	1	1	1	1	1
	Ryegrass	0	0	0	0	0	0	0	0
KCl 501	Clover	0	0	1	1	1	1	2	1
	Ryegrass	0	0	0	0	0	0	0	0
KCl 1194	Clover	0	0	1	2	1	3	2	4
	Ryegrass	0	0	0	0	0	1	1	2
Lactose solution 370	Clover	0	1	0	1	1	1	2	1
	Ryegrass	0	0	0	0	0	0	0	0
Lactose solution 1406	Clover	0	0	0	4	4	3	4	4
	Ryegrass	0	0	0	2	2	3	3	3
Lactose solution + KCl 464	Clover	0	0	0	1	1	1	2	1
	Ryegrass	0	0	0	0	1	1	1	1
Lactose solution + KCl 1311	Clover	0	0	1	4	3	3	3	3
	Ryegrass	0	0	0	1	1	2	2	2

= Very strong burning

= Strong burning

= Moderate burning

= Light burning

= No burning

5.5.1.2 Weather at time of pilot trial

There was no rainfall during the pilot trial. On days one, two, three and four the weather was cloudy and warm. On day five it was sunny and hot with no wind. On day six the weather was overcast, cool with little wind. On day seven, the weather was hot and sunny with a cool breeze.

5.5.1.3 Effluent composition applied in pilot trial

The effluent pH was generally around 4, though it was slightly higher (up to 5) in the treatments with added lactose (Table 5-6). The electrical conductivity ranged from ~1000 to 7000 mS/m which is regarded as high (EPA, 2012). The addition of KCl to the effluent increased the effluent total dissolved solids, total potassium and chloride (Table 5-7). The ESP ranged from ~5 to 48 however the majority of samples have an ESP above 25% which is consider very strongly sodic (terraGIS, 2017). KCl 501 and KCl 1194 had a lower ESP than the effluent by itself and all other treatments due to the addition of potassium (Table 5-7). In the treatments where lactose solution was added, total sodium, total sulphur, total nitrogen and sulphate increased (Table 5-7). The sodium adsorption ratio was higher in treatments with added lactose solution than other treatments (Table 5-7). Total calcium, total magnesium, TKN and dissolved reactive phosphorus were higher in the treatment lactose solution 1406 compared to other treatments (Table 5-7). In the treatments that had added KCl and lactose, there was higher total sulphur, total nitrogen and sulphate compared to other treatments (Table 5-7). The sodium adsorption ratio was increased in treatments with added KCl plus lactose solution (Table 5-7). Total calcium, total magnesium, total sodium, TKN and dissolved reactive phosphorus was higher in the KCl + lactose solution 1311 treatment than in other treatments (Table 5-7, Appendix 8).

Table 5-7. Pilot trial effluent composition.

Effluent Composition	Effluent only 216*	KCl 501*	KCl 1194*	Lactose solution 370*	Lactose solution 1406*	KCl + Lactose solution 464*	KCl + Lactose solution 1311*
pH	4.4	3.8	4	4.1	5	4	4.6
Electrical Conductivity (mS/m)	1,031	2,710	7,250	1,578	3,210	2,170	4,760
Total Dissolved Solids (TDS) (g/m^3)	15,200	26,000	51,000	37,000	169,000	31,000	122,000
Total Calcium (g/m^3)	650	390	490	650	1,460	550	940
Total Magnesium (g/m^3)	110	132	116	185	560	153	360
Total Potassium (g/m^3)	1,120	5,700	20,000	1,990	6,000	4,000	13,600
Sodium Absorption Ratio	11.6	17	12.6	20	41	18.1	32
Total Sodium (g/m^3)	1,220	1,530	1,190	2,200	7,300	1,860	4,500
Total Sulphur (g/m^3)	1,230	1,360	1,150	2,300	6,000	1,920	4,000
Chloride (g/m^3)	710	5,700	22,000	1,210	4,200	3,700	11,500
Total Nitrogen (g/m^3)	330	370	300	470	1,300	460	860
Nitrite-N (g/m^3)	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10
Nitrate-N (g/m^3)	1.22	6.9	7.7	6.4	5.7	6.5	6.3
Nitrate-N + Nitrite-N (g/m^3)	1.25	6.9	7.7	6.4	5.7	6.5	6.3
Total Kjeldahl Nitrogen (TKN) (g/m^3)	330	370	290	460	1,300	450	850
Dissolved Reactive Phosphorus (g/m^3)	280	210	240	260	670	250	430
Sulphate (g/m^3)	4,300	4,500	3,600	6,900	21,000	6,300	12,100
ESP	39.3	19.7	5.5	43.8	47.6	28.3	23.2
Max Burn: Clover	4	1	2	3	2	4	2
Max Burn: Ryegrass	2	0	0	2	0	3	1

* = measured osmolality of each effluent treatment.

5.5.2 Effluent properties and maximum burning of clover and ryegrass

Maximum burning was compared with effluent properties (Figures 5-15 to 5-33). There were positive correlations between clover burning and osmolality, electrical conductivity, total potassium, chloride, nitrate-N, total calcium, total dissolved solids and nitrate-N + nitrite-N (Figure 5-15 to 5-23). Ryegrass burning positively correlated with osmolality, pH, electrical conductivity, total magnesium, sulphate, total sulphur, total sodium, total nitrogen, dissolved reactive phosphorus, total kjeldahl nitrogen and the sodium absorption ratio (Figure 24-33). Other effluent properties did not show a positive correlation ($R^2 < 0.5$, Appendix 6). There was a strong positive correlation between the osmolality and burning in both clover (R^2=0.98) and ryegrass (R^2=0.9, Figure 5-15; 5-16). Osmolality and electrical conductivity had the strongest positive relationship with both clover (Figure 5-15; 5-23) and ryegrass (Figure 5-16; 5-30) burning.

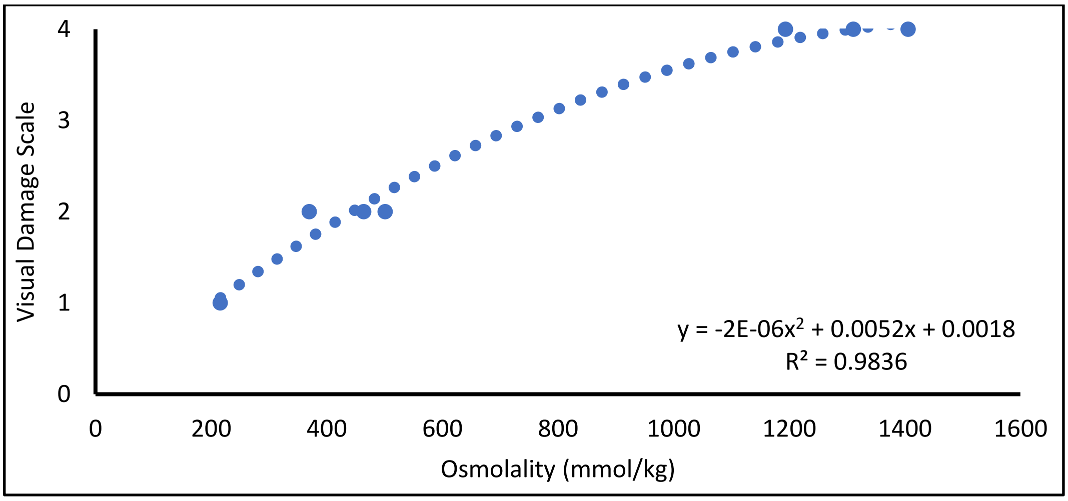


Figure 5-15. Pilot Trial: osmolality vs maximum clover burning.

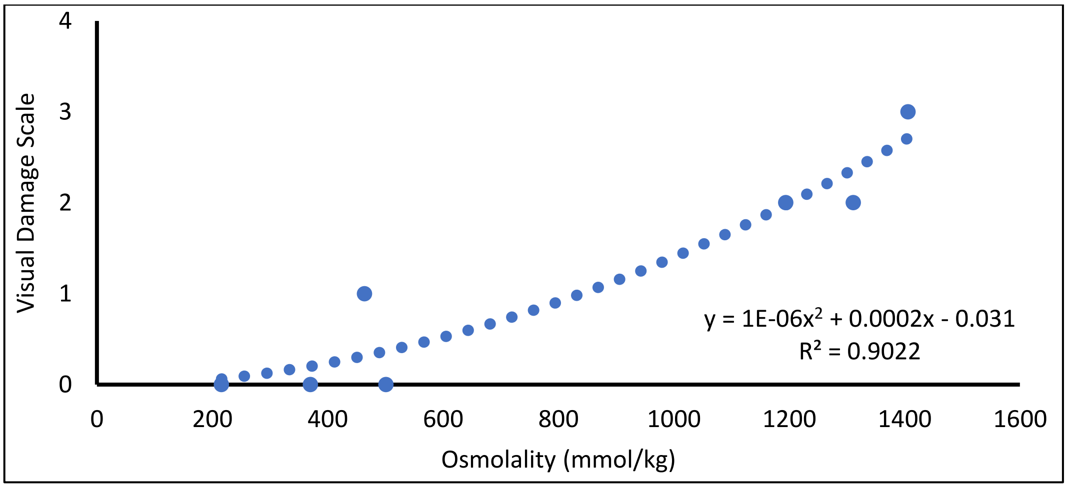


Figure 5-16. Pilot Trial: osmolality vs maximum ryegrass burning.

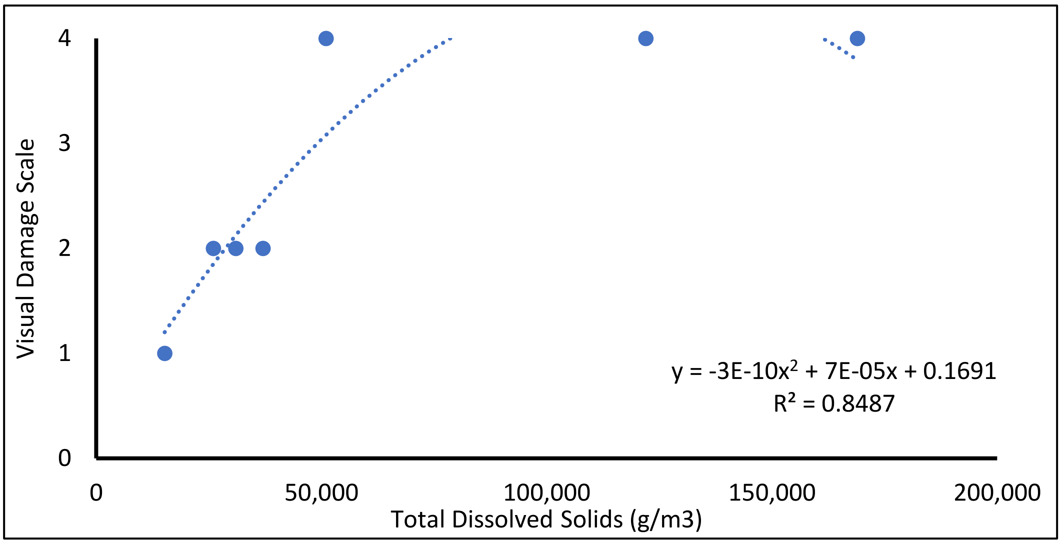


Figure 5-17. Pilot Trial: Total dissolved solids vs maximum clover burning.

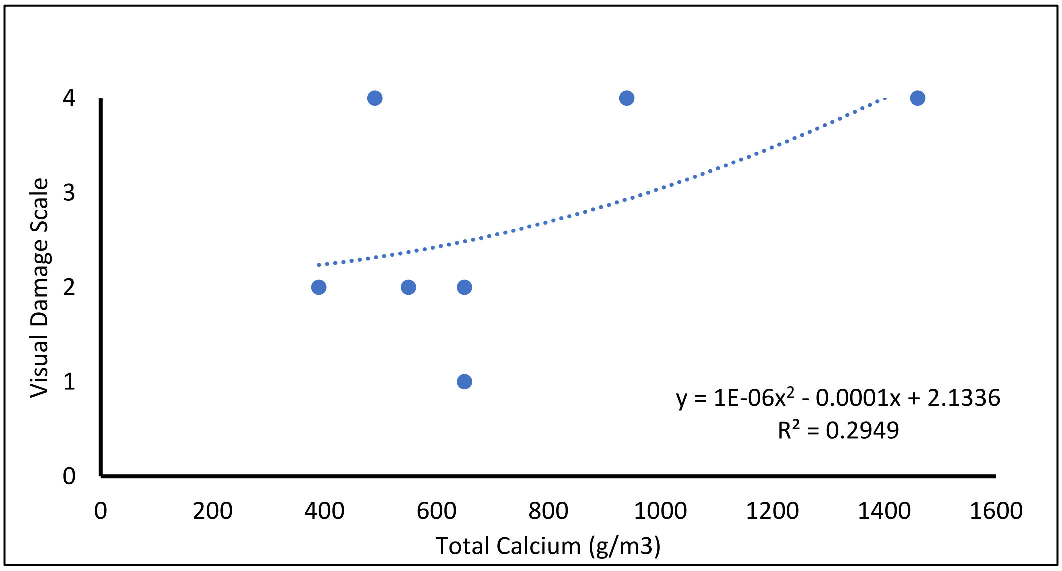


Figure 5-18. Pilot Trial: Total Calcium vs maximum clover burning.

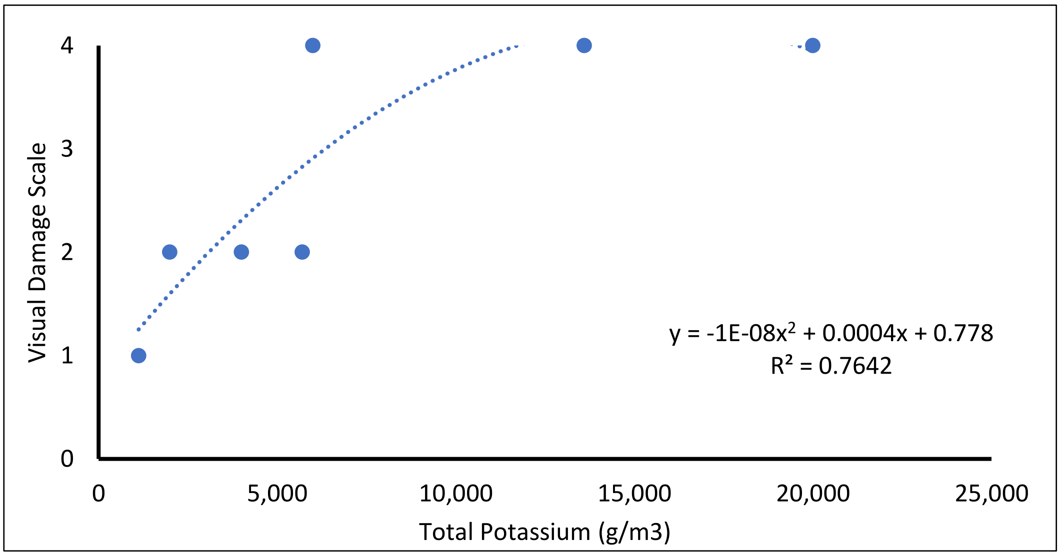


Figure 5-19. Pilot Trial: Total Potassium vs maximum clover burning.

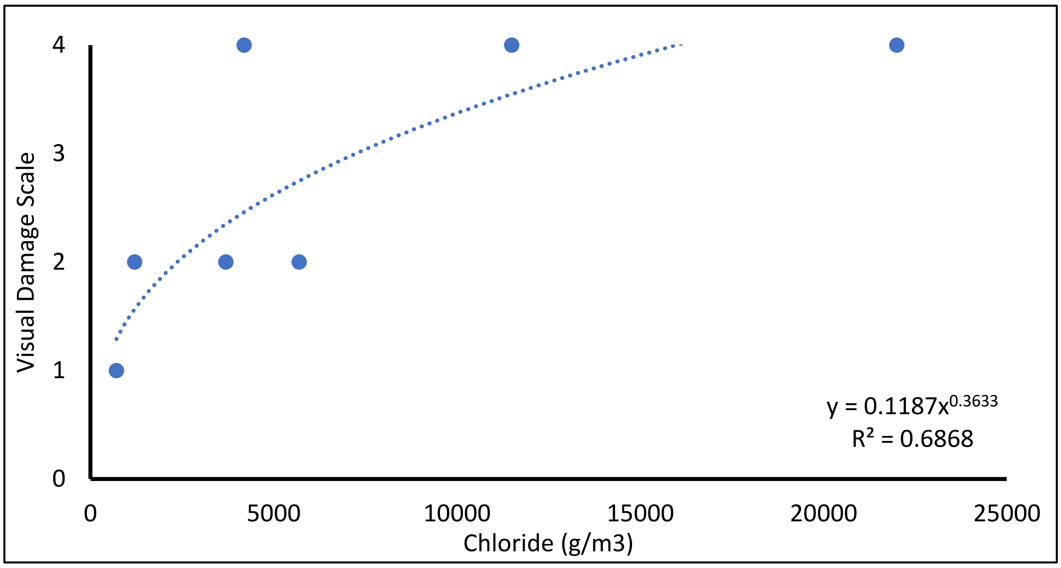


Figure 5-20. Pilot Trial: Chloride vs maximum clover burning.

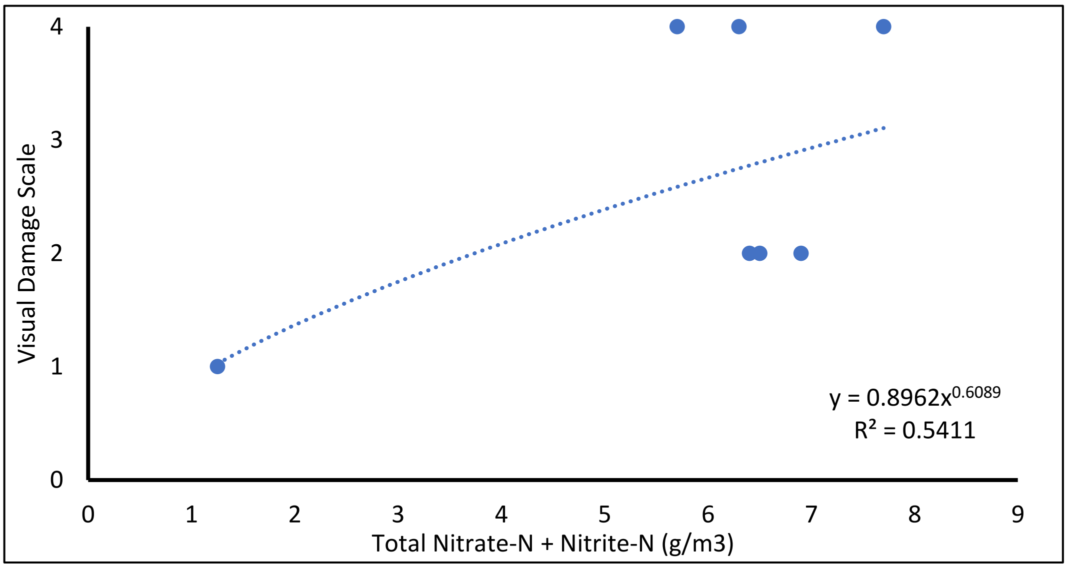


Figure 5-21. Pilot Trial: Total Nitrate-N + Nitrite -N vs maximum clover burning.

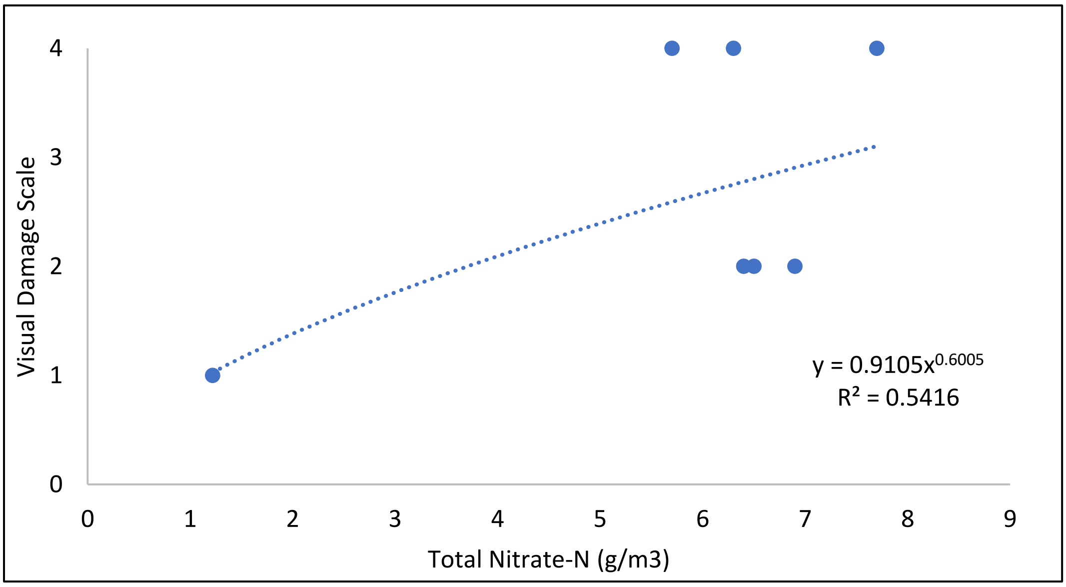


Figure 5-22. Pilot Trial: Total Nitrate-N vs maximum clover burning.

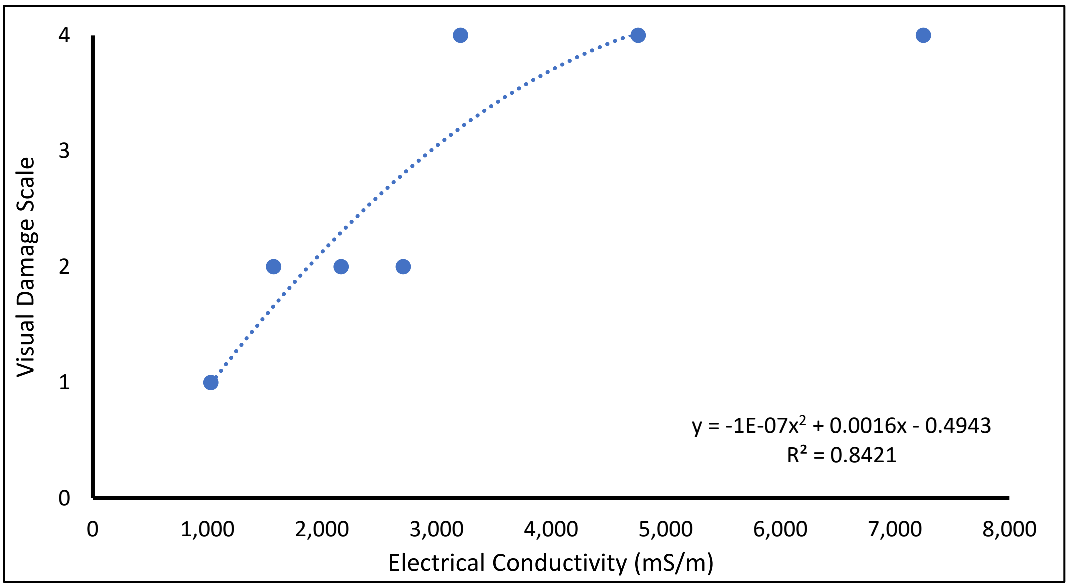


Figure 5-23. Pilot Trial: Electrical Conductivity vs maximum clover burning.

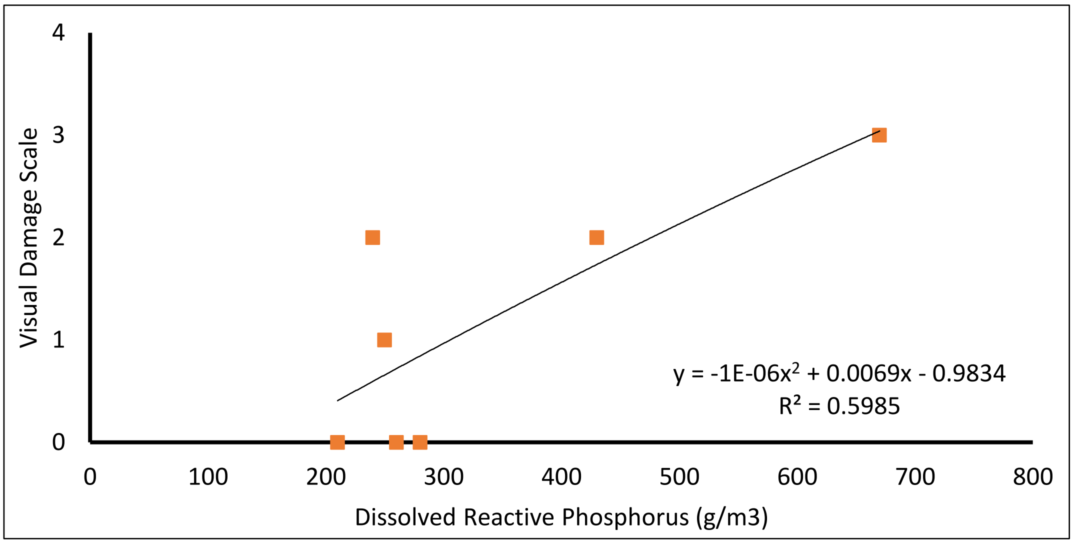


Figure 5-24. Pilot Trial: Dissolved Reactive Phosphorus vs maximum ryegrass burning.

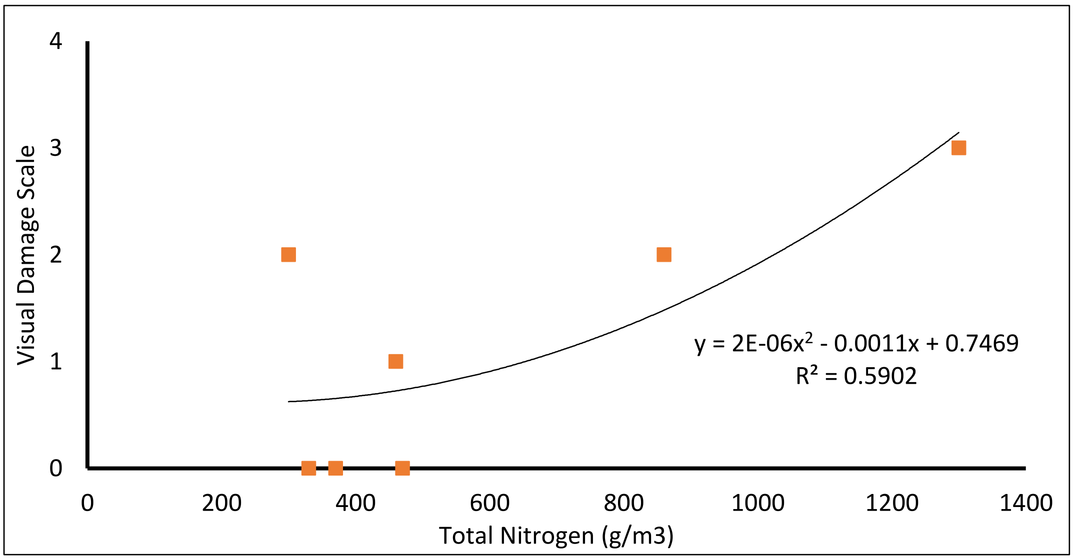


Figure 5-25. Pilot Trial: Total Nitrogen vs maximum ryegrass burning.

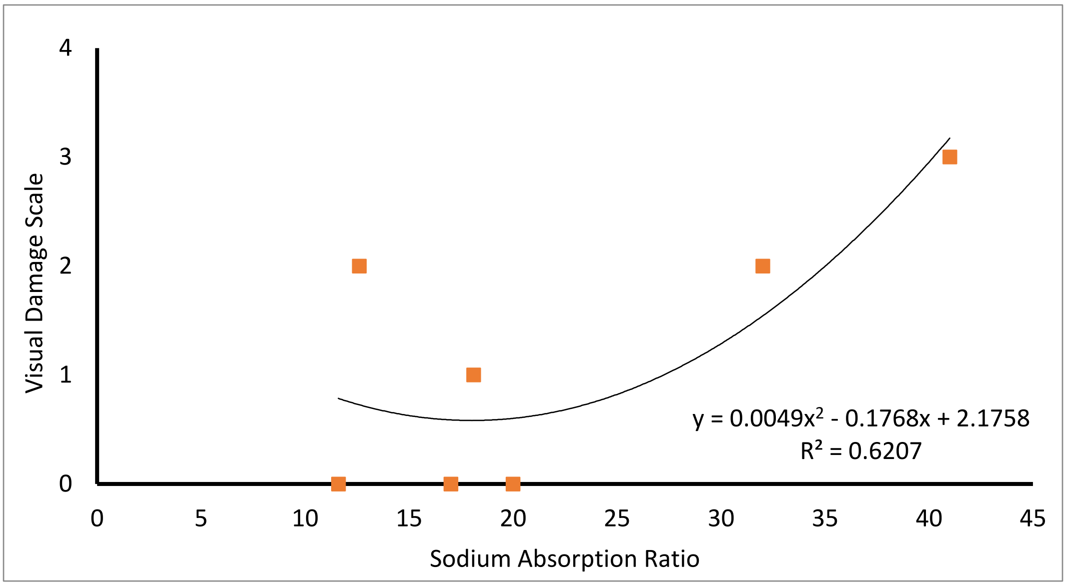


Figure 5-26. Pilot Trial: Sodium Absorption Ratio vs maximum clover burning.

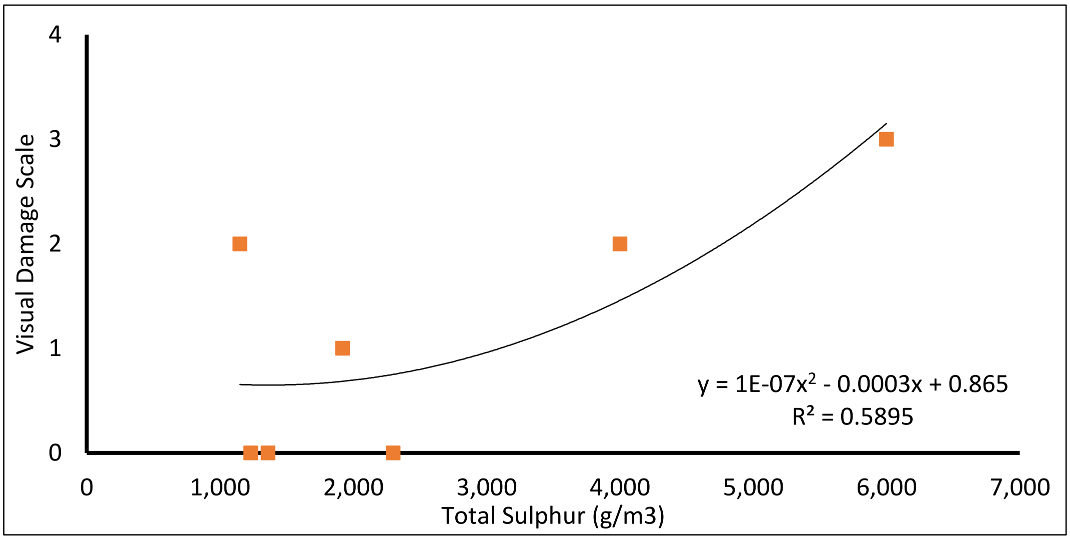


Figure 5-27. Pilot Trial: Total Sulphur vs maximum ryegrass burning.

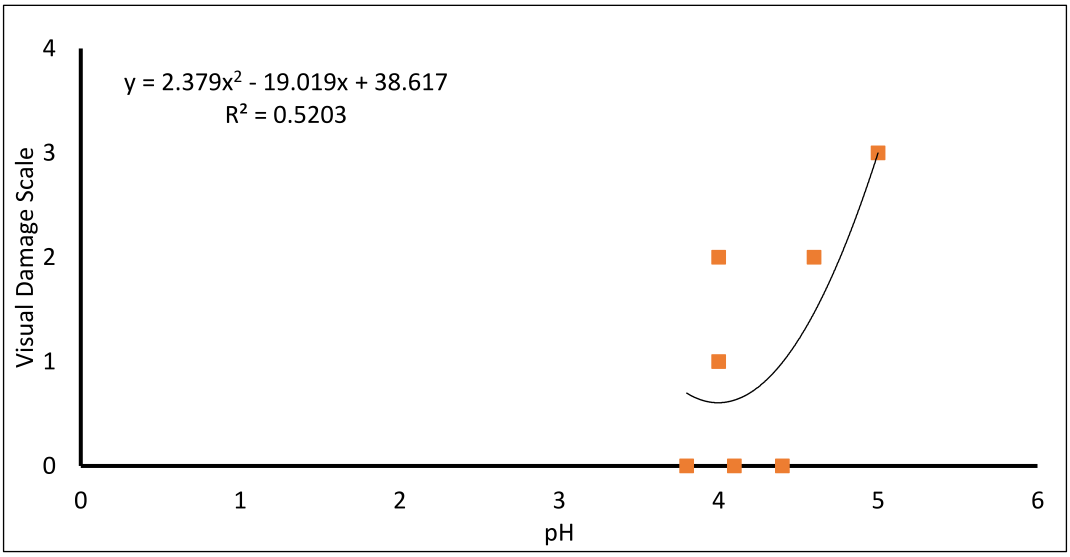


Figure 5-28. Pilot Trial: pH vs maximum ryegrass burning.

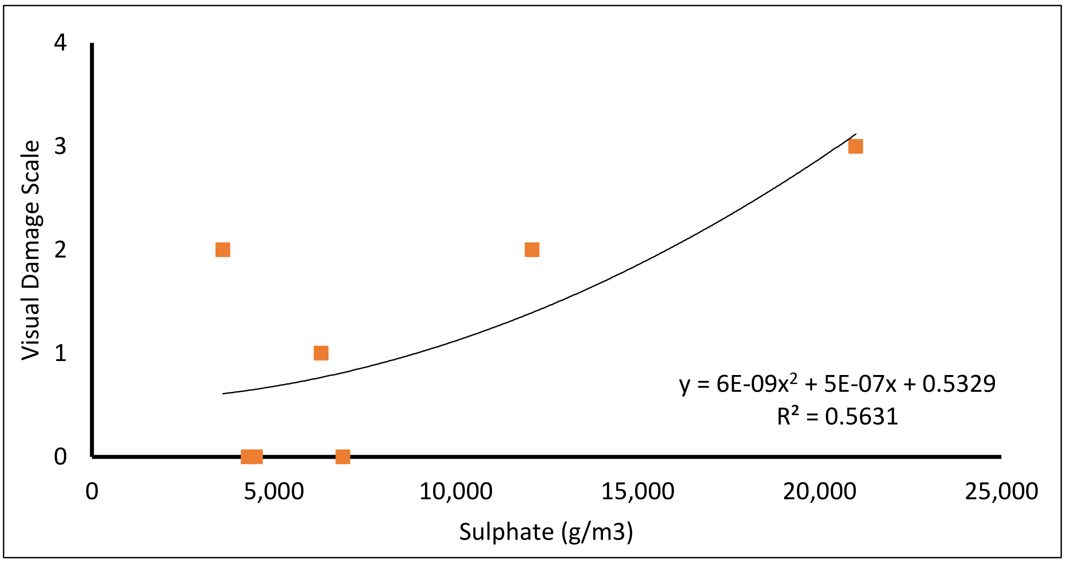


Figure 5-29. Pilot Trial: Sulphate vs maximum ryegrass burning.

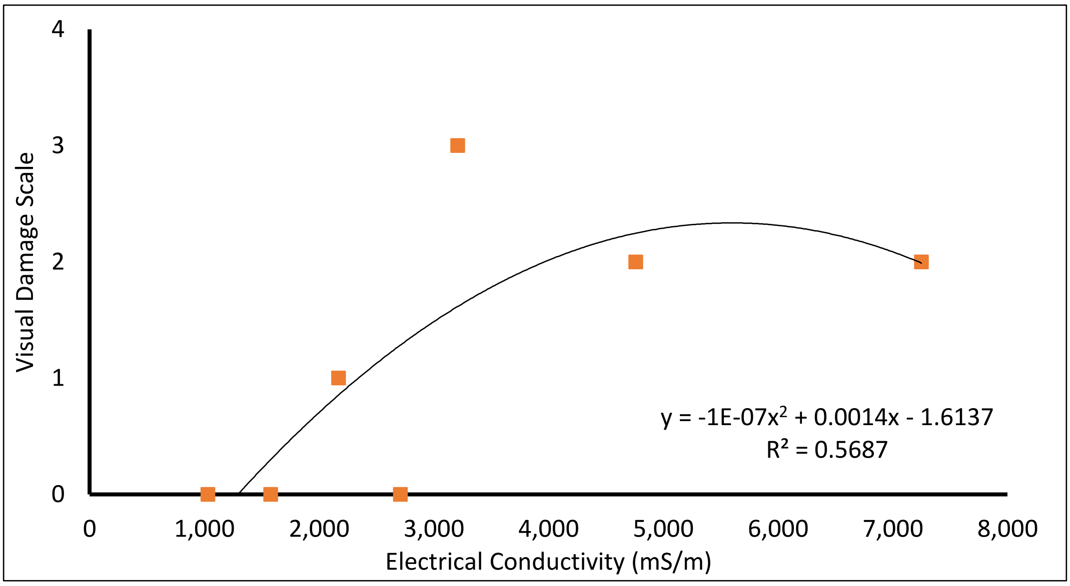


Figure 5-30. Pilot Trial: Electrical Conductivity vs maximum ryegrass burning.

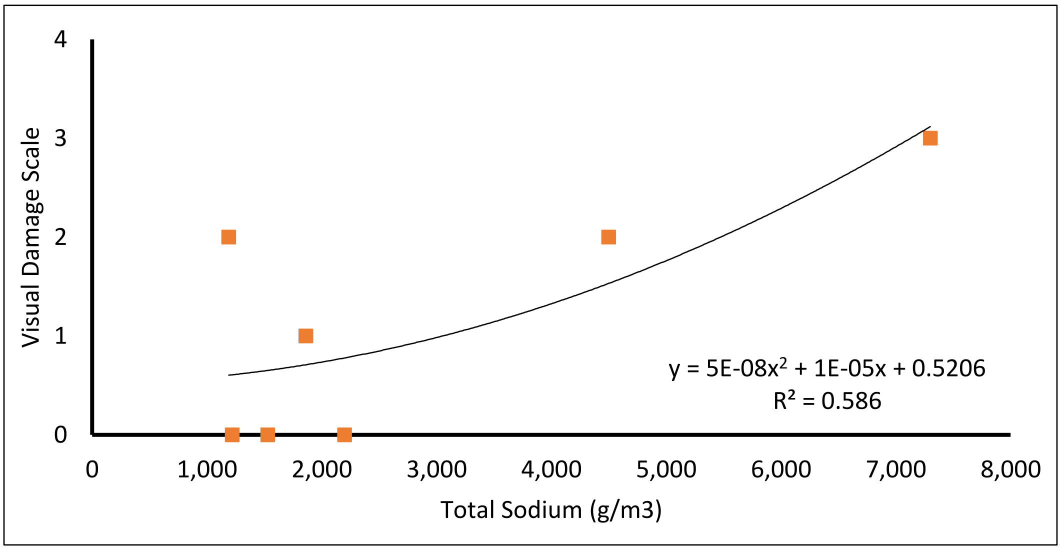


Figure 5-31. Pilot Trial: Total Sodium vs maximum ryegrass burning.

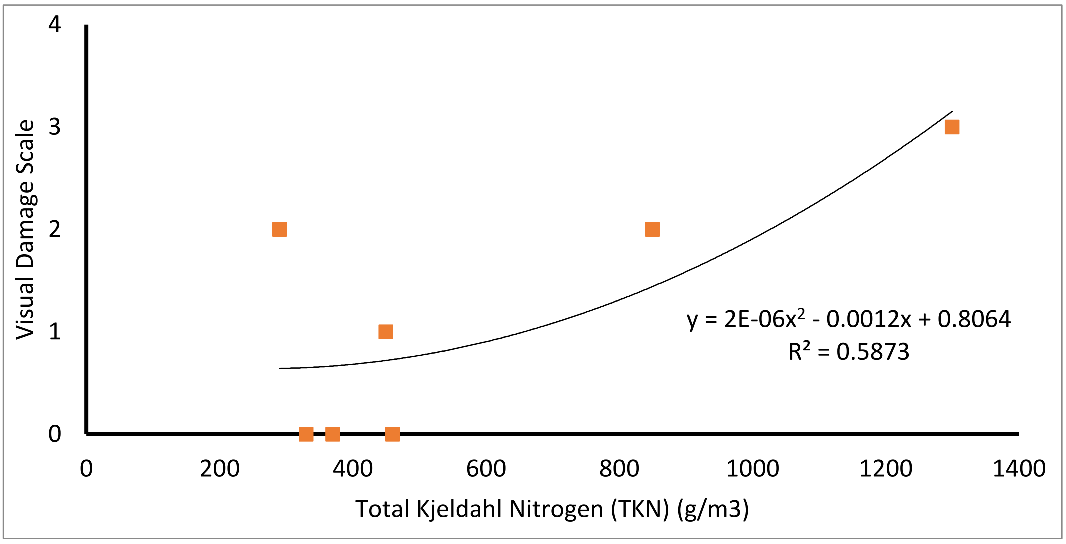


Figure 5-32. Pilot Trial: Total Kjeldahl Nitrogen (TKN) vs maximum ryegrass burning.

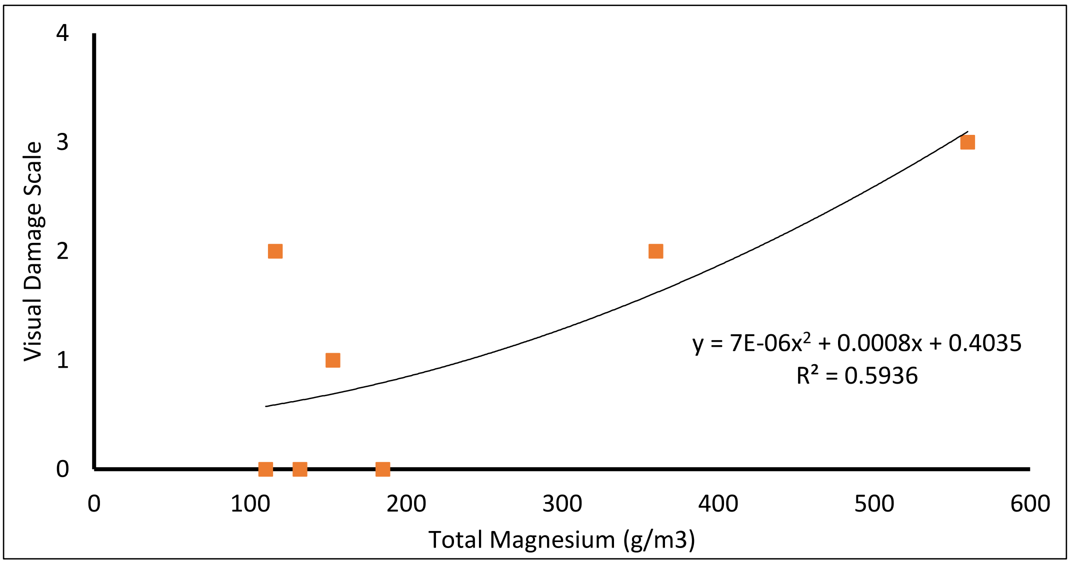


Figure 5-33. Pilot Trial: Total Magnesium vs maximum ryegrass burning.

5.5.2.1 Pilot Trial conclusion

The pilot trial showed a strong relationship between increasing osmolality and pasture burning. Clover burnt more than ryegrass. There were positive correlations between clover burning and osmolality, electrical conductivity, total potassium, chloride, nitrate-N, total calcium, total dissolved solids and nitrate-N + nitrite-N. Ryegrass burning positively correlated with osmolality, pH, electrical conductivity, total magnesium, sulphate, total sulphur, total sodium, total nitrogen, dissolved reactive phosphorus, total kjeldahl nitrogen and the sodium absorption ratio properties correlated positively with pasture burning in both clover and ryegrass.

5.5.3 Main experiment: Block 1 (no progibb and urea)

5.5.3.1 Burn Record

The results from block 1 (no progibb and urea) (Table 5-7, Appendix 7.) show that strong clover burning occurred on day 1 when the effluent was applied in the plot treated with KCl 1064, no other plots showed severe burning (Appendix 6). All KCl treatments with an osmolality of 570 or below showed slight burning of clover (level 1) or no burning (level 0). All plots treated with lactose solution and lactose solution + KCl solutions caused slight burning of clover. Plots treated with lactose solution + KCl 645 and lactose solution + KCl 1095 showed moderate clover burning.

Plots treated with lactose solution 803 and lactose solution + KCl 847 showed moderate ryegrass burning. Ryegrass burning occurred slightly (level 1) and moderately (level 2) in the plots treated with lactose solution and lactose solution + KCl treatments with an osmolality above >800. Slight ryegrass burning started on day 4. All KCl treatments caused slight burning (level 1) to ryegrass. The control plot showed no burning until day 10 where moderate burning occurred.

Table 5-7. Burning recorded the day of and the days following effluent application in main experiment block 1.

Treatments		Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 8	Day 10
Untreated 0	Clover	0	0	1	0	0	0	0	0
	Ryegrass	0	0	0	0	0	0	0	2
Water only 51	Clover	0	0	1	0	0	0	0	0
	Ryegrass	0	0	0	0	0	0	0	1
Effluent only 233	Clover	0	0	1	0	1	1	1	0
	Ryegrass	0	0	0	0	0	0	0	1
KCl 382	Clover	1	2	2	2	1	1	1	0
	Ryegrass	0	0	0	1	0	0	1	1
KCl 570	Clover	1	2	2	2	1	2	0	0
	Ryegrass	0	0	0	0	0	0	0	1
KCl 818	Clover	1	2	2	2	3	1	0	0
	Ryegrass	0	0	0	0	0	0	1	0
KCl 1064	Clover	3	4	4	4	4	3	0	0
	Ryegrass	0	0	0	0	1	1	0	0
Lactose solution 356	Clover	0	0	1	0	0	0	0	0
	Ryegrass	0	0	0	0	0	0	0	1
Lactose solution 656	Clover	0	0	1	1	1	1	0	0
	Ryegrass	0	0	0	0	0	0	1	1
Lactose solution 803	Clover	0	0	1	1	0	0	0	0
	Ryegrass	0	0	0	0	0	0	1	2
Lactose solution 921	Clover	1	1	1	1	0	0	0	0
	Ryegrass	0	0	0	0	1	1	1	1
Lactose solution + KCl 395	Clover	0	0	1	1	1	1	0	0
	Ryegrass	0	0	0	0	0	0	0	1
Lactose solution + KCl 645	Clover	0	0	1	2	1	1	0	0
	Ryegrass	0	0	0	0	0	0	0	1
Lactose solution + KCl 847	Clover	0	0	1	1	1	1	0	0
	Ryegrass	0	0	0	0	0	0	2	0
Lactose solution + KCl 1095	Clover	1	1	1	1	2	2	0	0
	Ryegrass	0	0	0	0	2	2	1	2

= Very strong burning

= Strong burning

= Moderate burning

= Light burning

= No burning

5.5.3.2 Weather at time of main experiment, block 1.

On day one and two the weather was hot, sunny and humid. On day three the weather was cool, rainy and windy. On day four and five it was overcast and cool. On day six the weather was warm, raining and windy. On day seven, eight, nine and ten the weather was cloudy with light rain.

5.5.3.3 Effluent composition applied in main experiment, block 1.

The pH (about 4-5), nitrite-N, nitrate-N and nitrite-N + nitrate-N concentrations were similar through all treatments despite the addition of KCl, lactose, or KCl + lactose solution (Table 5-9). As expected, the addition of KCl caused higher amounts of total dissolved solids, total potassium, and chloride (Table 5-9). The ESP was lower in treatments with added KCl due to the addition of potassium (Table 5-9). The electrical conductivity was higher in KCl 570, KCl 818 and KCl 1064 (Table 5-9).

The addition of lactose solution to the effluent increased the total dissolved solids, total sodium, total sulphur, total nitrogen, total TKN, and sulphate in all lactose solution only treatments (Table 5-9). Total calcium, total potassium, chloride, and dissolved reactive phosphorus were high in all lactose-only treatments, apart from lactose solution 356 (Table 5-9). The sodium absorption ratio was high in all treatments where only lactose solution was added (Table 5-9). The electrical conductivity was higher in lactose solution 656, lactose solution 803 and lactose solution 921 (Table 5-9).

The addition of KCl and lactose solution to the effluent caused a higher amount of total dissolved solids, total potassium, total sodium, chloride, total TKN, and sulphate to present in the effluent treatments (Table 5-9). Total sulphur, total nitrogen, and dissolved reactive phosphorus was also higher but only in treatments KCl + lactose solution 645, KCl + lactose solution 847, KCl + lactose solution 1095 (Table 5-9). The sodium absorption ratio was also higher as the lactose solution contained high amounts of sodium. The ESP was lower in treatments with lactose solution only, due to the added potassium (Table 5-9, Appendix 8).

Table 5-9. Main experiment; Block 1 effluent composition.

Effluent Composition	Water only 55*	Effluent only 223*	KCl 382*	KCl 570*	KCl 818*	KCl 1064*	Lactose solution 356*	Lactose solution 656*	Lactose solution 803*	Lactose solution 921*	KCl + Lactose solution 395*	KCl + Lactose solution 645*	KCl + Lactose solution 847*	KCl + Lactose solution 1095*
pH	6.7	4.2	4.3	4.1	4	4.4	4.1	4.7	4.9	5	4.2	4.4	4.6	4.6
Electrical Conductivity (mS/m)	9.9	1,166	1,595	3,490	5,920	6,740	1,578	2,030	2,360	2,520	2,210	3,020	3,720	4,120
Total Dissolved Solids (TDS) (g/m^3)	102	17,100	23,000	28,000	47,000	48,000	37,000	71,000	104,000	143,000	30,000	64,000	79,000	94,000
Total Calcium (g/m^3)	5.5	750	1,020	570	610	840	650	1,160	1,290	1,130	720	690	930	510
Total Magnesium (g/m^3)	2.1	122	133	116	110	152	185	240	300	320	122	182	230	210
Total Potassium (g/m^3)	3.4	1,470	2,500	9,300	16,200	18,300	1,990	3,000	4,100	4,500	4,500	6,800	9,800	10,400
Sodium Absorption Ratio	0.8	12.5	11.7	12.9	12	13.2	20	21	27	30	13.8	22	24	27
Total Sodium (g/m^3)	8.9	1,410	1,500	1,290	1,230	1,580	2,200	3,100	4,100	4,500	1,520	2,500	3,100	2,800
Total Sulphur (g/m^3)	1.7	1,250	1,400	980	1,000	1,020	2,300	2,600	3,400	3,700	1,200	1,800	2,100	2,200
Chloride (g/m^3)	10.8	940	2,200	8,300	16,500	21,000	1,210	2,300	3,100	3,300	4,200	6,600	9,100	9,700
Total Nitrogen (g/m^3)	< 6	330	290	280	270	370	470	700	950	980	340	500	700	680
Nitrite-N (g/m^3)	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10
Nitrate-N (g/m^3)	0.69	5.6	9.1	7.4	8.4	8.5	6.4	8.2	9.3	7.1	8.7	8.5	7.8	5.5
Nitrate-N + Nitrite-N (g/m^3)	0.72	5.6	9.1	7.4	8.4	8.5	6.4	8.2	9.3	7.1	8.7	8.5	7.8	5.5
Total Kjeldahl Nitrogen (TKN) (g/m^3)	< 5	330	280	270	260	360	460	690	940	970	330	490	690	670
Dissolved Reactive Phosphorus (g/m^3)	0.042	340	490	280	330	510	260	590	640	500	380	430	560	350
Sulphate (g/m^3)	7.3	3,800	4,100	3,200	3,200	3,600	6,900	8,400	10,600	11,400	4,000	6,100	7,700	7,700
ESP	44.72	37.57	29.10	11.44	6.77	7.56	43.78	41.33	41.87	43.06	22.15	24.57	22.04	20.11
Max Burn: Clover	1	1	2	2	3	4	1	1	1	1	1	2	1	2
Max Burn: Ryegrass	1	2	1	1	1	1	1	1	2	1	1	1	2	2

* = measured osmolality of each effluent treatment.

5.5.4 Effluent properties and maximum burning of clover and ryegrass

Maximum burning was compared with effluent properties (Figure 5-34 to 5-39). There was a positive correlation between clover burning and electrical conductivity, exchangeable sodium percentage, total potassium and chloride. There were no strong trends ($R^2 > 0.5$) between block 1 effluent properties and ryegrass burning. The electrical conductivity, total potassium, exchangeable sodium percentage, and total chloride showed the strongest trends ($R^2 = 0.81, 0.82$) in clover burning (Figure 5-36 – 5-39). Osmolality was not strongly correlated to either clover ($R^2 = 0.26$) or ryegrass ($R^2 = 0.24$, Figure 5-34, 5-35).

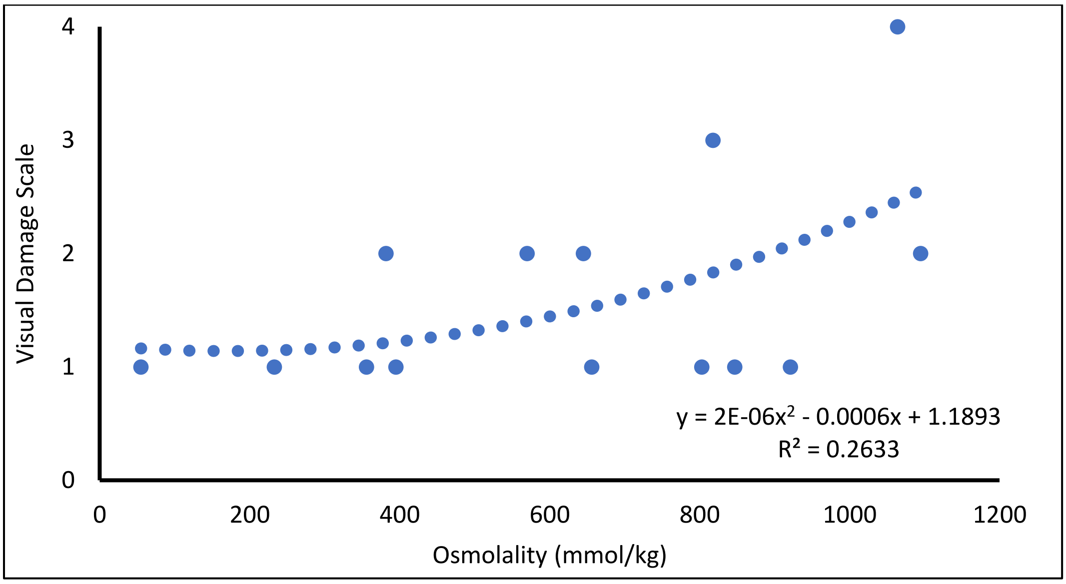


Figure 5-34. Main Experiment: Osmolality vs maximum clover burning.

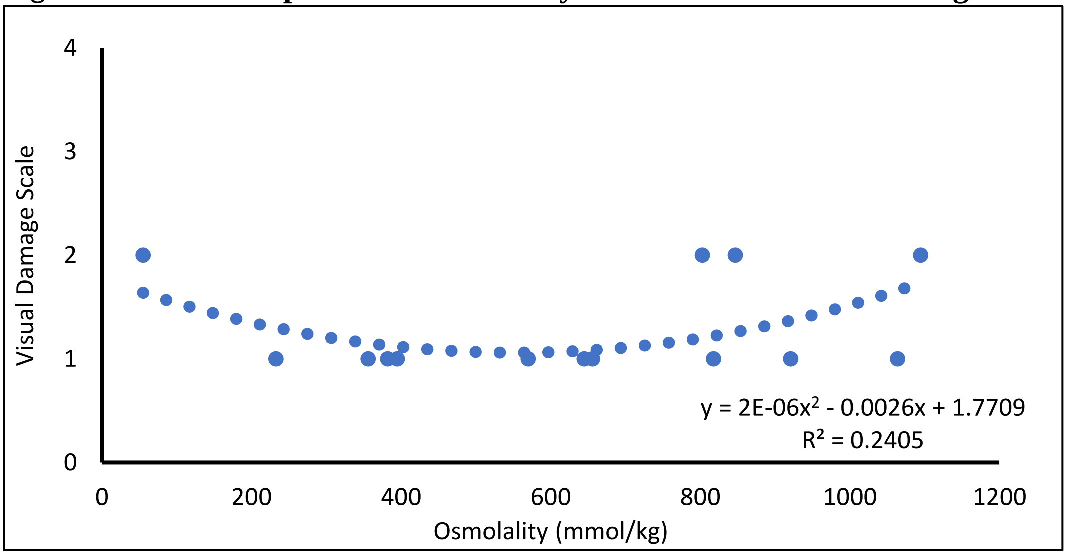


Figure 5-35. Main Experiment: Osmolality vs maximum ryegrass burning.

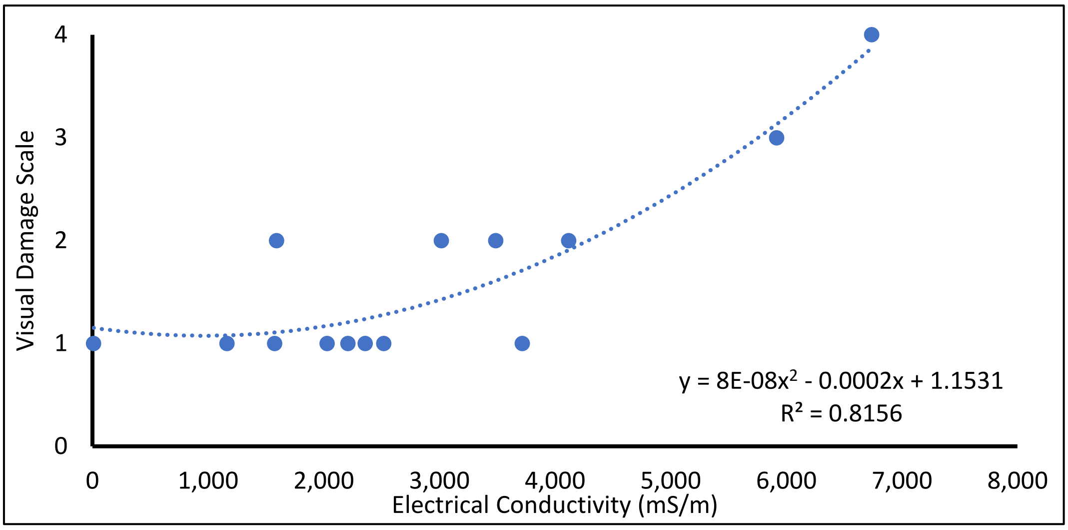


Figure 5-36. Main Experiment; Block 1: Electrical Conductivity vs maximum clover burning.

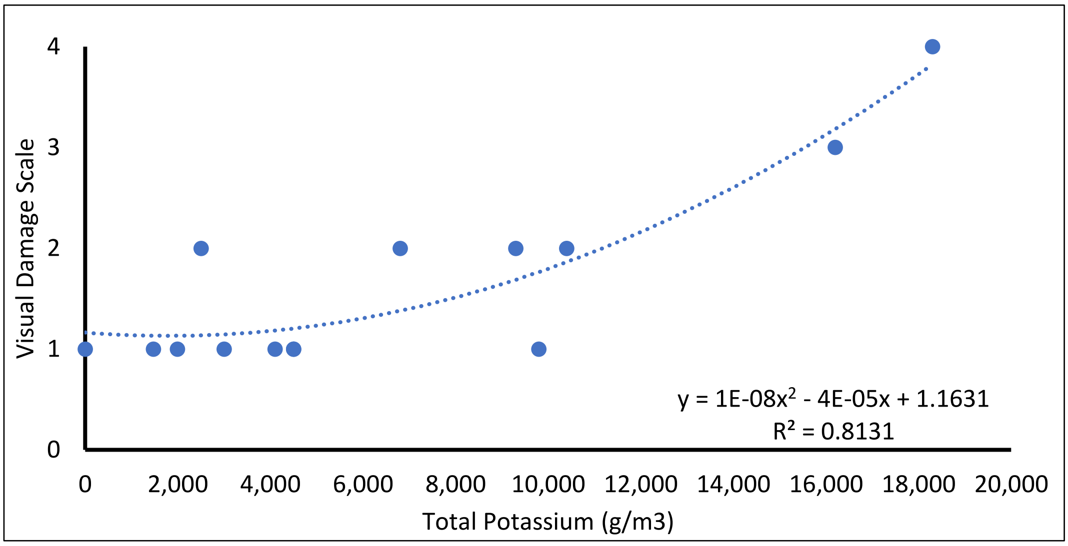


Figure 5-37. Main Experiment; Block 1: Total Potassium vs maximum clover burning.

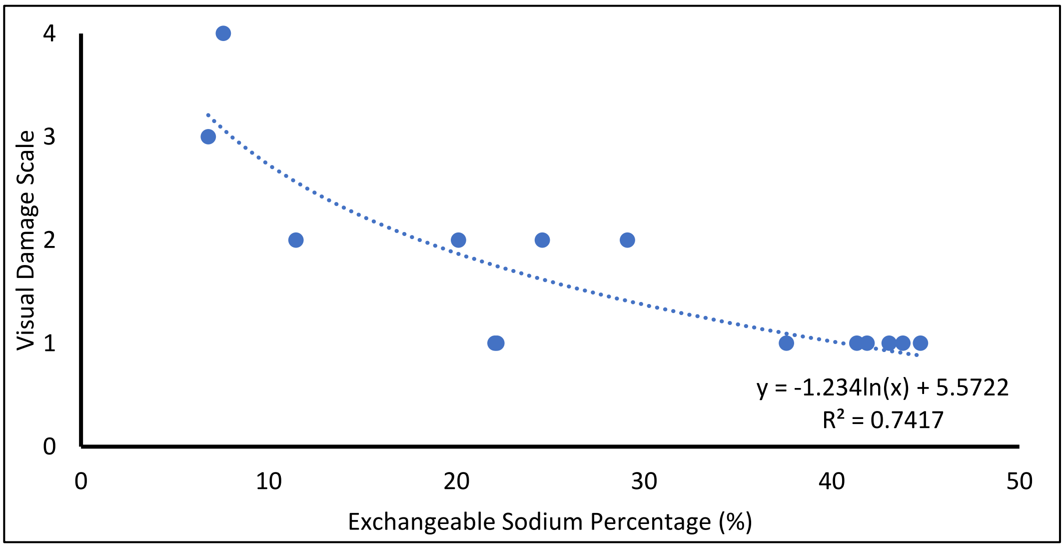


Figure 5-38. Main Experiment; Block 1: Exchangeable Sodium Percentage vs maximum clover burning.

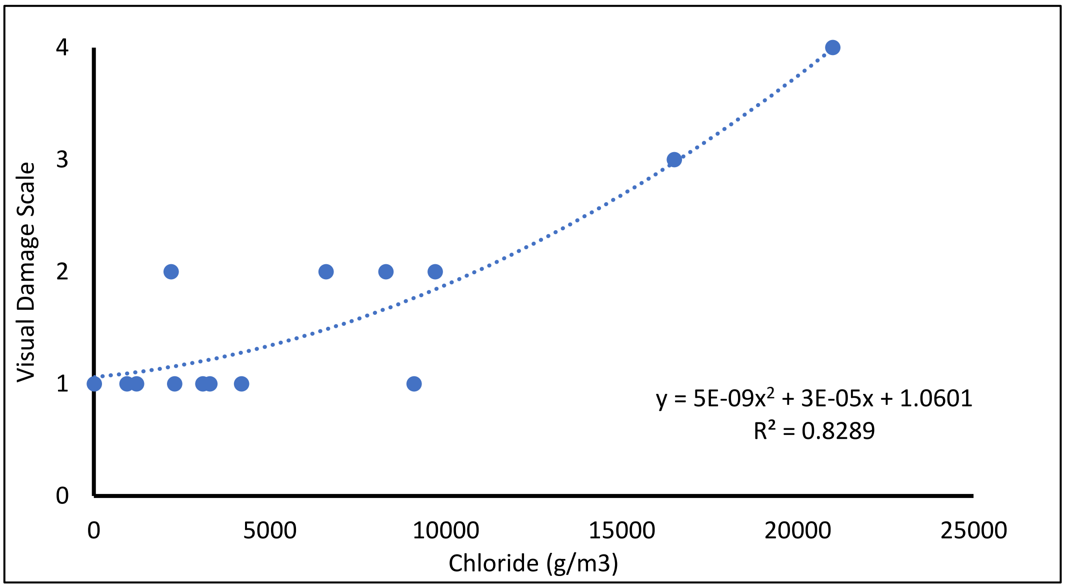


Figure 5-39. Main Experiment; Block 1: Chloride vs maximum clover burning.

5.5.4.1 Conclusion

Ryegrass burning was slight to moderate overall. The plots treated with KCl 818 and KCL 1064 had the worst clover burning reaching moderate to strong burning. The correlation between osmolality and burning was weak. However, burning strongly correlated with electrical conductivity, chloride and total potassium.

5.5.5 Main experiment: Block 2 (with progibb and urea)

5.5.5.1 Burn Record

Burning results (Table 5-8, Appendix 7) show that clover was somewhat more susceptible to burning that ryegrass where the plots treated with KCl 797 and KCl 990 had strong (level 3) to very strong burning (level 4) on day 3. All other plots started burning on day three and four, however burning was only slight (Table 5-8). By day nine, most of the clover had recovered with no burning evident (Table 5-8, Appendix 6).

Ryegrass burning was strong (level 3) in plots treated with KCl 990, lactose solution 768 and lactose solution + KCl 876. Slight burning (level 2) was evident in some plots on day four (Table 5-8). On day seven, slight tip burning occurred in plots treated with lactose solution + KCl 876, lactose solution + KCl 993 and KCl 440 (Table 5-8). After day seven, all plots apart from KCl 990 had recovered (level 0) (Table 5-8).

Table 5-8. Burning recorded on each day of the main experiment block 2.

Treatments		Day 1	Day 2	Day 3	Day 4	Day 5	Day 7	Day 9
Untreated 0	Clover	0	0	0	0	0	0	0
	Ryegrass	0	0	0	0	0	0	0
Water only 49	Clover	0	0	0	0	0	0	0
	Ryegrass	0	0	0	0	0	1	0
Effluent only 202	Clover	0	1	1	1	2	0	0
	Ryegrass	0	0	0	0	0	0	0
KCl 440	Clover	0	1	1	1	1	2	1
	Ryegrass	0	0	0	0	0	2	1
KCl 604	Clover	0	1	2	2	2	2	0
	Ryegrass	0	0	0	2	2	0	0
KCl 797	Clover	0	1	3	3	2	0	0
	Ryegrass	0	0	0	0	1	0	0
KCl 990	Clover	0	1	4	4	3	2	1
	Ryegrass	0	0	0	3	1	2	2
Lactose solution 365	Clover	0	1	1	1	1	1	1
	Ryegrass	0	0	0	0	1	1	0
Lactose solution 570	Clover	0	1	1	1	1	0	0
	Ryegrass	0	0	0	0	0	1	0
Lactose solution 768	Clover	0	1	1	1	1	1	1
	Ryegrass	0	0	0	2	2	0	0
Lactose solution 967	Clover	0	1	1	1	2	1	0
	Ryegrass	0	0	0	0	1	0	0
Lactose solution + KCl 370	Clover	0	1	1	1	1	0	0
	Ryegrass	0	0	0	0	0	0	0
Lactose solution + KCl 421	Clover	0	0	1	1	1	0	0
	Ryegrass	0	0	0	0	1	1	0
Lactose solution + KCl 876	Clover	0	1	1	2	2	2	0
	Ryegrass	0	0	0	2	1	2	1
Lactose solution + KCl 993	Clover	0	1	1	1	2	1	0
	Ryegrass	0	0	0	0	1	2	0

= Very strong burning

= Strong burning

= Moderate burning

= Light burning

= No burning

5.5.5.2 Weather at time of main experiment, block 2.

On day one and two the weather was cool, rainy and windy. On day three and four it was overcast and cool. On day five and six the weather was warm, raining and windy. On day seven, eight and nine the weather was cloudy.

5.5.5.3 Effluent composition applied on main experiment, block 2.

The pH, total calcium, nitrite-N, nitrate-N, nitrate-N + nitrite-N, and dissolved reactive phosphorous present in all of the effluent solutions remained similar despite the addition of KCl and lactose solution (Table 5-9). Total dissolved solids, total potassium and chloride was higher in treatments with added KCl compared to effluent only (Table 5-9).

The electrical conductivity was higher in all treatments containing added KCl (Table 5-9). The ESP was lower compared to effluent only in all KCl treatments due the increased in potassium (Table 5-9).

All treatments with additional lactose solution were higher in total sodium, sodium absorption ratio, total sulphur, total nitrogen and sulphate (Table 5-9). The electrical conductivity, total magnesium and total TKN were higher in lactose solution and lactose solution + KCl treatments (Table 5-9). The ESP was lower compared to effluent only in treatments KCl + lactose solution as the lactose solution has a stronger mineral content (Table 5-9, Appendix 8).

Table 5-9. Main experiment; Block 2 effluent composition.

Effluent Composition	Water only 49*	Effluent only 202*	KCl 440*	KCl 604*	KCl 797*	KCl 990*	Lactose solution 365*	Lactose solution 570*	Lactose solution 768*	Lactose solution 967*	KCl + Lactose solution 370*	KCl + Lactose solution 421*	KCl + Lactose solution 876*	KCl + Lactose solution 993*
pH	4.5	6.6	4.4	4.4	4.4	4.4	4.3	4.6	4.8	5.1	4.2	4.5	4.8	4.7
Electrical Conductivity (mS/m)	1,196	9.4	2,570	5,480	3,010	6,350	1,590	1,913	2,350	2,560	1,947	2,480	3,690	4,160
Total Dissolved Solids (TDS) (g/m^3)	16,900	90	26,000	41,000	25,000	48,000	48,000	74,000	120,000	126,000	31,000	39,000	85,000	101,000
Total Calcium (g/m^3)	870	5.4	760	590	660	690	590	740	890	950	450	760	910	500
Total Magnesium (g/m^3)	125	1.87	118	128	106	121	169	220	290	310	123	155	220	240
Total Potassium (g/m^3)	1,430	2.8	5,400	15,400	7,700	16,700	2,200	3,000	4,100	4,500	3,700	5,000	9,400	11,300
Sodium Absorption Ratio	11.7	0.7	11.8	12.8	11.4	12.7	21	25	31	34	17.5	16.5	23	30
Total Sodium (g/m^3)	1,390	7.4	1,320	1,310	1,190	1,370	2,300	3,000	4,200	4,800	1,630	1,910	2,900	3,200
Total Sulphur (g/m^3)	1,260	1.7	1,140	970	920	1,110	1,900	2,500	3,400	3,800	1,300	1,380	2,200	2,200
Chloride (g/m^3)	1010	11.3	5,800	15,900	7,100	19,400	1,570	2,300	2,900	3,400	3,400	5,100	8,900	9,800
Total Nitrogen (g/m^3)	280	< 6	330	270	330	310	400	650	970	1090	350	410	710	600
Nitrite-N (g/m^3)	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10
Nitrate-N (g/m^3)	5.6	0.65	5.3	4.8	4.3	5.3	6.5	5.9	5.6	5.8	5.5	5.6	5.3	5.3
Nitrate-N + Nitrite-N (g/m^3)	5.6	0.66	5.3	4.8	4.3	5.3	6.5	5.9	5.6	5.8	5.5	5.6	5.3	5.3
Total Kjeldahl Nitrogen (TKN) (g/m^3)	270	< 5	330	270	330	310	390	650	960	1080	340	400	700	590
Dissolved Reactive Phosphorus (g/m^3)	440	0.004	410	320	310	410	260	340	380	440	220	460	490	350
Sulphate (g/m^3)	3,800	6	3,700	3,100	3,100	3,600	6,200	7,800	11,200	12,400	4,500	4,700	7,500	7,700
ESP	36.43512451	42.35832856	17.37299289	7.51663989	12.32394366	7.255971612	43.73455029	43.10344828	44.30379747	45.45454545	27.6130781	24.40894569	21.59344751	20.99737533
Max Burn: Clover	0	2	2	2	3	4	1	1	1	2	1	1	2	2
Max Burn: Ryegrass	1	0	2	2	1	3	1	1	2	1	0	1	2	2

* = measured osmolality of each effluent treatment.

5.5.6 Effluent properties and maximum burning of clover and ryegrass

In block 2, there were positive correlations ($R^2 > 0.5$) between clover burning and electrical conductivity, chloride and total potassium (Figure 5-40, 5-42, 5-44). Electrical conductivity, chloride and potassium had a positive correlation ($R^2 =$ 0.67, 0.6, 0.59) ryegrass burning.

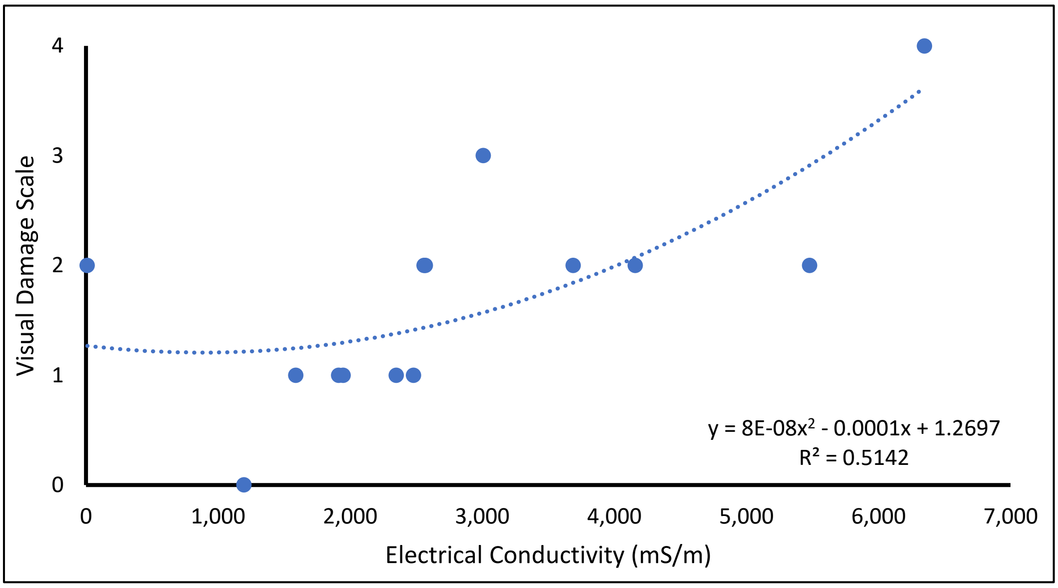


Figure 5-40. Main Experiment; Block 2: electrical conductivity vs maximum clover burning.

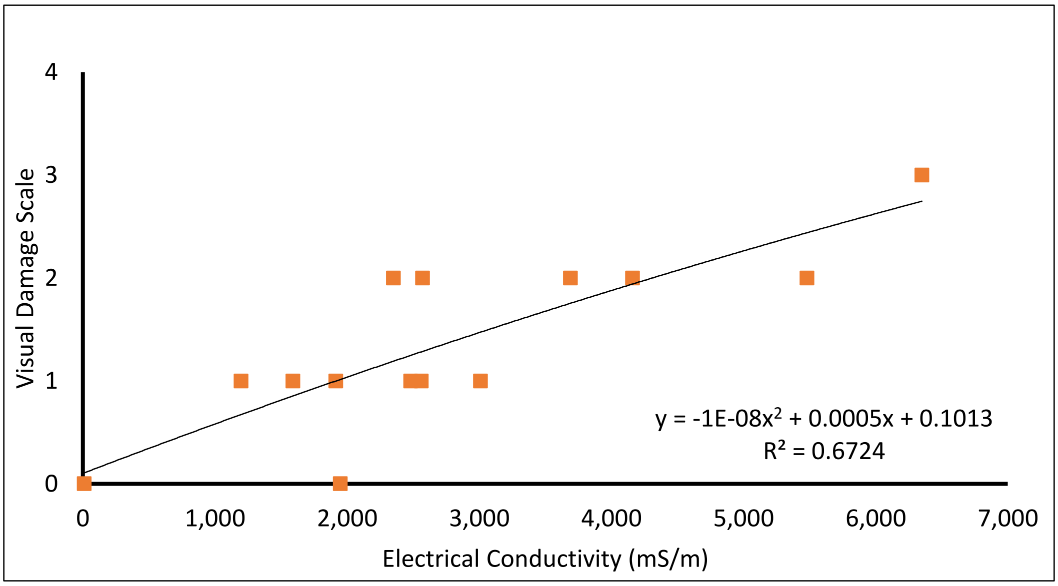


Figure 5-41. Main Experiment; Block 2: electrical conductivity vs maximum ryegrass burning.

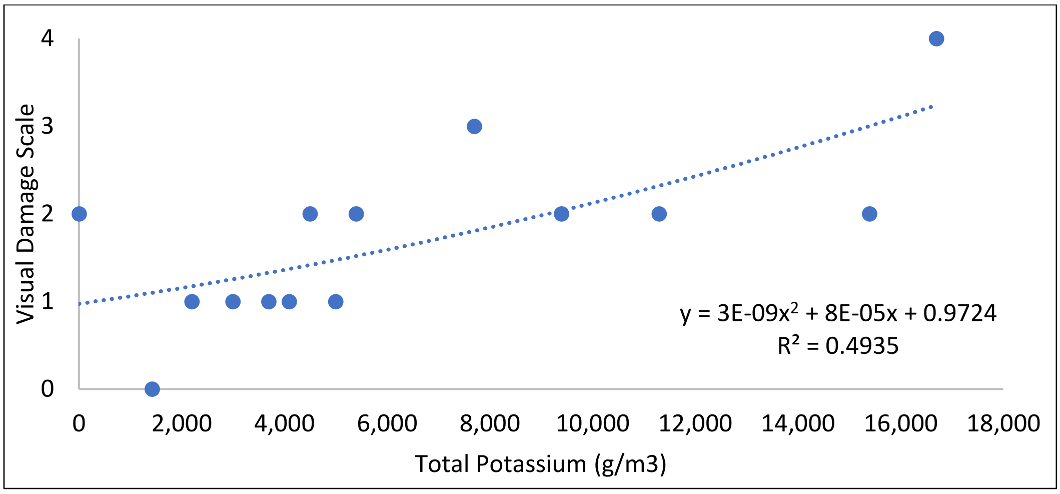


Figure 5-42. Main Experiment; Block 2: total potassium vs maximum clover burning.

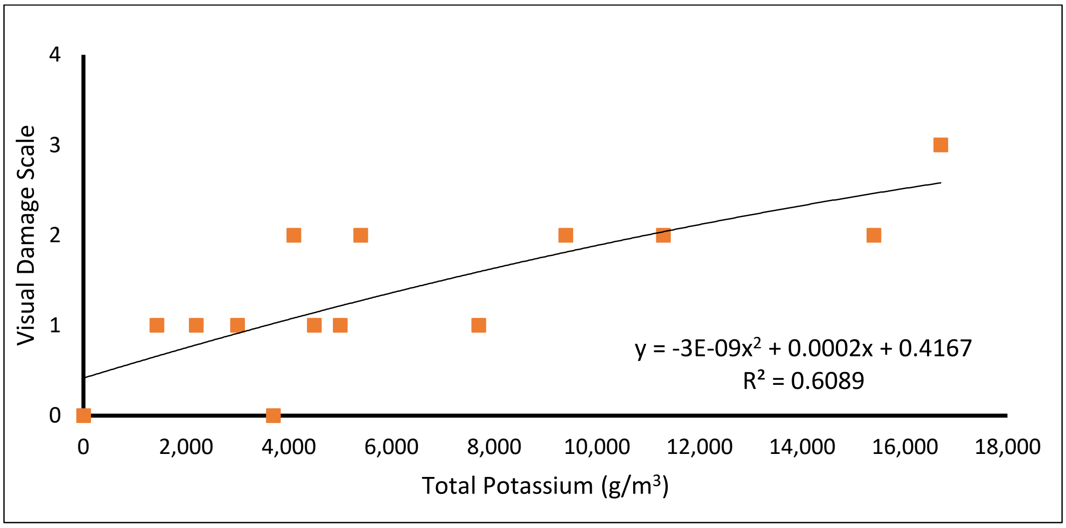


Figure 5-43. Main Experiment; Block 2: total potassium vs maximum ryegrass burning.

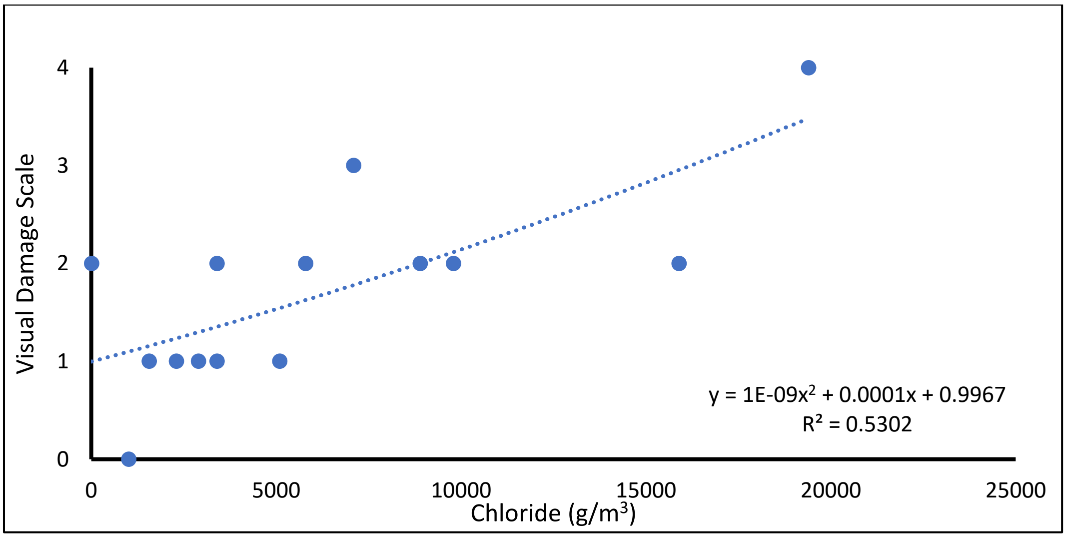


Figure 5-44. Main Experiment; Block 2: chloride vs maximum clover burning.

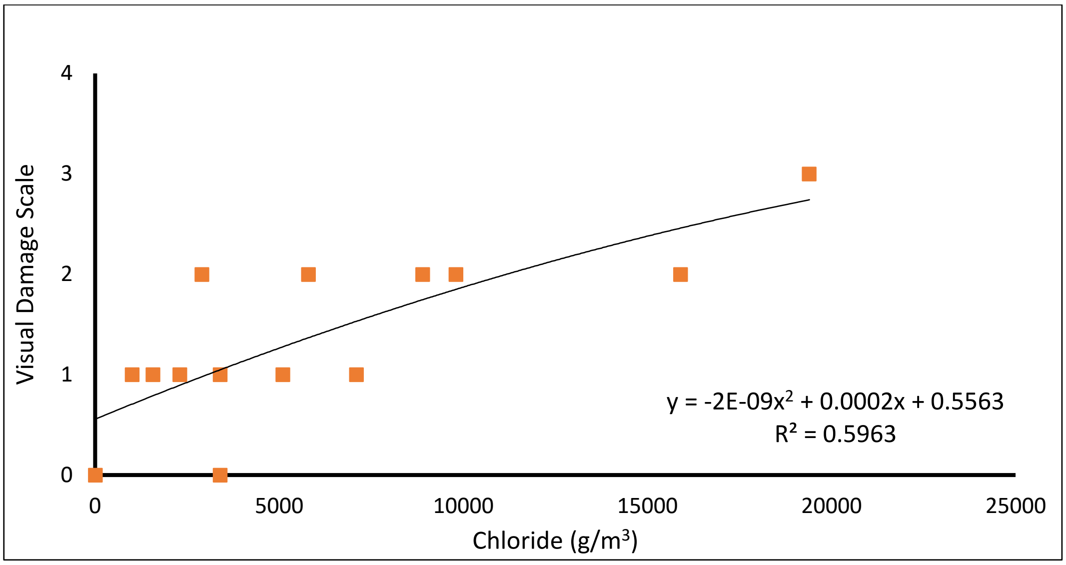


Figure 5-45. Main Experiment; Block 2: chloride vs maximum ryegrass burning.

5.5.6.1 Conclusion

Ryegrass burning was moderate in plots treated with KCl 797 and 990 and clover burning was strong to very strong burning in plots treated with KCl 797 and KCl 990 (Table 5-8). There was minimal burning in block 2 under all other treatments and burning did not occur until three which may have been attribute to the rain which diluted the effluent reducing the concentration of ions being absorbed by the pasture. Electrical conductivity and chloride positively correlated with clover burning. Ryegrass burning positively correlated with electrical conductivity, chloride, and total potassium.

5.6 Discussion

5.6.1 Effluent properties and maximum burning

The results from the pilot trial and main experiment were combined where maximum burning was compared against all effluent properties. There was a positive correlation between osmolality, total potassium, chloride and the electrical conductivity when graphed against maximum clover burning (Figure 5-46, 5-47, 5-48). There was no strong positive correlation between ryegrass burning and effluent properties.

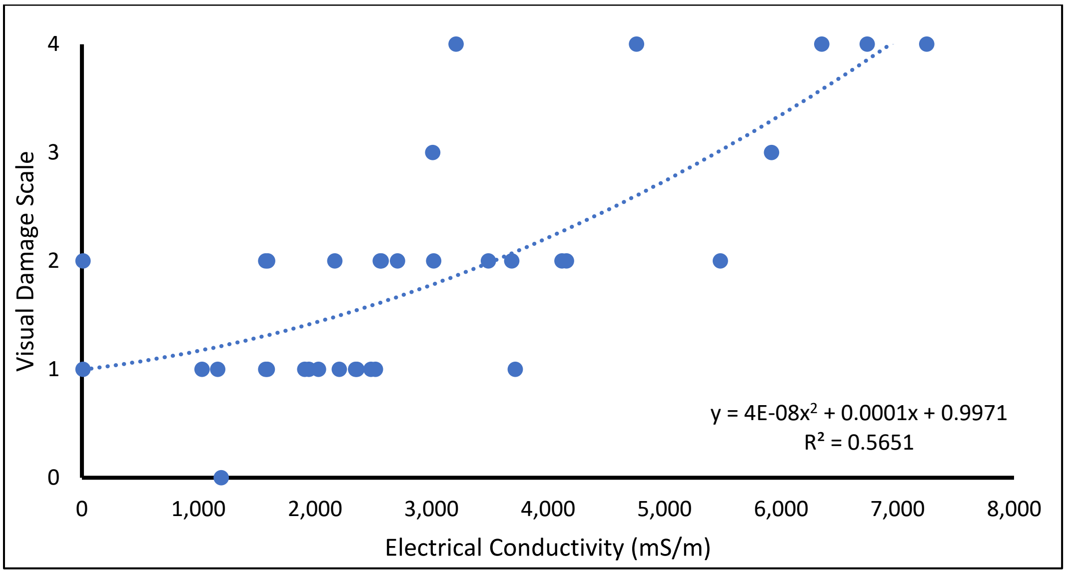


Figure 5-46. Pilot Trial + Main experiment - block 1 and 2: electrical conductivity vs maximum clover burning.

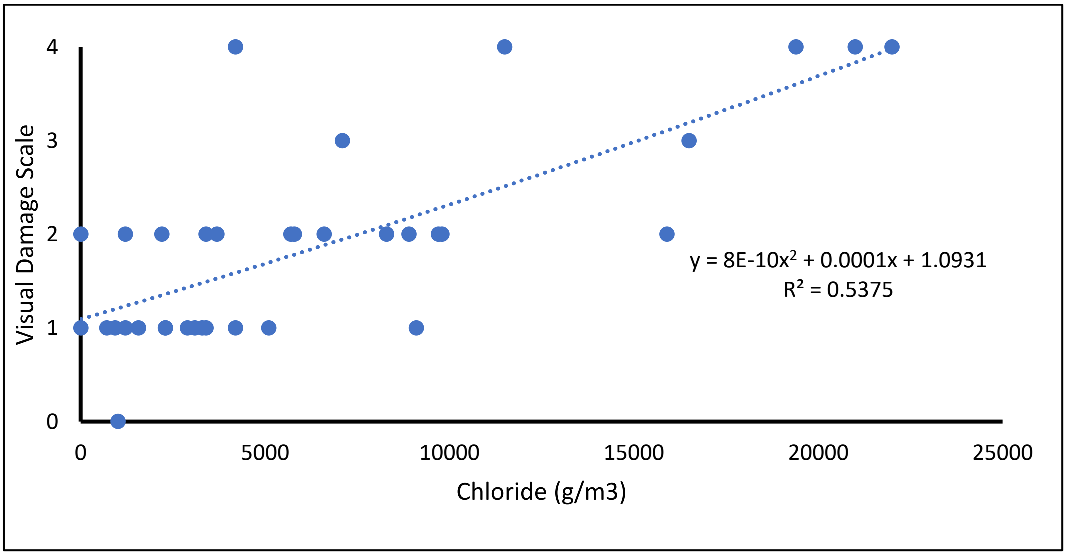


Figure 5-47. Pilot Trial + Main experiment - block 1 and 2: chloride vs maximum clover burning.

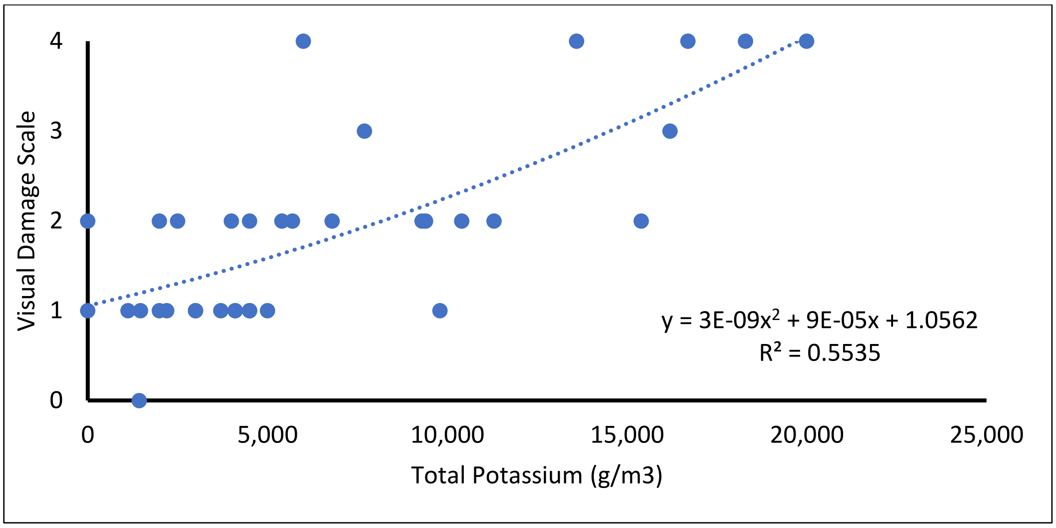


Figure 5-48. Pilot Trial + Main experiment - block 1 and 2: total potassium vs maximum clover burning.

5.6.2 Osmolality

The effluent that caused the most pasture burning generally had a higher osmolality. In the pilot trial, the three treatments (KCl, lactose solution and KCl + lactose) with the highest osmolality caused strong to very strong burning. In the main experiment, block 1 and 2 showed similar burning patterns and intensity. In both blocks of the main experiment, the KCl treatments with a high osmolality caused strong burning (KCl 797, KCL 990, KCl 1064). All other treatments in the main experiment showed slight to moderate burning. The experiment confirmed that the osmolality of the high strength effluent should not exceed ~450 mmol/kg otherwise moderate to strong burning will occur (Figure 5-49).

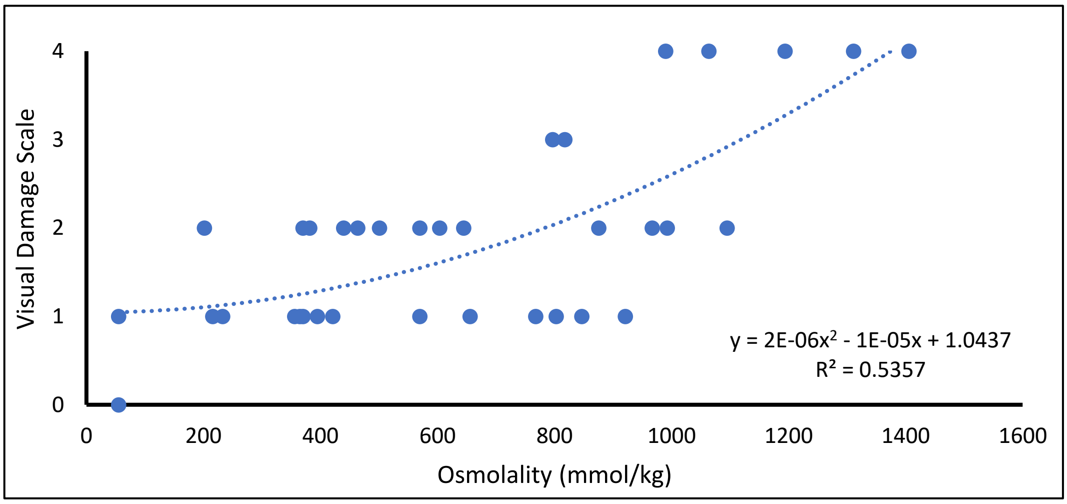


Figure 5-49. Pilot Trial + Main experiment - block 1 and 2: osmolality vs maximum clover burning

As the mean osmolality of the clover was 415 mmol/kg and the mean osmolality of the ryegrass 535 mmol/kg (Section 4.7) and the results from the experiments confirmed that osmolality of the effluent should not exceed ~450 mmol/kg, the osmolality is a good indicator of when pasture burning will occur. If the osmolality of the effluent exceeds that of the pasture, then a dehydration effluent can occur where if the osmolality inside the plant cells is lower that the surrounding solution the water inside the plant cells will move out of the plant (Nabors, 1973, Kowles, 2010). If the electrical conductivity exceeds 1500 mS/m, moderate to severe pasture burning may occur however, the osmolality is a better measure of burning.

5.6.3 Effect of weather on pasture burning

In both the pilot trial and the main experiment clover was more susceptible to burning than ryegrass. In the pilot trial, very strong burning occurred on day three. The weather during the pilot trial was warm and cloudy until day four. In the main experiment, block 1 was treated one day before block 2. The weather when block 1 was treated was hot and sunny. When block 2 was treated, it rained on day 1 and day two and three cool and overcast. The difference in the weather between the treatment of block 1 and block 2 seemed to affect when and how severe pasture burning was. In block 1, strong clover burning occurred on day one in the plots treated with KCl 1064. In block 2, strong to very strong clover burning did not occur until day three in plots treated with KCl 797 and KCl 990. If the weather remained hot when block 2 was treated, it would be expected that clover burning would have occurred on day one and would have been more severe. The delay in burning between block 1 and the pilot trial/block 2 suggests that the heat influenced the severity and time pasture burning occurred.

Ryegrass burning in the pilot trial and main experiment occurred on day three and day four however burning was only light to moderate. The difference in weather did not seem to affect the severity or timing of ryegrass burning. Ryegrass is considered to be more tolerant to salts than clover (NSW Department of Primary Industries report, 2017).

Towards the end of the main experiment, the untreated plots became damaged as an orange rust had spread through the experiments which may account for the damage to the plots that were untreated.

5.6.4 Susceptibility to pasture burning

The clover was generally more susceptible to burning compared to the ryegrass. Crush et al, (2005) confirmed that white clover seemed to be more susceptible to high sodium and low pH than ryegrass (Rogers et al., 1997). By adding KCl and lactose to each treatment for the pilot trial and main experiment, understanding if it was the K^+, Cl^- or other ions that were causing the damage to the pasture is key.

Salt absorption directly through the leaf can damage the leaf surface (Ayers & Westcot, 1994). A high concentration of Cl^- in irrigation water can accumulate in the leaf causing leaf scorch (Kafkafi et al., 2001). Cl^- is continually absorbed into the leaf as long as the surface of the leaf remains wet (Kafkafi et al., 2001) so that the ions remain in solution for absorption. Injury varies depending on the temperature, relative humidity and the amount of water present for absorption (Kafkafi et al., 2001). If evaporation is high, the salt concentration in the leaf will increase which can cause leaf damage (Kafkafi et al., 2001). Chloride toxicity commonly occurs at the tips of the plants where injury is seen along the edges and progresses the more severe the toxicities becomes (Kafkafi et al., 2001).
In both the pilot trial and main experiment, clover was observed to burn at the tips and strong burning was seen as damage throughout the whole leaf. Ryegrass burning also occurred at the tip of the leaf.

Excess potassium may also cause toxic effects on both clover and ryegrass. Excess potassium will cause the stomata to open and water can be lost (Van Brunt, 1998). Excess nutrients can also be absorbed if the stomata remain open for too long (Van Brunt, 1998). Both potassium and chloride may be responsible for pasture burning, each having their own role in plant survival.

In the main experiment, KCl had a stronger effect on the clover than lactose. The addition of lactose solution increased the total calcium, total magnesium, total sodium, total sulphur, total sulphate and organic nitrogen present in the treatments. It would be assumed that burning would be more severe with the addition of lactose solution due to the lactose solution being highly concentrated, however severe burning did not occur in the main experiment. Burning was strongest in the plots treated with KCl suggesting K^+ and/or Cl^- have a large impact on pasture burning. Reducing the amount of ions/minerals present in the effluent will lower the concentration and potentially pasture burning as treatments with high amounts of lactose solution caused strong burning. Salt tolerant species of white clover have been recognised (Wang et al., 2010), thus investigation of more salt tolerate clover species may be an option.

Despite block 2 being treated with progibb and urea to increase pasture growth, the pasture in block 1 also grew well as the weather was optimal for pasture growth and the farm had high nutrient levels. As the pasture was green and lush in both block 1 and block 2, determining if new growth burnt more than mature pasture could not be confirmed. However, observations made by the Fonterra irrigation officers and the literature suggests that new growth does burn more than mature pasture (Fageria et al., 2008, Waskom et al., 2010, Penn State College of Agricultural Sciences, 2017, Fonterra Edgecumbe Irrigation team, pers comm, 2017).

5.7 Summary and conclusion

- A pilot trial was carried out to determine if pasture burning could be related to an increase in effluent osmolality. The pilot trial confirmed that an effluent osmolality above 1194 mmol/kg caused clover and ryegrass burning.
- The main field experiment was carried out to determine a cut off point for the osmolality of the effluent to prevent severe pasture burning. It was suggested that if the osmolality exceeds 450 milliosmoles or the electrical conductivity exceeds 1500 mS/m, moderate to severe pasture burning may occur. Electrical conductivity was strongly correlated with pasture burning (Refer to figure 5-45.).
- Pilot trial showed a strong correlation (R^2 >0.9) between osmolality and pasture burning.
- Pilot trial also showed a positive correlation (R^2>0.5) between *clover burning* and electrical conductivity, total potassium, chloride, nitrate-N, total calcium, total dissolve solids and nitrate-N + nitrite-N. *Ryegrass burning* positively correlated with osmolality, pH, electrical conductivity, total magnesium, sulphate, total sulphur, total sodium, total nitrogen, dissolved reactive phosphorus, total kjeldahl nitrogen and the sodium absorption ratio.
- There was no marked correlation (R^2 <0.5) between clover burning and pH, total magnesium, sodium absorption ratio, total sodium, total sulphur, nitrite-N, TKN, dissolved reactive phosphorus or sulphate. There was also no strong correlation (R^2 <0.5) between ryegrass burning and total calcium, total potassium, chloride, nitrate-N, nitrite-N, or nitrate-N + nitrite-N.
- Ryegrass burning was less severe than clover burning.
- Treatments with added lactose solution burned less than treatments that contained KCl or KCl + lactose with a similar osmolality.
- Determining if new growth caused more pasture burning was unable to be confirmed as the pasture in both blocks 1 and block 2 was thriving thus the addition of progibb and urea to block 2 did not cause a marked difference in pasture growth.

- The weather may influence pasture burning where hot, sunny weather may lead to more severe burning as increased evaporation leaves the salts in the effluent more concentrated than in overcast weather.

Chapter 6

Discussion and Conclusion

6.1 Introduction

Chapter six summarises then discusses the overall results and conclusions of the previous chapters, as well as the limitations of my research and, recommendations for both future effluent management at Fonterra Edgecumbe and for further research to better elucidate the causes of pasture burning. My hypotheses are also reviewed.

6.2 Summary of previous chapters

6.2.1 Introduction

My thesis investigated pasture burning which was first observed by Fonterra in Edgecumbe in 1996. Pasture burning is the yellowing and dieback of pasture that occurs during spring and early summer when high strength effluent is applied to farms irrigated by Fonterra Edgecumbe. Pasture burning is reported to occur during each dairying season and within hours to days after the irrigation of high strength effluent. "Burned" pasture usually recovers within two weeks (Fonterra Edgecumbe Irrigation team, pers comm, 2017).

6.2.2 Literature review

The literature review identified the following possible causes, and contributors to pasture burning:

- clover has a lower tolerance to salts than ryegrass,
- high or low pH effluent applied directly to the leaf surface may lead to leaf damage. Lactic acid production via fermentation of the effluent left in pipes may lower the pH enough to cause damage to the leaf surface,
- high temperature effluent, if applied to the soil may reduce oxygen and nutrient up-take,
- if applied to the plant, high temperature effluent may directly damage the leaves,

- if the osmolality of applied effluent exceeds that of the plant, reverse osmosis may occur resulting in dehydration of the plant due to the build up of the ions in the leaf which draws water out the plant cells,
- high air temperatures and low humidity may enhance evaporation of the effluent thus concentration the salts in the solution applied,
- harsh UV radiation can reduce the epidermis of the plant leaf causing the plant to become more susceptible to environmental stressors and potential leaf burn,
- micro and macronutrient deficiencies can show as damage to the plant surface where yellowing and die-back can occur, however excess nutrients such as sodium, potassium and chloride can also lead to dehydration, yellowing and die-back,
- irrigating on water logged soils will may cause ponding and the die-back of pasture due to reduced oxygen levels.

6.2.3 Preliminary observations

On-site preliminary observations were carried out to try and narrow down potential causes of pasture burning at the Fonterra Edgecumbe irrigation sites. Pasture burning was observed to occur after the application of high strength effluent to young pasture. Damage to the tips of the leaves which turned yellow and died-back was observed.

High strength effluent analytical data collected from the 24-hr composite sampler were analysed from season 2013-2014 through to season 2016-2017 and compared with analysis of 11 samples of high strength effluent collected in the field from Awaroa farm, Rowlands farm, and McDonalds farm. Field samples of effluent varied in effluent composition from run to run. Short term continuous monitoring also showed that the effluent varied more than is captured in the daily in the 24-hr composite sampler data.

The 24-hr composite sampler data had a similar composition to the effluent samples collected from the farms where the pH was low (~4), the amount of total dissolved solids ranged between 14,000 and 19,000 g/m^3, total calcium ranged between 980 g/m^3 and 1,500 g/m^3, total potassium ranged between 1,500 g/m^3 and 1,700 g/m^3, total sodium was around ~1,400 g/m^3, TKN ranged from 200 and 400 g/m^3 and dissolved reactive phosphorus was around 400 g/m^3.

Field samples were sometimes lower, or higher than the data from the compost sampler. For instance, one sample from Rowlands farm contained only 6,600 g/m^3 of total dissolved, 540 g/m^3 of calcium, 690 g/m^3 of potassium, 700 g/m^3 of sodium, 95 g/m^3 TKN and 22 g/m^3 of dissolved reactive phosphorus which is about half the amount of ions compared to the 24-hr composite sampler data.

Continuous monitoring of effluent electrical conductivity, pH and temperature from the 6th to the 21st of December 2016, in the sampling shed, showed that the effluent did spike in electrical conductivity (49 to 151 mS/cm or 4,900 to 15,100 mS/m) during the day which was not captured in the 24-hr composite sampler. There was a large spike in electrical conductivity on the 7th of December 2016 reaching 5000 mS/cm (50,0000 mS/m) showing that the effluent does vary more than is detected in the composite samples. The 24-hr composite data ranged in electrical conductivity between 1,100 to 1,300 mS/m which is lower than that recorded using continuous monitoring probes. The temperature varied between 20 and 60^{o}C with no obvious diurnal pattern. The pH spiked between 4 and 12. The pH spiked high when CIP's (cleaning in place) occurred. The continuous monitoring data from the Awaroa outlet on 10th to the 13th of February 2017 showed similar results to the continuous monitoring data which was recorded in the sampling shed. The temperature ranged between ~35^{o}C and ~55^{o}C and the conductivity ranged between ~40 mS/cm to ~85 mS/cm (4,000 mS/m to 8,500 mS/m) however, no large spikes were recorded.

Field operator observations recorded 38 pasture burning events between 14th of September 2016 to the 10th of December 2016. There were no obvious patterns related to pasture burning occurrences.

The weather data, when graphed against irrigation events, did not show a pattern when temperature, rainfall, humidity, wind speed, wind direction or solar radiation were compared with pasture burning events.

Osmolality may be a good indicator of pasture burning. Osmolality measures the amount of solutes present whereas electrical conductivity measures only the ions present in a solution. As the effluent contains many different solutes, measuring the osmolality may provide a better overall picture of the potential impact of the effluent on the pasture.

If the osmolality of the effluent exceeds the osmolality of the pasture, pasture burning may be able to be predicted and therefore adverse burning could be avoided.

Measures of the osmolality of fresh clover and ryegrass (400 - 500 mmol/kg and 500 - 600 mmol/kg) and burned clover and ryegrass were higher than that of the high strength effluent (202 – 233 mmol/kg). Both burned clover and ryegrass had a higher osmolality than fresh clover and ryegrass and the effluent. However, it is possible that where spikes in effluent occur, higher osmolarities are experienced.

6.2.4 Field experiments and results

A pilot trial was undertaken to test whether an effluent with a high osmolality could cause pasture burning. Effluent was spiked with KCl, lactose, or a mixture of KCl and lactose, to increase the osmolality. The osmolality of the effluent before the addition of KCl and lactose varied from 172 – 266 mmol/kg. The effluent solutions used in the pilot trial had a low pH (~4) and a high concentration of total sodium in treatments that contained high amounts of lactose (lactose 1406). The SAR and ESP (>25%) of the effluent was high also. The pilot trial supported the hypothesis that a solution with a high osmolality caused severe pasture burning.

A further ("main") experiment was carried out to try to determine the cut-off point of osmolality in terms of burning, and to test whether new growth was more susceptible to burning compared to mature pasture. The main experiment had similar effluent compositions to the pilot trial and showed similar burning results to the pilot trial where the effluent with the highest osmolality caused the most severe burning, though the correlation was not as strong as that of the pilot trial.

When the pilot trial and main experiment results were combined, clover burning positively correlated with electrical conductivity, chloride, total potassium and osmolality (Figure 6-1, 6-2, 6-3). Ryegrass burning did not correlate with any effluent properties.

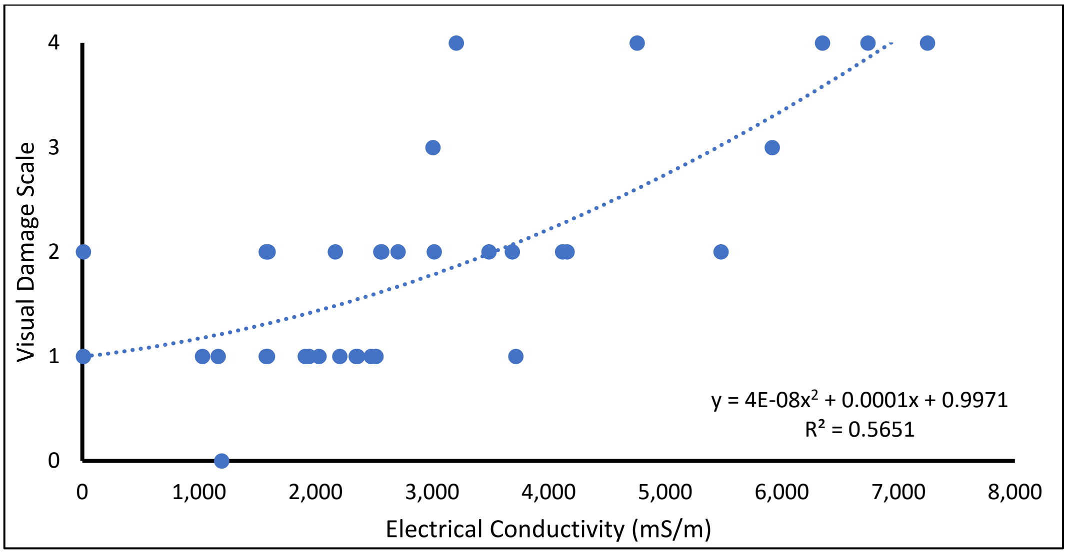


Figure 6-1. Pilot Trial + Main experiment - block 1 and 2: electrical conductivity vs maximum clover burning.

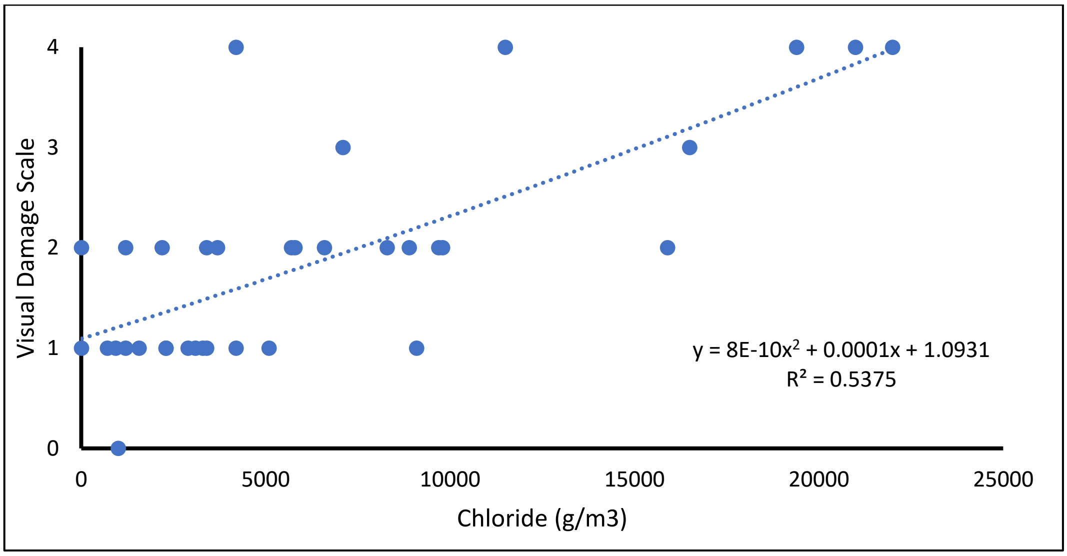


Figure 6-2. Pilot Trial + Main experiment - block 1 and 2: chloride vs maximum clover burning.

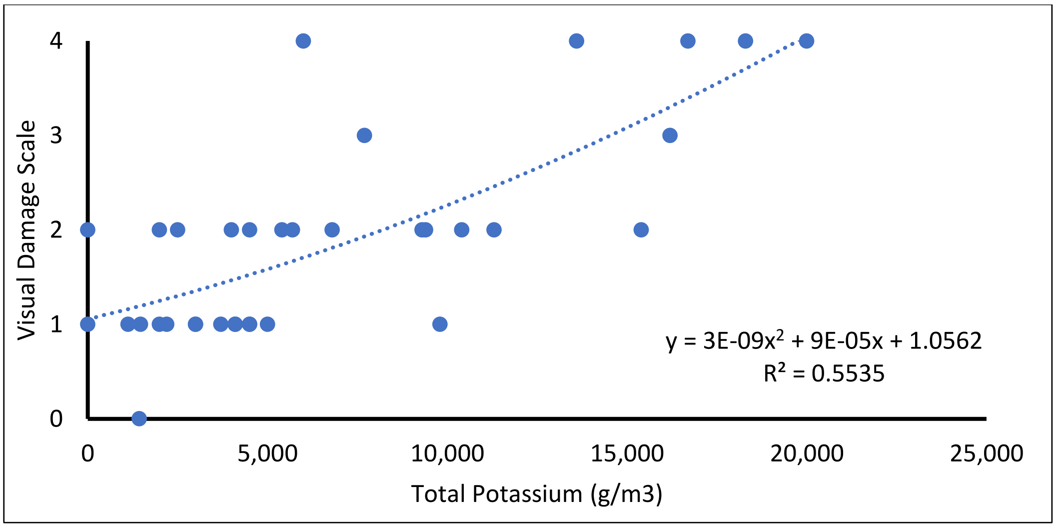


Figure 6-3. Pilot Trial + Main experiment - block 1 and 2: total potassium vs maximum clover burning.

Determining if new growth burned more than master pasture was not successful as the weather and soil nutrient conditions were optimal for pasture growth thus the pasture was growing near optimal levels on both treatments. Crown rust damage may have caused burning to look worse than it was.

It was concluded that if the osmolality exceeds 450 milliosmoles or the electrical conductivity exceeds 1500 mS/m, moderate to severe pasture burning may occur. Electrical conductivity was strongly correlated with pasture burning (Refer to figure 5-45.).

6.3 General Discussion

6.3.1 Effect of osmolality on pasture burning

The pilot trial and main experiment showed that as the osmolality of the effluent increased, the severity of pasture burning increased (Figure 6-1). Clover burned more than ryegrass which may be due to clover's broad leaves and lower tolerance to salts (Agriculture Victoria, 2015). In blocks one and two, very strong burning occurred when plots were treatment with KCl solutions with the highest osmolarities. However, strong burning occurred in plots treated with both lactose solution and lactose solution + KCl treatments also.

Electrical conductivity of the effluent may also be a good indicator of potential for pasture burning however, the osmolality of the effluent would be a better measurement of potential pasture burning as ions as well as sugars and other molecules are accounted for. Electrical conductivity is somewhat simpler to measure and an automated system could be more easily adopted for standard use.

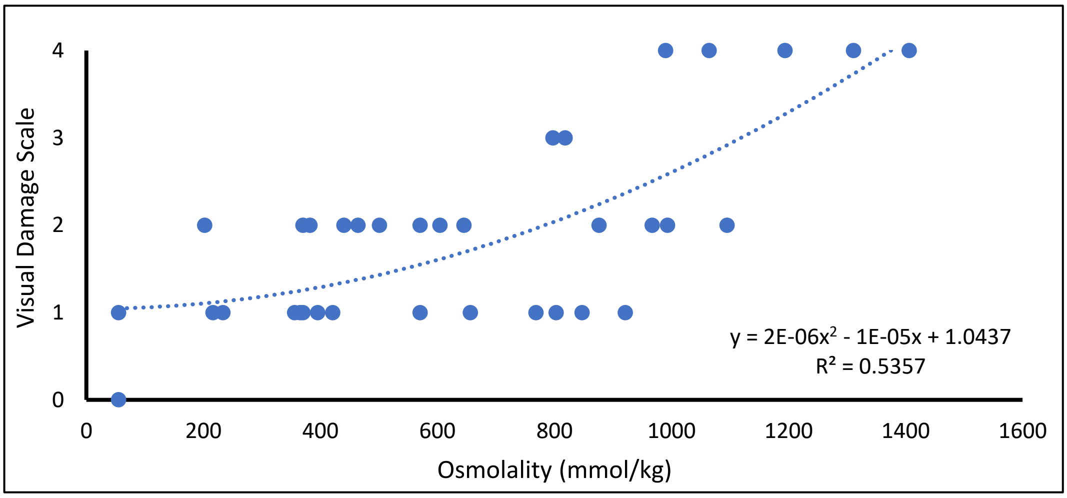


Figure 6-4. Pilot Trial + Main experiment - block 1 and 2: osmolality vs maximum clover burning.

6.3.2 Effluent composition and properties that correlated with pasture burning

Fonterra Edgecumbe produces low strength, medium strength, and high strength effluent. Medium strength effluent, which is irrigated at the Omehue end of the irrigation scheme contains low amounts of milk minerals and more 'cleaning in place' chemicals compared to the high strength which has a higher amount of milk minerals and a lower amount of cleaning chemicals.

The medium strength effluent does not generally cause problems with pasture burning. Fonterra Edgecumbe's high strength effluent has high sodium, potassium, sulphur, chloride, magnesium and sulphate concentrations as well as a high electrical conductivity and total dissolved solids in regard to levels stated by State Government of Victoria (1997), Watkins and Nash, (2010), Tikariha and Sahu, (2014), and Smart-fertilizer (2016). The effluent is moderately salty (Prince, 2016.).

In the pilot trial clover burning positively correlated with osmolality, electrical conductivity, total potassium, chloride, nitrate-N, total calcium, total dissolved solids and nitrate-N + nitrite-N. Ryegrass burning positively correlated with osmolality, pH, electrical conductivity, total magnesium, sulphate, total sulphur, total sodium, total nitrogen, dissolved reactive phosphorus, total kjeldahl nitrogen and the sodium absorption ratio. However, in the main experiment, clover burning only positively correlated with electrical conductivity, exchangeable sodium percentage, total potassium and chloride and there were no strong trends ($R^2 > 0.5$) between block 1 effluent properties and ryegrass burning. In block 2, there were positive correlations ($R^2 > 0.5$) between clover burning and electrical conductivity, chloride and total potassium (Figure 5-40, 5-42, 5-44). Electrical conductivity, chloride and potassium had a positive correlation ($R^2 = 0.67, 0.6, 0.59$) ryegrass burning. Table 6-1. shows the range of each effluent property for which strong to very strong burning occurred for clover and ryegrass.

Table 6-1. Range for each effluent property through which strong to very strong burning occurred for clover and ryegrass.

Effluent Composition	Range for which strong to very strong burning occurred for clover and ryegrass
pH	4 – 4.4
Electrical Conductivity (mS/m)	3,010 – 7,250
Total Dissolved Solids (TDS) (g/m^3)	25,000 – 169,000
Total Calcium (g/m^3)	490 - 1,460
Total Magnesium (g/m^3)	106 - 840
Total Potassium (g/m^3)	6,000 - 20,000
Sodium Absorption Ratio	11.4 – 20
Total Sodium (g/m^3)	1,190 – 7,300
Total Sulphur (g/m^3)	920 – 6,000
Chloride (g/m^3)	4,200 – 22,000
Total Nitrogen (g/m^3)	270 – 1,300
Nitrite-N (g/m^3)	<0.10
Nitrate-N (g/m^3)	4.3 – 8.5
Nitrate-N + Nitrite-N (g/m^3)	4.3 – 8.5
Total Kjeldahl Nitrogen (TKN) (g/m^3)	260 – 1,300
Dissolved Reactive Phosphorus (g/m^3)	240 - 670
Sulphate (g/m^3)	3,100 – 21,000
ESP	5.5 – 47.6

Many of the effluent properties measured are interconnected where as one effluent property increases, another effluent property increases. The electrical conductivity will increase in regards to the amount of ions present. If potassium is added, the exchangeable sodium percentage (ESP) will decrease. The sodium absorption ratio increased when lactose solution was added to the effluent as the lactose solution contains a higher concentration of Na^+ than other effluent streams. When lactose solution was added to the effluent treatments, the amount of total calcium, total magnesium, total sodium, total sulphur, sodium absorption ratio, TKN, sulphate and ESP increased.

6.3.3 Salinity of the effluent

In terms of clover and ryegrass salt tolerance, Agriculture Victoria (2015) determined that the salinity of the irrigation water must be <3.00 dS/m to prevent salt damage to clover and ryegrass (Table 6-2.).

Table 6-2. Tolerance of different plants to salt (Agriculture Victoria, 2015.).

Salinity of irrigation water	Plants that will be damaged
0 to 0.75 dS/m	Will cause damage to clovers: white, red,cluster, suckling, subterranean
0.75 to 1.5 dS/m	Will cause damage to: balansa clover, persian clover, strawberry clover, Berseem clover, lucerne
1.5 to 3.00 dS/m	Will cause damage to: sorghum, tall fescue, phalaris, perennial ryegrass, cocksfoot, wimmera ryegrass, crested wheatgrass, barley (hay), wheat, reed canary grass, paspalum.
3.00 to 5.00 dS/m	Will cause damage to: tall wheatgrass, puccinellia, bermuda grass, barley (grain), saltwater couch, salt bush

To calculate the approximate salinity of the effluent solutions used in the pilot trial and main experiment, an online salinity calculator from http://chemiasoft.com/chemd/salinity_calculator was used (Table 6-3.).

Table 6-3. Average salinity of effluent from the pilot trial and main experiment.

Effluent Solution (~40ºC)	Electrical conductivity (us/cm)	Salinity (dS/m)
Effluent Only (Pilot trial)	10310	6.776
Effluent Only (Block 1)	11660	7.735
Effluent Only (Block 2)	11960	7.949
KCl 400 (Pilot trial)	27100	19.309
KCl 1200 (Pilot trial)	72500	57.616
Lactose solution 400 (Block 1)	15780	10.722
Lactose solution 1000 (Block 1)	25200	17.834
Lactose solution + KCl 400 (Block 2)	19470	13.465
Lactose solution + KCl 1000 (Block 2)	41600	30.938

Based on the online calculator salinity results, the salinity of the effluent was very high (Table 6-1;6-2) and would be expected to cause damage to both clover and ryegrass. The effluent alone caused only slight to moderate burning (level 1 and 2) of the clover in the pilot trial and main experiment. Ryegrass, however did not burn when effluent only was applied.

The salt tolerance of clover and ryegrass may have increased over the years as effluent application to land in the Edgecumbe area has occurred since 1996. A study completed by Rogers et al., (1997) showed that clover can adapt to high saline conditions, where NaCl can be excluded from the shoots. As clover reacted strongly to potassium and/or chloride, a high concentration of salts may relate to pasture burning where dehydration due to an increase excess ions in the leaf can cause tip burning leading to osmotic stress, especially with young growth (Lauchi & Epstein, 1984, Sonon et al., 2015).

Clover may not have developed salt-compartmentation mechanisms that enable the controlled uptake of ions (Lauchi & Epstein, 1984) thus large amounts of salt present in the effluent may cause ion toxicity (Lauchi & Epstein, 1984). Wu et al., (2017) state that ryegrass seedlings can become salt stressed when treated with 250 mM NaCl. An increase in Na^+ concentrations caused a decrease in K^+, Ca^{2+} and Mg^{2+} thus high levels of Na^+ present in the ryegrass could create osmotic stress (Wu et al., 2017).

6.3.4 Clover and ryegrass tolerance to chloride

Chloride is also known to have toxic effects in plants if it accumulates in the older leaves resulting in “burning” where the tips turn brown and die back (Ayers and Westcot, 1994; Agriculture Victoria, 2015; Prince, 2016; smart-fertilizer 2016; College of Agriculture and Natural Resources, 2017.). The chloride content of the effluent may be a factor in the observed pasture burning.

The amount of chloride in the effluent, apart from effluent only, lactose solution 370 (pilot trial), lactose solution 356 (block 1), lactose solution 365 (block 2) was high (above 1925 g/m^3) (as defined by Spectrum Analytic Inc, n.d.) thus moderate to very strong burning may have been the result of the chloride content.

6.3.5 Soil properties

Changes in soil properties due to effluent application may affect the growth of plants (Delgado & Gomez, 2016). As pasture burning within one to four days after irrigation as patches or strips, changes in soil properties as a cause of pasture burning was initially ruled out. However, the level of salts in the soil on Reeves farm (which is irrigated by Fonterra) is high in potassium (2.14 me/100g) and sodium (0.85 me/100g) (Analysis by Hills Laboratory, 2017.). Additional salts applied through irrigation could cause the soil salt levels to increase causing reverse osmosis in the roots and thus dehydrating the pasture (Prince, 2016).

6.3.6 The role of weather in pasture burning

The weather was thought to play a role in pasture burning. Hot weather can cause rapid evaporation so the salts in the effluent concentrate on the leaf surface. Leaf burn may be related to high wind and low humidity (Krogmeier et al., 1989; Prince, 2016.). During the pilot trial it did not rain and stayed sunny throughout the whole experiment. However, during the main experiment it started to rain lightly and cooled down on day two and three. During the pilot trial the ryegrass started to burn two days into the experiment compared to the main experiments where ryegrass started to burn three or four days into the experiment. The delay in burning of the ryegrass between the pilot trial and main experiment may have been a reflection of the weather where the prolonged hot weather during the pilot trial contributed to higher evapotranspiration rates thus high salt concentrations in the leaf compared to the main experiment. As the temperature starts to increase and the humidity decreases, the absorption of nutrients through the plant leaves increases because of slow drying conditions (Latimer, 2015.). The rain may have also washed the effluent off the leaf surface, or diluted the effluent thus reducing burning of the ryegrass. The clover, compared to the ryegrass, seemed to be more sensitive to salts overall meaning burning occurred faster and was more severe. Washing down the pasture after irrigation was suggested to reduce pasture burning as the effluent becomes diluted or less is absorbed directly through the leaf.

6.3.7 Age of pasture

Anecdotal evidence suggested that new young growth may be more susceptible to pasture burning. Fageria et al., 2008 and Waskom et al., 2010 also suggested that young new growth can be sensitive to salts and other ions in high concentrations. A high salt concentration present in young plants can cause dehydration, and therefore tip burning (Sonon et al., 2015). While we attempted to test the hypothesis that new growth burned more than mature pasture by stimulating new growth, our experiment was not successful as the weather was optimal for pasture growth during the main experiment.

6.4 Limitations of the research

Many limitations of this project have been recognized. The pasture burning event record could have been more accurate when determining the severity of pasture burning. The visual damage scale used in the pilot trial and main experiment should have been given to the irrigation officers so that a more accurate comparison of pasture burning could be made. The weather data collected from the Bay of Plenty Regional Council website may have varied from that at the effluent irrigation sites. To gain an accurate measurement of the weather, field weather assessments of rainfall, temperature, humidity, wind speed, and wind direction should have been taken to ensure the weather was accurate.

The experiment did not have replications of each treatment due to practical constraints.

The watering can used to apply the treatments to each plot was difficult to use in that some effluent spilt as it was being poured into the watering can. However, the amount of effluent spilled would not have been enough to affect the experiment. To ensure no effluent solution is spilt if this experiment is repeated a funnel could be used to accurately pour all effluent solutions into the watering can.

The KCl added to the effluent did not dissolve fully before the effluent was applied to the plots thus highly concentrated KCl solution may have been applied and not evenly spread across the whole plot.

However, all plots that had an effluent solution spiked with KCl and KCl + lactose solution show the same pattern thus un-dissolved KCl did not seem to impact burning.

To ensure the KCl is dissolved, heating the effluent and constantly mixing the solution should be done if this experiment is to be repeated. In block two the lactose solution + KCl 421 solution should have been closer to 600 milliosmoles to better test the range of osmolality.

During the preliminary investigations, I collected data using two YSI. However, while collecting the data from the sampling shed, the Fonterra YSI was removed and the council YSI probe was used. The council YSI probe was then taken out and the Fonterra YSI was put back in. Alternating between the two YSI probes should not have been done and both probes should have been run at the same time to ensure the probes gave similar readings. By removing the Fonterra YSI probe, large spikes were missed and valuable data may have been lost.

The effluent irrigated by Fonterra has a high salt content. The high salt content means that when the effluent is sent into holding tanks before it is irrigated stratification may occur where the dense cold salty effluent may settle at the bottom of the hold tanks. The dense cold salty effluent may then be irrigated causing a spike in salty effluent to be applied to the pasture. Installing an agitator in all effluent holding tanks could prevent the potential for stratification. Monitoring the holding tanks for stratification should be part of future investigations.

The pH of the effluent was considered as a cause of pasture burning. A solution with a low or high pH may damage the outer layer of a leaf (Haines et al., 1984; Sant'Anna-Santos et al., 2006). A study carried out by Crush et al., (2005) on pasture burning at Fonterra Edgecumbe showed that an effluent with a pH 2 or less will burn. However, during the preliminary investigations of this project, the effluent was found to have pH of ~4 and seemingly did not reach a pH of 2. As the pH of the effluent did not reach a pH of 2. The pH was not included as a variable in my experiments.

The effluent Fonterra irrigates contain high amounts of lactose solution which can further be broken-down to produce lactic acid (Bylund, 2015). If enough lactic acid is produced, the pH may become low on some occasions contributing to burning. Lactic acid production should be monitored by sampling in the field at time of effluent application.

6.5 Review of hypotheses

My data supported, but did not unequivocally prove the hypothesis that: "when effluent with a "high osmolality is irrigated "pasture burning" occurs".

A range of effluent osmolarities were tested to determine a limit above which pasture burning occurred. In the pilot trial, the effluent solutions with the lower osmolality, lactose solution 370, KCl 501 and lactose solution + KCl 464, caused minimal burning to the clover and ryegrass. However, the solutions with the highest osmolarities, lactose solution 1406, KCl 501 and lactose solution + KCl 1311, caused severe burning to the clover and some burning of the ryegrass. In the main experiment, the results were similar to the pilot trial where the effluent solutions with the higher osmolarities (>797 mmol/kg) burned more severely than lower osmolarities. The clover that was treated with >KCl 797 caused strong to very strong burning. Ryegrass burning was not as severe as clover burning even when a higher osmolality effluent was applied. The osmolality positively correlated with clover burning (R^2 = 0.53) and thus can support this hypothesis.

The second hypothesis that "new growth is more susceptible to "pasture burning" than mature pasture" could not be accepted or rejected. The application of progibb and urea failed to markedly increase pasture growth compared to the block without progibb and urea. As the pasture growth was excellent on both blocks due to plentiful nutrient availability and warm wet weather when the experiment was carried out, there was no marked increase in new growth due to application of urea and progibb. Though the hypothesis that new growth is more susceptible to pasture burning was not proven in this experiment, anecdotal evidence suggests that as pasture burning occurs mostly in spring that new growth could contribute to susceptibility of pasture to burning.

6.6 Recommendations for future research

There is still much work that needs to be done to clarify the causes of pasture burning, including:

- Osmolality as an indicator of pasture burning needs to be researched more where more measurements of the osmolality of pasture and effluent need to be taken,
- determining the properties of effluent when burning occurs; collect effluent samples before, during and after as many irrigation events as possible which should then be frozen. If burning occurs, the frozen samples can be sent away to measure the osmolality, electrical conductivity, total dissolved solids, Na^+, K^+, Ca^{2+}, Mg^{2+}, Cl^-, total sulphur, total nitrogen, TKN, dissolved reactive phosphorous and sulphate. The more samples that are taken the better the record will be of effluent variability in the field,
- using a chlorophyll fluorometer before and after the plants become burnt will determine how stressed the plant is after irrigation,
- investigate potential for salt-tolerant strains of clover and ryegrass.

6.7 Recommendations for future effluent management

- Place conductivity and pH probes at the outlet of each effluent line after the effluent leaves the holding tanks so any spikes in the effluent can be identified. Crush et al., (2005) stated that the pH of the effluent should not drop below 2. The electrical conductivity of the high strength effluent could be a general measure of pasture burning and ideally should not exceed 1500 mS/m if strong burning is to be avoided. If the high strength effluent exceeds 1500 mS/m, the effluent should be recirculated through the holding tanks to re-mix and lower the concentration of the “spike” if so.
- Installing an agitator in all effluent holding tanks could prevent the potential for stratification. Monitoring the holding tanks for stratification should be part of future investigations.
- The effluent could also be diluted or further treated to create a lower strength effluent.

6.8 Summary and Conclusion

- My thesis investigated the causes and potential solutions of pasture burning on farms that Fonterra Edgecumbe irrigates with highs strength effluent.
- Preliminary data collected pH, temperature, and electrical conductivity data from the high strength effluent in the Awaroa line and Awakeri line. Results showed that the high strength effluent does vary in terms of pH, temperature and electrical conductivity on an hourly scale.
- A pasture burning record to document all burning events and their severity was also collected. However, no clear pattern as to when and why pasture burning occurs could be concluded.
- Samples of effluent collected from the irrigation sites varied in effluent composition in the field from run to run and short term continuous monitoring also showed that the effluent varied more than is captured in the daily in the 24-hr composite sampler data. No specific cause of effluent variability were identified.
- Literature suggested that if the osmolality of the effluent is higher than the plant cell osmolality, pasture burning will occur. An effluent with a high osmolality may lead to dehydration of the leaf by drawing water out of the plant or osmotic shock may occur due to a build-up ions in the plant leaves resulting in a toxicity.
- Fresh clover and ryegrass (400 - 500 mmol/kg) had a similar mean osmolality compared to burnt clover and ryegrass (500 - 600 mmol/kg). The high strength effluent had a lower mean osmolality (217 mmol/kg) compared to fresh and burnt clover and ryegrass. If the effluent spikes, the osmolality of the effluent may exceed that of the pasture.
- A pilot trial was designed to test if pasture burning correlated with an increase in osmolality. A main experiment was then designed to determine a cut off point for the osmolality regarding the severity of burning,
- When combing the results of the pilot trial and main experiment, clover burning positively correlated with electrical conductivity, chloride, total potassium and osmolality (R^2 >0.5).

- In the pilot trial, ryegrass burning positively correlated with osmolality, pH, electrical conductivity, total magnesium, sulphate, total sulphur, total sodium, total nitrogen, dissolved reactive phosphorus, total kjeldahl nitrogen and the sodium absorption ratio. However, in the main experiment ryegrass burning did not correlate with any effluent properties.
- The pilot trial and main experiment showed that as the osmolality of the effluent increased, pasture burning also increased – more specifically the white clover.
- My data supported, but did not unequivocally prove the hypothesis that: "when effluent with a "high osmolality is irrigated "pasture burning" occurs". The second hypothesis that "new growth is more susceptible to "pasture burning" than mature pasture" could not be accepted or rejected. The application of progibb and urea failed to markedly increase pasture growth compared to the block without progibb and urea. However, the literature and anecdotal evidence suggested that young growth can be more susceptible to burning.
- Hot weather may influence burning where more severe burning occurred when it was hot and dry, potentially due to increased evapotranspiration, and thus an increase in the concentration of the effluent.
- The osmolality may be a stronger indicator of pasture burning than electrical conductivity. My data suggests that the osmolality of the effluent should not exceed 450 mmol/kg and the electrical conductivity of the effluent should not exceed 1500 mS/m.
- Further research to determine the relationship between osmolality, weather at time of application and occurrence the of burning is required to see if osmolality is a more useful indicator.

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Appendices

Appendix 1
Fonterra Edgecumbe Resource Consent 65800-AP

Consent Number: **65800**

Bay of Plenty Regional Council

Resource Consent

Pursuant to the Resource Management Act 1991, the **Bay of Plenty Regional Council**, by a decision dated 21 December 2009 and amended by the **Environment Court**, by a decision dated 1 April 2010, **Hereby Grants** to:

SEE TRANSFER FONTERRA LIMITED
~~FONTERRA CO-OPERATIVE GROUP LIMITED~~

A resource consent under the Resource Management Act 1991 to undertake a discretionary activity being to **Discharge Treated Dairy Manufacturing Wastewater to Land and undertake the associated Discharge of Contaminants to Air** subject to the following definitions and conditions:

Definitions

For the purpose of this consent the following definitions apply:

Buffer zones:	*An area established around an activity (in this case irrigation) to separate the environment beyond the buffer zone from the adverse effects of that activity. The buffer zone is measured from the edge of the spray-zone and not the position of the irrigator.*
Irrigation event:	*An irrigation event is the period of time over which wastewater is irrigated on a particular disposal area within a single rotation period. An irrigation event lasts up to 3 days using in-ground irrigation.*
Riparian margins:	*A strip of land adjacent to the bed of a stream, river, lake or wetland, which contributes or may contribute to the maintenance and enhancement of the natural functioning, quality and character of the stream, river, lake or wetland.*
Surface water body:	*Means freshwater in a river, lake, stream or pond. This includes modified watercourses and intermittent watercourses.*
Year:	*From 1 June to 31 May inclusive*
Infiltration capacity:	*The rate at which water enters the soil*
Field capacity:	*The moisture content of a soil when free drainage immediately after a rain or irrigation has virtually stopped. It is a measure of the maximum amount of water a soil can retain against the force of gravity*

Consent Number: **65800**

1 Purpose

To discharge treated wastewater from the Edgecumbe dairy manufacturing plant to land and the associated discharge of contaminants (including odour) to air.

2 Location of Discharges

2.1 Medium strength wastewater shall be irrigated onto the land described in Schedule 1 (Schedule of Irrigation Properties – medium strength wastewater) and shown on BOPRC 65800/1.

2.2 High strength wastewater shall be irrigated onto the land described in Schedule 2 (Schedule of Irrigation Properties – high strength wastewater) and shown on BOPRC 65800/2.

2.3 Truck spreading of either high strength or medium strength wastewater shall be undertaken on farmland within the Rangitaiki Plains.

3 Notification Requirements

3.1 Within two weeks of the commencement of this consent, the consent holder shall provide to the Bay of Plenty Regional Council details of who is responsible for irrigation management and compliance with consent conditions and their contact details (see Advice Notes 1 and 2). If the person responsible for the irrigation systems changes during the term of this consent, the consent holder shall notify the Council of the new details no later than five working days after that person(s) take responsibility.

3.2 The consent holder shall notify the Bay of Plenty Regional Council of proposed additions to the irrigation areas or wastewater storage facilities authorised by this consent (see Advice Notes 1, 3 and 4). This notification shall occur prior to the commissioning of any new areas of irrigation or new storage facilities not already authorised by this consent, and shall include the following information:

a) A map clearly showing the proposed irrigation area - irrigation areas only;
b) The irrigable area (ha) - irrigation areas only;
c) Legal description(s);
d) The current land owners;
e) The type of wastewater that will be irrigated or stored; and
f) The irrigation or storage system to be used.

3.3 The consent holder shall notify the Murnanes (landowners 87 Angle Road, RD 3, Whakatane) at least 8 hours prior to the commencement of wastewater irrigation within paddocks immediately adjoining their property. The consent holder shall use "best endeavours" to ensure that the said notice of the commencement of irrigation is received.

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4 Quantity and Rate

Medium Strength Wastewater Irrigation Systems

4.1 The rate of application using centre pivot irrigation systems shall not exceed 15 mm per pass.

4.2 The rate of application using in-ground sprinkler systems, pod irrigation systems or long lateral irrigation systems shall not exceed 60 cubic metres per hectare per hour.

4.3 The maximum volume applied over an irrigation area during any irrigation event using centre pivot irrigation systems, in-ground sprinkler systems or long lateral irrigation systems shall not exceed 50mm.

High Strength Wastewater Irrigation Systems

4.4 The rate of application using travelling irrigators shall not exceed 16 mm per irrigation event.

Truck Spreading of Wastewater

4.5 The rate of application using truck disposal shall not exceed 50 cubic metres per hectare per application.

4.6 Any area receiving wastewater by truck disposal shall be rested for at least a 10-day period, or longer, between applications unless otherwise agreed in writing by the Chief Executive of the Bay of Plenty Regional Council or delegate.

4.7 Within any area receiving wastewater by irrigation, the return cycle, being the period of an irrigation event to the first day of the next irrigation event, shall not be less than 14-days (unless otherwise agreed in writing by the Chief Executive of the Bay of Plenty Regional Council or delegate).

4.8 The maximum nitrogen loading rate for those properties receiving medium strength wastewater (identified in Schedule 1 to this consent) shall not exceed the following nitrogen limits:

	Period	Annual limit
	Prior to 1 July 2010	760 kgN/ha/year
SEE CHANGE 2 & 3	1 July 2010 to 30 June ~~2016~~ 2018	550 kgN/ha/year
SEE CHANGE 2 & 3	From 1 July ~~2016~~ 2018	400 kgN/ha/year

SEE CHANGE 3 ~~**See advice note 14**~~

4.9 The maximum nitrogen loading rate for those properties receiving high strength wastewater (identified in Schedule 2 to this consent) or wastewater applied by truck shall not exceed 150 kgN/ha/year.

4.10 The maximum phosphorus loading rate for those properties receiving high strength wastewater (identified in Schedule 2 to this consent) or wastewater applied by truck shall not exceed 200 kgP/ha/year.

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4.11 The Omeheu farm and Brophy block properties listed in Schedule 1 onto which medium strength wastewater is irrigated shall only be used for drystock farming and cut and carry pasture operations. The cut and carry pasture shall be exported from the properties.

SEE CHANGE 3

5 Irrigation Management

5.1 The consent holder shall prepare and submit updated versions of the **Medium Strength Waste Water Irrigation Management Plan** (submitted as Appendix 4 to the application), **High Strength Awaroa and Omeheu Fertiliser Irrigation Schemes Management Plan** (submitted as Appendix 5 to the application) and **Truck Spreading of Wastewater Management Plan** (submitted as Appendix 6 to the application), to the Chief Executive of the Bay of Plenty Regional Council or delegate for approval within three months of the commencement of this consent. These Plans shall be consistent with the conditions of this consent (see Advice Note 1) and shall be revised to include the following:

a) Identify key personnel and contact addresses/numbers – including the following persons where applicable:

1. Site manager
2. Environmental manager.

b) Clear identification on a map or plan of the drains and watercourses in the irrigation disposal areas, paddocks with sub-surface drainage and paddocks that are used for dairy farm effluent irrigation so that appropriate management procedures can be undertaken to avoid contamination of surface water by wastewater;

c) Clear identification on a map or plan of properties potentially affected by odour or spray-drift effects, so that appropriate management procedures can be undertaken to avoid such effects;

d) Maps of all the irrigation supply pipe-work including on-farm pipe layout, hydrants identification of all pipe crossings and the location of all isolation valves;

e) Provisions for monitoring and recording application rates to ensure the relevant consent requirements are being met;

f) Maintenance procedures and programmes, including identification of items critical to the operation and correct application of wastewater and how and at what frequency monitoring will be undertaken to verify the integrity of the pipelines, canal crossings, farm isolation valves, wastewater storage facilities and associated irrigation equipment;

g) Contingency measures in the event of irrigation equipment or pipeline failure;

h) Procedures for auditing set-up and operation of the irrigation systems to assess compliance with the conditions of this consent;

i) Procedures for reviewing the overall system performance – including frequency of reports to the Bay of Plenty Regional Council regarding complaint frequencies and site upgrades;

j) Complaint and incident recording and investigation procedures;

k) Staff training procedures - methods, frequency and how records will be maintained;

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l) A description of the main potential sources of odour emission, a description of any odour mitigation measures and identification of operating procedures and parameters that need to be controlled to minimise emissions (in particular to include the matters listed in the further information received by letter on 1 October 2009, which forms part of the application);

m) A sampling programme and procedures that meet the requirements of conditions listed under sections 8, 9, 10, 11 and Schedules 4 to 7 of this consent; and

n) Other matters not currently covered by the Management Plans but that form requirements of this consent, such as protection of well-heads from contamination; preventing soil damage; and the development of riparian management plans for watercourses on irrigation properties pursuant to condition 15.2 and condition 15.3 of this consent.

5.2 Irrigation of wastewater and maintenance of the irrigation system shall be undertaken in accordance with the most current and approved version of the Management Plans required by condition 5.1 of this consent.

5.3 The Management Plans required by condition 5.1 of this consent shall be reviewed by the consent holder at least once every year to ensure that they reflect best management practices. Any proposed changes to the Management Plans that may affect the consistency of the Management Plans with the conditions of this consent shall be submitted to the Chief Executive of the Bay of Plenty Regional Council or delegate for approval. Changes shall not be implemented until approval has been received in writing (see Advice Note 10).

5.4 Wastewater shall not be applied to areas that have also received dairy-effluent irrigation at any time within the preceding 12 months.

5.5 The consent holder shall ensure that no wastewater will reach surface waters as a result of overland flow, sub-surface drainage or discharges from irrigation pipe-work, hydrants or irrigators, spray irrigation outlets or truck spreading (see Advice Note 11).

5.6 The irrigation of wastewater shall not result in significant ponding of wastewater. For the purpose of this consent, significant ponding is deemed to have occurred if wastewater remains on an area of more than 10 square metres, 24 hours after irrigation of that area ceased.

5.7 The soil and pasture system in the irrigation areas shall be managed in a way that minimises organic nitrogen mobilisation in the soil.

5.8 Wastewater shall not be applied within the buffer zones identified in condition 5.9. (See Advice Note 5). The distance of the irrigator or spray irrigation outlet from the buffer zone shall be increased if necessary (for example in windy conditions) to ensure that spray-drift does not encroach into the buffer zone.

5.9 The consent holder shall ensure that the following buffer zones are maintained at all times during irrigation operations:

a) A buffer zone no less than 10 metres wide between the sprayed irrigated area and any stream or drain; and

b) A buffer zone no less than 10 metres wide between the sprayed irrigated area and property boundaries (expect where that property is identified in Schedule 1 or 2 or the written approval to a lesser buffer has been received by the Bay of Plenty Regional Council from the owner and occupier of the neighbouring property); and

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c) A buffer zone no less than 45 metres wide between the sprayed irrigated area and any residential dwelling (except where that property is identified in Schedule 1 or 2 or the written approval to a lesser buffer has been received by the Bay of Plenty Regional Council from the owner and occupier of the neighbouring property).

d) A buffer distance not less than 60 metres between the sprayed irrigated area and the Murnane's current residential dwelling on 87 Angle Road, RD 3, Whakatane.

5.10 If any irrigation system is also used to distribute water, a backflow preventer manufactured in accordance with AS 2845.1 (1998) or an equivalent standard, shall be installed within the pump outlet or plumbing to prevent the backflow of water or contaminants into the water source.

5.11 The consent holder shall ensure that the wastewater discharged by irrigation does not cause pasture-burn to the extent that it has the potential to have an adverse effect on the productivity of the pasture that has been irrigated.

5.12 Where the natural infiltrative capacity of the soil has been impeded through the accumulation of sodium (as identified by the monitoring required by condition 11.1 of this consent), the consent holder shall apply an appropriate soil conditioner. Soil conditioning shall be undertaken as soon as practicable in a manner that minimizes the instantaneous load of sodium displaced to groundwater, and at least within one year of identification of sodium accumulation.

5.13 Any pipelines crossing drains or watercourses shall be constructed to a suitable standard to minimise the chances of pipe failure. At each pipeline crossing external to the farms, a sign shall be installed detailing pipeline contents and contact phone numbers in case of leakage or breakage.

5.14 The consent holder shall not make any changes to the discharges authorised by this consent that will or are likely to change the nature of the discharges or their effect on the environment without first notifying the Chief Executive of the Bay of Plenty Regional Council or delegate. (See Advice Notes 1 and 3).

6 Contingency Measures

The consent holder shall install and maintain an alarm and automatic switch-off system as a contingency measure to detect irrigation system failures.

7 Odour Management

7.1 The land disposal systems shall be operated and maintained in a manner that ensures there is no offensive or objectionable odour at or beyond the irrigation property boundaries (as defined in Schedules 1 and 2). (See Advice Note 6).

7.2 Irrigation lines shall be flushed with clean water once spraying of wastewater for a particular season has been completed.

7.3 The consent holder shall ensure that the wastewater storage silos are cleaned on a regular basis so as to prevent the generation of odour that may breach condition 7.1 of this consent. Any solid material removed is to be disposed of at an authorised disposal site and not to any land that currently receives any waste products such as dairy effluent, whey or wastewater.

7.4 The consent holder shall circulate the Complaints Procedure to residents of properties neighbouring irrigation areas within one month of the Management Plans required by condition 5.1 of this consent being approved. The consent holder shall circulate updated Complaints Procedures as required.

8 Wastewater Monitoring

8.1 The consent holder shall characterise the nature of the medium and high strength wastewater in accordance with the monitoring programme attached as Schedule 4 to this consent.

8.2 The consent holder shall maintain a weather station at its Omeheu Farm for the purpose of recording daily rainfall. The consent holder shall record the daily rainfall and record all days on which rainfall and wastewater irrigation coincide.

8.3 The volume of wastewater discharged each day, the area irrigated, and the paddock(s) irrigated (listed by farm and paddock number) shall be measured and recorded daily for the medium strength irrigation scheme.

8.4 The consent holder shall measure and record the daily volume of high strength wastewater discharged by each of the high strength irrigation schemes.

8.5 The consent holder shall measure and record the equivalent depth of application of the high strength wastewater applied by travelling irrigator for all farms receiving high strength wastewater at least once every three months.

8.6 The quantity of wastewater discharged by truck each day, the area irrigated, and the properties and paddocks onto which material is discharged shall be measured and recorded daily whenever wastewater is disposed of to land using trucking.

8.7 The daily records kept in accordance with conditions 8.2 to 8.6 of this consent shall be kept by the consent holder and shall be made available for inspection by Bay of Plenty Regional Council staff upon request.

9 Groundwater Monitoring

9.1 The consent holder shall maintain the groundwater monitoring bores (identified in Schedule 3 of this consent) to the satisfaction of the Chief Executive of the Bay of Plenty Regional Council or delegate.

9.2 The consent holder shall notify the Chief Executive of the Bay of Plenty Regional Council or delegate within one week of detection of an issue (such as damage) that makes a monitoring bore unusable for monitoring purposes. Any bores that cannot be used for monitoring purposes (for example due to damage) shall be repaired or replaced within three months (unless otherwise agreed to in writing by the Chief Executive of the Bay of Plenty Regional Council or delegate).

9.3 Prior to commissioning the additional medium strength wastewater irrigation areas proposed in the application (which are marked with an asterisk in Schedule 1, Table 2 to this consent), the consent holder shall submit proposed locations of additional groundwater monitoring bores and any changes required to the location of current monitoring bores to enable characterisation of groundwater quality up and down gradient of the additional and existing irrigation areas. The additional irrigation areas shall not be commissioned until the Chief Executive of the Bay of Plenty Regional

Council or delegate has approved the location of the additional monitoring bores. (See Advice Notes 1, 7 and 8).

9.4 The consent holder shall investigate possible locations for installing one groundwater monitoring bore between the areas of irrigation to the east of the Rangitaiki River and the Rangitaiki River for the purpose of intercepting any groundwater flow from the irrigation areas to the river. The consent holder shall supply a report on this investigation and a recommendation as to the preferred location of the groundwater monitoring bore to the Chief Executive of the Bay of Plenty Regional Council or delegate for approval of the proposed bore location within 6 months of the granting of this consent. If approval is granted the consent holder shall, within 6 months of approval being given, install the bore at the approved location. If installed this groundwater monitoring bore shall be added to the groundwater monitoring wells listed in Schedule 3.

9.5 The groundwater monitoring bores specified in conditions 9.1, 9.3 and 9.4 shall be levelled to Moturiki Datum.

9.6 The consent holder shall undertake groundwater monitoring in accordance with the monitoring programme attached as Schedule 5 to this consent, in order to characterise the nature of any effects on groundwater resulting from the irrigation operations authorised by this consent.

9.7 The consent holder shall engage a suitably qualified and experienced person to compare the groundwater quality data collected to background groundwater quality, current drinking water standards and historic groundwater data at least once every two years. The consent holder shall submit a report to the Chief Executive of the Bay of Plenty Regional Council or delegate that includes, but is not limited to:

a) A description of groundwater quality trends;

b) Any exceedances of the drinking water standards and an explanation for those exceedances; and

c) What (if any) action is required to avoid, remedy or mitigate adverse effects on groundwater quality resulting from the irrigation activities, or to refine the monitoring programme to ensure that potential effects are identified.

10 Surface Water Quality Monitoring

10.1 The consent holder shall establish surface water monitoring points at a minimum of three points along the Awaiti Canal (that runs adjacent to Awaiti South and North Roads) and submit details of these locations, including GPS references to the Bay of Plenty Regional Council. The sampling points shall be to the satisfaction of the Chief Executive of the Bay of Plenty Regional Council or delegate, and shall include at least one site upstream of all current and proposed irrigation activities, one site downstream of all current and proposed irrigation activities and one site immediately downstream of the confluence of the western arm of the Awaiti Canal (approximate grid reference 2843150, 6354500).

10.2 The consent holder shall undertake surface water monitoring in accordance with the monitoring programme attached as Schedule 6 to this consent, in order to characterise the nature of any effects on surface water resulting from the irrigation operations authorised by this consent.

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10.3 The consent holder shall engage a suitably qualified and experienced person to compare the surface water quality data collected to current ANZECC water quality guidelines, water standards set in any relevant regional plan and historic Rangitaiki Plains surface water quality data at least once every two years. The consent holder shall submit a report to the Chief Executive of the Bay of Plenty Regional Council or delegate that includes, but is not limited to:

a) A description of surface water quality trends;

b) Any exceedances of the relevant guidelines and standards and, where possible, an explanation for those exceedances; and

c) What (if any) action is required to avoid, remedy or mitigate adverse effects on surface water quality resulting from the irrigation activities or refine the monitoring programme to ensure that potential adverse effects are identified.

11 Soil Monitoring

11.1 The consent holder shall undertake soil monitoring in accordance with the monitoring programme attached as Schedule 7 to this consent, in order to characterise the nature of any effects on soil quality resulting from the irrigation operations authorised by this consent.

11.2 Within 12 months of the commencement of this consent, the consent holder shall install soil moisture measuring equipment at a location on the Fonterra Omeheu Farm that is capable of measuring the field capacity of the soil. This location shall be agreed in advance with the Chief Executive of the Bay of Plenty Regional Council or delegate. Once the equipment has been installed, soil moisture shall be measured and recorded daily by the consent holder.

11.3 The consent holder shall engage a suitably qualified and experienced person to compare the soil quality collected to the *Provisional Soil Quality Indicators in New Zealand, Landcare Science Research Series No.34, Sparling 2008* (or other appropriate standards as agreed with the Bay of Plenty Regional Council) and historic soil quality data at least once every two years. The consent holder shall submit a report to the Chief Executive of the Bay of Plenty Regional Council or delegate that includes, but is not limited to:

a) A description of soil quality and soil analyses data trends and how these trends might impact on soil quality or structure;

b) Any exceedances of the soil quality standards and an explanation for those exceedances;

c) What (if any) action is required to avoid, remedy or mitigate adverse effects on soil quality resulting from wastewater irrigation, or refine the monitoring programme to ensure that potential effects are identified.

12 Reporting and Record Keeping

12.1 The results of sampling undertaken in accordance with Schedules 4 to 7 of this consent shall be forwarded to the Bay of Plenty Regional Council within one month of receipt of the results. Results shall be provided in an electronic format to the satisfaction of the Chief Executive of the Bay of Plenty Regional Council or delegate.

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12.2 The consent holder shall provide the following information to the Bay of Plenty Regional Council by the 21st of each month:

a) The amount of Nitrogen and Phosphorus applied in the preceding month per farm as a result of medium strength water irrigation, to be expressed as kgN/ha and kgP/ha; and

b) The amount of Nitrogen and Phosphorus applied per irrigation scheme in the preceding month as a result of high strength water irrigation, to be expressed as kgN/ha and kgP/ha; and

c) The cumulative amount of Nitrogen and Phosphorus applied as a result of medium and high strength wastewater irrigation over the irrigation season (up to and including data from the preceding month), to be expressed as kgN/ha and kgP/ha.

12.3 The consent holder shall provide the following information to the appropriate landowner/occupier of the receiving environment by the 21st of each month unless notified in writing by that landowner/occupier that the information is not required:

a) The amount of Nitrogen and Phosphorus applied in the preceding month per farm as a result of medium strength water irrigation, to be expressed as kgN/ha and kgP/ha; and

b) The amount of Nitrogen and Phosphorus applied per irrigation scheme in the preceding month as a result of high strength water irrigation, to be expressed as kgN/ha and kgP/ha; and

c) The cumulative amount of Nitrogen and Phosphorus applied as a result of medium and high strength wastewater irrigation over the irrigation season (up to and including data from the preceding month), to be expressed as kgN/ha and kgP/ha, if no wastewater has been applied to a property during the preceding month then notification to the owner/occupier of that property is not required by this condition.

12.4 By 30 September each year, the consent holder shall submit an annual report for the activities authorised by this consent to the Chief Executive of the Bay of Plenty Regional Council or delegate. This report shall include, but not be limited to, the following:

a) The results of all monitoring required by the conditions of this consent undertaken in the previous 12 months (and not already provided);

b) Recommendations on alterations or additions to the monitoring programmes attached as Schedules 4 to 7 to this consent;

c) An assessment of the extent to which the discharges complied with the limits specified in this consent, and reasons for any non-compliances and what steps have been taken to mitigate the adverse environment effects (if any) associated with non-compliance and prevent future reoccurrence;

d) A report and discussion on any proposed operational changes at the Edgecumbe Dairy Manufacturing Plant that may result in a notable variation of wastewater volume or characterisation;

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e) An analysis of any trends evident from the monitoring data, particularly in comparison to previous years monitoring. This analysis should also incorporate the requirements of conditions 9.7, 10.3 and 11.3 of this consent (only required every second year);

f) A report on and discussion of any complaints received (see condition 14.1) or incidents (see condition 1.2) that have occurred in relation to the wastewater irrigation and truck-spreading operations. If no complaints and/or incidents have occurred then this should be noted in the report;

g) Discussion of feedback received from any community liaison activities undertaken by the consent holder;

h) Any actions recommended under conditions 9.7, 10.3 or 11.3 shall be reported back to Bay of Plenty Regional Council with the consent holder's recommendations and options for implementation; and

i) Any other issue considered important by the author.

12.5 By 1 September 2014, 1 September 2019, 1 September 2024 and 1 September 2029, the consent holder shall provide to the Chief Executive of the Bay of Plenty Regional Council or delegate, a report that assesses whether waste disposal is being undertaken in accordance with the best practicable option(s) to minimise adverse environmental effects and generation of wastewater. A suitably qualified and experienced specialist(s) shall undertake the assessment required by this condition, which shall be to the satisfaction of the Chief Executive of Bay of Plenty Regional Council or delegate. The report submitted to the Bay of Plenty Regional Council shall address, but not necessarily be limited to, the following:

a) An assessment of the consistency of the current method of disposal with any relevant national standards, codes of practice or industry guidelines in effect at that time;

b) A summary of any actual or potential effects of the continued discharge of wastewater to land, irrespective of whether those effects are in accordance with the conditions of this consent;

c) An outline of technological changes and advances in relation to dairy manufacturing wastewater management, treatment and disposal which may be available to address the identified adverse effects;

d) An assessment of whether any such options or combination of options represent the Best Practicable Option to minimise the effects of the discharge and to minimise the production of wastewater (and thereby disposal to land); and

e) Whether and when (if applicable) the consent holder intends to incorporate such changes.

13 Maintenance

13.1 All equipment that forms part of the wastewater irrigation systems (including truck tanks) shall be maintained in good working order and to the satisfaction of the Chief Executive of the Bay of Plenty Regional Council or delegate.

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13.2 The consent holder shall undertake inspections of all irrigation pipe-work and associated distribution network at least twice every year. At least one inspection shall be completed prior to the irrigation commencing at the start of the dairy manufacturing season, and the second inspection undertaken during the period 1 November to 29 February inclusive. The inspections shall be undertaken to check for leaks or any other event likely to cause the unintended discharge of wastewater. Records of these inspections shall be made available to the Bay of Plenty Regional Council officers upon request.

13.3 The consent holder shall undertake any maintenance works required as soon as possible to ensure that the requirements of this consent are satisfied.

14 Complaints and Incidents

14.1 The consent holder shall keep and maintain a register of all complaints it receives that relate to the discharges authorised by this consent. The following information shall be recorded:

a) Time and date of complaint.

b) Name and address of complainant (if provided).

c) The site about which the complaint was made.

d) The weather conditions at the time of complaint.

e) The nature of the complaint.

f) Any events in the management and operation of irrigation or trucking processes that may have given rise to the complaint.

g) Any remedial actions taken by the consent holder.

Complaint records shall be kept by the consent holder and shall be submitted to the Bay of Plenty Regional Council upon request.

14.2 The consent holder shall notify the Chief Executive of the Bay of Plenty Regional Council or delegate using the Pollution Hotline (0800 884 883) as soon as practicable, and at least within 2 hours, of any event or incident that has or is likely to result in any conditions of this consent being breached.

14.3 The consent holder shall establish a Community Liaison Group (CLG) within 6 months of the granting of this consent to which the following shall be invited:

- submitters on this consent (and/or consent 62522);
- neighbours who adjoin irrigated properties;
- the owners of land subject to Fonterra's irrigation activities;
- Ngati Awa and Ngati Tuwharetoa;and
- Bay of Plenty Regional Council.

a) The role of the CLG is to provide a forum:

- To facilitate communication and dialogue between the consent holder, the community and the Bay of Plenty Regional Council;
- To facilitate communication arising from the consent holder's irrigation operation (including, the results of monitoring, concerns and complaints of residents, and aspects of non-compliance (if any) and means of alleviating them).

b) The consent holder shall ensure that meetings of the CLG are held at least every six months. Representatives of the consent holder shall attend all meetings of the CLG. Meetings of the CLG are to be open to any member of the public to attend.

15 Riparian Management

15.1 The consent holder shall prevent all stock access, from properties owned by the consent holder, to surface water bodies. Stock shall be excluded by the installation of fencing or any other method that effectively prevents stock accessing surface water bodies.

15.2 The consent holder shall, on properties owned by the consent holder, develop a riparian management plan for watercourses traversing and immediately adjacent to the irrigation areas.

15.3 The consent holder shall, in conjunction with landowners, develop a riparian management plan for watercourses traversing and immediately adjacent to the irrigation areas. For the avoidance of doubt, the consent holder shall not be considered to be in non compliance with this condition if individual landowners (other than the consent holder) are unwilling to participate.

16 Review Conditions

16.1 The Bay of Plenty Regional Council may, at any time within three months of the fifth, tenth, fifteenth or twentieth anniversary of the grant of this consent, or within three months of receiving a report under condition 12.5, serve notice on the consent holder under section 128 of the Resource Management Act of its intention to review the conditions of this consent for any of the following purposes:

a) To deal with an adverse effect on the environment which may arise from the exercise of this consent, and which it is appropriate to deal with at a later stage; or

b) To require the consent holder to adopt the best practicable option to remove or reduce an adverse effect on the environment; or

c) To review the adequacy of, and necessity for, the monitoring required to be undertaken by the consent holder; or

d) To provide for compliance with any regional plan that sets rules relating to minimum standards or water quality or air quality and that has been made operative since the grant of this consent; or

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e) To ensure that the consent conditions are consistent with any relevant national environmental standards.

16.2 The consent holder shall pay to the Bay of Plenty Regional Council the actual and reasonable costs incurred whilst undertaking a review of consent conditions in accordance with condition 16.1 of this consent.

17 Term of Consent

This consent shall expire on 31 December 2034.

18 Resource Management Charges

The consent holder shall pay the Bay of Plenty Regional Council such administrative charges as are fixed from time to time by the Bay of Plenty Regional Council in accordance with section 36 of the Resource Management Act 1991.

19 **The Consent** hereby authorised is granted under the Resource Management Act 1991 and does not constitute an authority under any other Act, Regulation or Bylaw.

Advice Notes

1) *Notification/Reporting required by consent conditions shall be directed (in writing) to: The Manager Pollution Prevention, Bay of Plenty Regional Council, PO Box 364, Whakatane 3158 or fax 0800 884 882 or email notify@boprc.govt.nz. This notification should include the consent number 65800.*

2) *The contact identified in condition 3.1 of this consent will be the primary contact for Bay of Plenty Regional Council staff for compliance monitoring purposes and in the event of an incident or complaint. Nothing in that condition removes or limits the consent holder's liability to ensure compliance with the consent and its conditions.*

3) *Any significant changes to the irrigation system or irrigable areas that were not included in the consent application lodged on 15 July 2009 may require a change of consent conditions or a new consent.*

4) *New irrigation properties will be added to the relevant Schedule(s) of this consent. In some circumstances this may need a formal change to the consent conditions.*

5) *The buffer zone is measured from where the wastewater is discharged to land and not the position of the irrigator. The discharge must cease or the volume of discharge reduced or irrigator moved when necessary to meet conditions 5.8 and 5.9.*

6) *Bay of Plenty Regional Council will consider an odour effect to be offensive or objectionable to have occurred if any appropriately experienced council officer seems it so after having regard to:*

a) The frequency, intensity, duration, nature of odour and location of the effect(s); and/or

b) Relevant written advice from an Environmental Health Officer, territorial authority of health authority.

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7) *Once approved, the additional monitoring bores will be added to Schedule 3. The consent holder may also propose that existing monitoring bores be removed from the Schedule as part of this process.*

8) *Additional consents may be required to drill new monitoring bores or replace existing bores.*

9) *Failure to comply with the conditions of this consent may result in enforcement action being taken. Therefore, it is advised that all staff, and contractors, associated with the wastewater disposal system be made aware of the requirements of this consent.*

10) *The Bay of Plenty Regional Council does not anticipate being asked to review and approve administrative changes or corrections to typographical errors with regard to the Management Plans required by this consent.*

11) *Non-return valves and other appropriate technology can be used to prevent the incidental discharge of wastewater following disconnection of pipe-work.*

12) *The consent holder will use best endeavours to ensure that staff comply with the relevant clauses in the Management Plans relating to spotlights. Of particular concern is Clause (iv), which reads: "When operating at night, be mindful of the vehicle spotlights illuminating the neighbours house. This is particularly disconcerting if the lights are left shining into a neighbour's house for any length of time. A vehicle should be turned to minimise this nuisance."*

13) *The Bay of Plenty Regional Council recognises the importance of the consent holder managing and operating the wastewater irrigation system on a day-to-day basis and the benefits that have been gained since the consent holder took over this management from individual landowners.*

DATED at Whakatane this 27th day of May 2010

For and on behalf of
The Bay of Plenty Regional Council

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Change 1

The change to this resource consent was approved under delegated authority of the Bay of Plenty Regional Council, dated 18 October 2010, as follows:

Change condition 4.8 to read:

The maximum nitrogen loading rate for those properties receiving medium strength wastewater (identified in Schedule 1 to this consent) shall not exceed the following nitrogen limits:

Period	**Annual limit**
Prior to 1 July 2010	760 kgN/ha/year
1 July 2010 to 30 June 2012**4**	675 kgN/ha/year
1 July 2012**4** to 30 June 2015	475 kgN/ha/year
From 1 July 2015	400 kgN/ha/year

See Advice Note 14

Add advice note 14 to read:

The date for the completion of the nitrogen loading limit period of 675 kgN/ha/year is likely to be influenced by the resolution of Trustpower application 65750 (to change the operating regime of the Rangitāiki River)). Once that application has been determined, the consent holder intends to implement the expansion of the irrigation areas or an alternative wastewater disposal strategy. The Regional Council requests that the consent holder provides an update regarding this decision within 3 months of consent 65750 being determined.

Helen Creagh
Consents Manager

for W E Bayfield
Chief Executive

Change 2

The change to this resource consent was approved under delegated authority of the Bay of Plenty Regional Council, 6 June 2014.

Helen Creagh
Consents Manager

for Mary-Anne Macleod
Chief Executive

Consent Number: **65800**

Transfer

The transfer of the whole of this resource consent from FONTERRA CO-OPERATIVE GROUP LIMITED to FONTERRA LIMITED was approved under delegated authority of the Bay of Plenty Regional Council, dated 21 July 2014.

Helen Creagh
Consents Manager

for Mary-Anne Macleod
Chief Executive

Change 3

The change to this resource consent was approved under delegated authority of the Bay of Plenty Regional Council, 9 February 2016.

Reuben Fraser
Consents Manager

for Mary-Anne Macleod
Chief Executive

Consent Number: **65800**

SCHEDULE 1

PROPERTIES ONTO WHICH MEDIUM STRENGTH WASTEWATER IS IRRIGATED AND PROPOSED TO BE IRRIGATED

1. **Property Legal Descriptions:**

Parties	Legal Description	Area (Ha)	Title Ref	Address
Fonterra (Omeheu Farm)	Pt lot 3 & 4 DP 19552	38.4375	816/123	Omeheu Road
	Lot 3 DP 21192	11.8747	624/3	Omeheu Road
	DP 24954	16.1874	6512/182	Omeheu Road
Fonterra (Brophy Block)	Lot 2 DP 377149	29.8992	310012	Awaiti South Road
	Lot 4 DP 21027	22.6881	25A/1218	
McLean F A & Searle G G	Lot 1 DPS 71866	11.1075	57D/166	Awaiti South Road
	Lot 2 DPS 71866	23.0185	57D/167	Awaiti South Road
AB & MI McLean	Lot 1 DPS48858	7.3349	42C/312	Awaiti South Road
	Lot 1 DP 21931	75.0482	42C/312	Awaiti South Road
Mullins P J & K J*	Lot 1 DP 350387	8.7280	SA639/216	Awaiti South Road
	Lot 1 DPS 29959	21.1650	206081	Awaiti South Road
Shakes*	Lot 2 DP 62758	60.9487	SA50C/438	Awaiti South Road
Woods B H & JF "Dreamfields Family Trust"*	Lot 2 DP 333367	63.278	136786	Grieve Road
Gow Family Trust*	Lot 3 DP 21027	66.9577	25A/1217	Awaiti North Road
	Lot 2 DP 21027	60.6649	487/134	Awaiti North Road
	Lot 1 DP 21027	40.4584	10D/1349	Awaiti North Road
	Lot 2 DPS 16556	48.1575	36D/854	Awaiti North Road

* Proposed additional irrigation areas

2. **Summary of Irrigation Properties and Land Area over which irrigation occurs and is proposed to occur**

Farm	Owned by	Irrigation Land area (ha)	Irrigation type
Omeheu	Fonterra	51	Fixed In-ground
Brophys	Fonterra	41	Fixed In-ground
McLeans	Private Farm	40	Fixed In-ground
Mullins*	Private Farm	67	Pod system
Gow*	Private Farm	80	Pivot combined with movable sprinklers
Woods*	Private Farm	39	Pivot combined with movable sprinklers
Total		**318**	

* Proposed additional irrigation areas

Consent Number: **65800**

SCHEDULE 2

PROPERTIES ONTO WHICH HIGH STRENGTH WASTEWATER IS IRRIGATED (AWAROA AND OMEHEU FERTILISER SCHEMES)

1. Property Legal Descriptions:

Owner	Legal Description
~~**Morgan**~~ By de Ley	ALLT 148 Rangitaiki PSH
	ALLT 146 Rangitaiki PSH
	LOT 1 DPS 92285
~~**Baird**~~—Orini Dairies Limited	ALLT 282 Rangitaiki PSH
~~**Walker**~~-Rowlands	LOT 9 DPS 28741
	LOT 13 DPS 28742
	LOT 12 DPS 28742
	LOT 6 DPS 53150
	LOT 5 DPS 53150
~~**Oliver**~~ Langdon	LOT 1 DPS 25935
	LOT 3 DP 9093
	ALLT 152 Rangitaiki PSH
MacDonald (Angle Park Ltd)	LOT 2 DP 9896
	LOT 3 DP 9896
	LOT 2 DP 9896
	LOT 1 DP 9896
	LOT 2 DPS 15867
	LOT 3 DP 10444
	LOT 6 DP 9896
	LOT 2 DP 10444
Carter- Brian	PT LOT 2 DP 32694
	PT LOT 1 DP 32694
Barr	PT ALLT 1 Rangitaiki PSH
	LOT 2 DP 22567
	ALLT 12B2B Rangitaiki PSH
	LOT 1 DPS 77635
Campbell	LOT 2 DPS 3619
	LOT 2 DPS 81525
	PT LOT 2 DP 18069
	ALLT 164 Rangitāiki PSH
	PT ALLT 87 Rangitaiki PSH
Reeves	LOT 5 DPS 70925
	LOT 3 DPS 70925
	PT ALLT 87 Rangitaiki PSH
	LOT 2 DPS 15170
	LOT 4 DPS 70925
	LOT 1 DPS 70925
	LOT 6 DPS 70925
	LOT 4 DPS 9156
Haultain	LOT 3 DPS 57409
	1B4 Omataroa
	PT 1A Omataroa
Zink	1B2B2 Omataroa
	PT LOT 5 DPS 57409
	LOT 2 DP 16162
	(3A1A&B)1B Omataroa
	LOT 4 DPS 57409
	(3A1A&B)1A Omataroa
	1B2A Omataroa
	1B2B1 Omataroa
Ngati Awa farms	6A Omataroa
	PT 1B5B Omataroa
	PT LOT 1 DPS 30796
~~McCracken— William~~ **Virbickas**	LOT 2 DP 36308
~~McCracken— Bernard~~ **By de Ley**	PT LOT 1 DP 36308
Fonterra- Awaroa	LOT 4 DPS 33289
	PT LOT 1 DPS 33289
	LOT 3 DPS 33289
	LOT 5 DPS 33289
	LOT 2 DPS 33289
	PT LOT 2 DP 33506
Gow	PT LOT 1 DP 21192
	LOT 5 DP 21192
Martin-Steiner	LOT 1 DP 330781
	LOT 1 DP 365672
	LOT 3 DP 365672
	LOT 2 DP 365672
Watkins	LOT 2 DPS 81986
	PT LOT 1 DP 22903
	LOT 2 DP 22903
Virbickas	SECT 1 SO 50615
	LOT 1 DPS 5827
	LOT 1 DPS 91296
	SECT 2 SO 50615
	ALLT 256 Matata PSH
	PT LOT 2 DPS 5827
	ALLT 199 Matata PSH
	LOT 4 DPS 62758
	LOT 2 DPS 91296
	PT ALLT 257 Matatā PSH
	LOT 2 DP 366378
Mullins	**LOT 1 DPS 29959** **LOT 2 DPS 62758** **LOT 1 DP 350387**
LeLievre	LOT 1 DPS 75379
	LOT 4 DPS 15910
	LOT 1 DPS 75292
	LOT 2 DPS 75292
	LOT 5 DPS 15910
	PT LOT 6 DPS 15910
B Sullivan	Lot 1 DPS 88398
Bradley	Pt lot 4 DP 18069
	Lot 1 DPS 35290
	Lot 2 DPS 35290
W Olsen	Allot 289 Rangitaiki Parish (SO

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Owner	Legal Description
	50006)
	Allot 287 Rangitaiki Parish (SO 50005)
	Allot 307 Rangitaiki Parish (SO 50866)

2. Summary of Irrigation Properties and Land Area over which irrigation occurs

SEE CHANGE 2

Line	Current Land owner	No. Irrigators	Irrigable area 2013/14
Angle	~~BAIRD~~ **ORIINI DAIRIES LIMITED**	1	37
	~~OLIVER~~ **LANGDON**	2	82
	~~B. McCRACKEN~~ **BY de LEY**	1	43
	CARTER	2	49
	MacDONALD	2	62
	~~WALKER~~ **ROWLANDS**	2	67
			340
Awakeri	BARR	1	47
	BRADLEY	1	35
	CAMPBELL	1	79
	SULLIVAN	1	46
	REEVES	1	94
	NGATI AWA	1	120
	~~W. McCRACKEN~~ **VIRBICKAS**	1	52
	ZINK	2	65
	HAULTAIN	1	39
			577
Omeheu	VIRBICKAS	2	105
	GOW	2	48
	~~MARTIN~~ **STEINER**	1	38
	MULLINS	**1**	**67**
	WATKINS	2	87
	LELIEVRE	3	144
			422
Putiki	AWAROA	1	58
	~~MORGAN~~ **BY de LEY**	2	60
	OLSEN	1	37
	LANGDON	1	12
			167
Total		36	1573

SEE CHANGE 2

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SCHEDULE 3

GROUNDWATER MONITORING BORES ASSOCIATED WITH THE FONTERRA EDGECUMBE IRRIGATION OPERATIONS

Bore identification number or description	Physical location	GPS Coordinates	
Bore 1	Omeheu Zone 8	37°57.312S	176°47.108E
Bore 2	Omeheu Zone 2	37°57.686S	176°47.542E
Bore 3	McLeans Zone 4	37°57.607S	176°47.292E
Bore 4	Omeheu Zone 7	37°57.672S	176°46.816E
Bore 5	Omeheu Zone 1	37°57.927S	176°47.542E
Bore 6	McLeans Zone 6	37°58.399S	176°46.750E
Bore D1	Corner Omeheu Rd and SH2	37°57.775S	176°48.130E
Bore D2	Corner Gow Rd and SH2	37°57.771S	176°48.185E
Mullins 21800	Awaiti Rd South	37°57.380S	176°46.810E
Sturme 21747	State Highway 2 – north side	37°57.604S	176°47.907E
Orr 21854	Omeheu Road - cowshed	37°58.180S	176°47.948E
Ngati Awa (Skillings)	Hydro Road	38°00.842S	176°49.496E
Awaroa	Eastbank Road – tanker turnaround	37°55.454S	176°49.496E

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SCHEDULE 4

WASTEWATER MONITORING PROGRAMME

1 The consent holder shall undertake the sampling and analyses for both the medium strength and high strength wastewater as provided in Table 1, unless otherwise agreed to in writing by the Chief Executive of the Bay of Plenty Regional Council or delegate:

Table 1: Wastewater Sampling and Analysis Requirements

Frequency	Sample Type	Parameters
Weekly	24 hour composite samples	Total Kjeldahl Nitrogen Nitrate-nitrogen Nitrite-nitrogen
Monthly	24-hour composite	Sodium Calcium Chloride Potassium Magnesium Total phosphorus COD Total BOD_5 Conductivity pH

The requirement to analyse the wastewater for BOD may be dropped after a two year sampling period if a good condition correlation between COD and BOD can be demonstrated by the consent holder.

2 Sample collection, storage, analyses and reporting of results shall be carried out in accordance with sections 1 and 10 of the *Australian/New Zealand Standard AS/NZS 5667:1998 Water Quality – Sampling* (unless otherwise agreed to in writing by the Chief Executive of the Bay of Plenty Regional Council or delegate).

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SCHEDULE 5

GROUNDWATER MONITORING PROGRAMME

1 The water level, corrected to the Moturiki datum, in the groundwater monitoring bores shall be measured and recorded at least once in February, April, June, August, October and December of each year.

2 A representative sample of water from each of the groundwater monitoring bores shall be collected at least once in February, April, June, August, October and December of each year and analysed for the following constituents:

Parameter	Units
Conductivity	mS/m
Total nitrogen	mg/L
Nitrate-nitrogen	mg/L
Total phosphorus	mg/L
Dissolved reactive phosphorus	mg/L
Sodium	mg/L
Potassium	mg/L
Calcium	mg/L
Total BOD_5	mg/L
pH	

3 The consent holder shall undertake the monitoring required by condition 2 of this Schedule, within 24 hours of the soil moisture measuring equipment required to be installed by condition 11.2 of this consent indicating field capacity has been exceeded. This monitoring shall be undertaken up to 3 times per year, and if possible 2 of these monitoring events being undertaken in the winter and spring periods. The consent holder shall by 30 November notify the Bay of Plenty Regional Council if soil moisture conditions in the winter and spring periods have not exceeded the soil field capacity.

4 Sample collection, storage, analyses and reporting of results shall be carried out in accordance with sections 1 and 10 of the *Australian/New Zealand Standard AS/NZS 5667:1998 Water Quality – Sampling* (unless otherwise agreed to in writing by the Chief Executive of the Bay of Plenty Regional Council or delegate).

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SCHEDULE 6

SURFACE WATER MONITORING PROGRAMME

1 A representative sample of water from each of the surface water monitoring points identified in condition 10.1 shall be collected in February, April, June, August, October and December of each year and analysed for the following parameters:

Parameter	Units
Conductivity	mS/m
Dissolved oxygen	mg/L
Temperature	°C
Total nitrogen	mg/L
Nitrate-nitrogen	mg/L
Nitrite-nitrogen	mg/L
Ammonium-nitrogen	mg/L
Total Kjeldahl nitrogen (TKN)	mg/L
Dissolved Reactive Phosphorus	mg/L
Sodium	mg/L
Total BOD_5	mg/L
Total suspended solids	mg/L
pH	

The depth of the water in the surface water body and any visual observations of a general nature, at the time of monitoring, shall be recorded.

2 Sample collection, storage, analyses and reporting of results shall be carried out in accordance with sections 1 and 6 of the *Australian/New Zealand Standard AS/NZS 5667:1998 Water Quality – Sampling* (unless otherwise agreed to in writing by the Chief Executive of the Bay of Plenty Regional Council or delegate).

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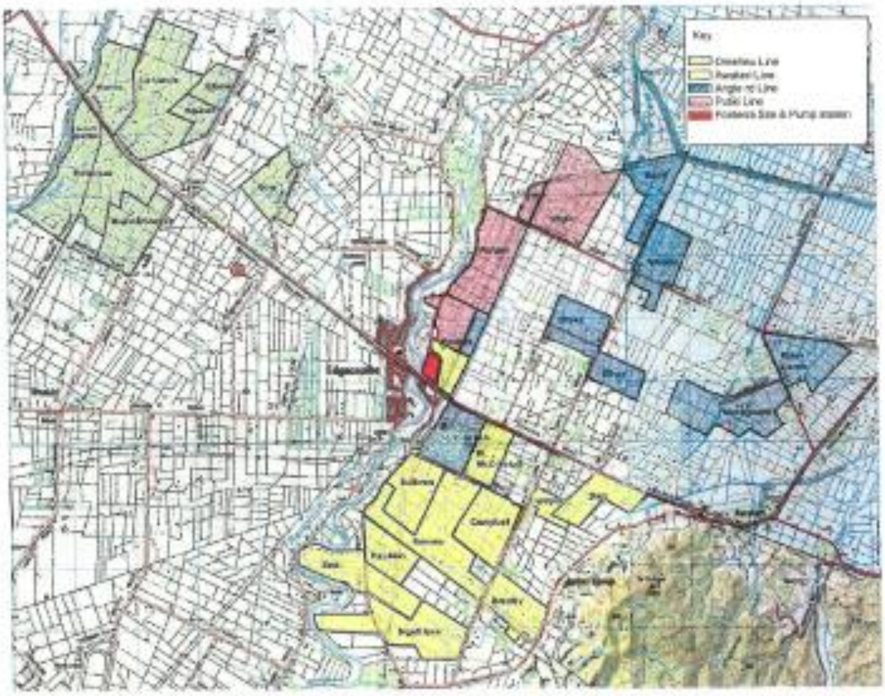
c) Mineralisable N;

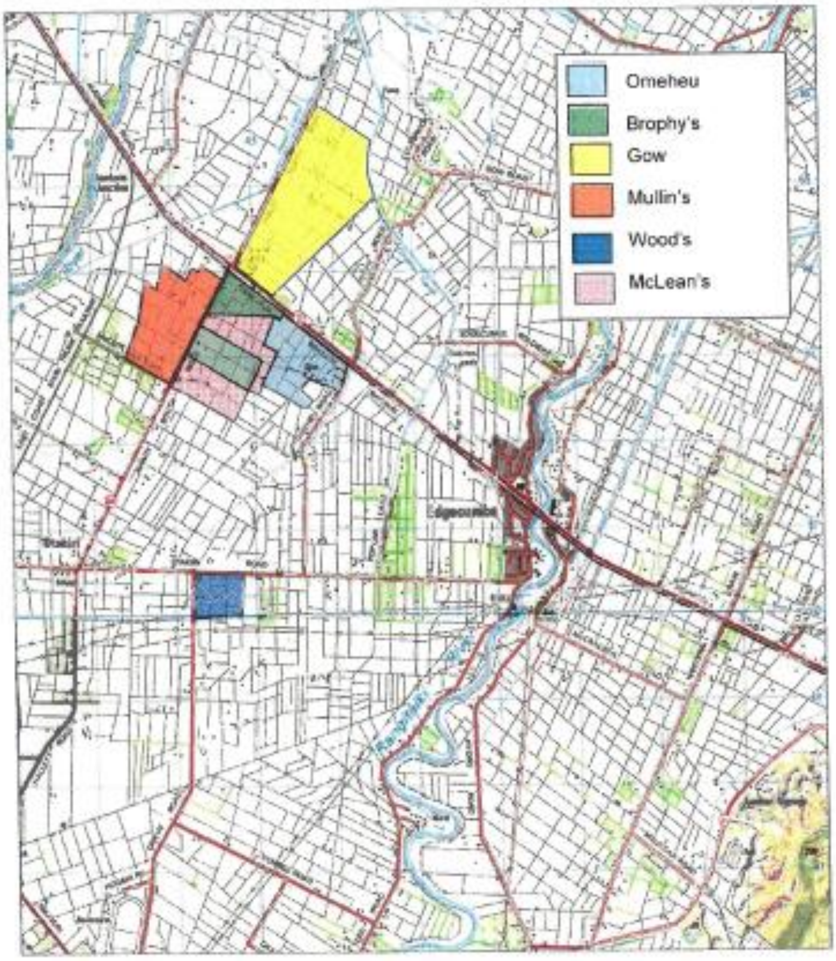
d) Nitrification potential; and

e) Denitrification potential.

4 Sample collection, storage, analyses and reporting of results shall be carried out to a recognised standard to the satisfaction of the Bay of Plenty Regional Council.



B.O.P.R.C. PLAN No.
RC 65800/2



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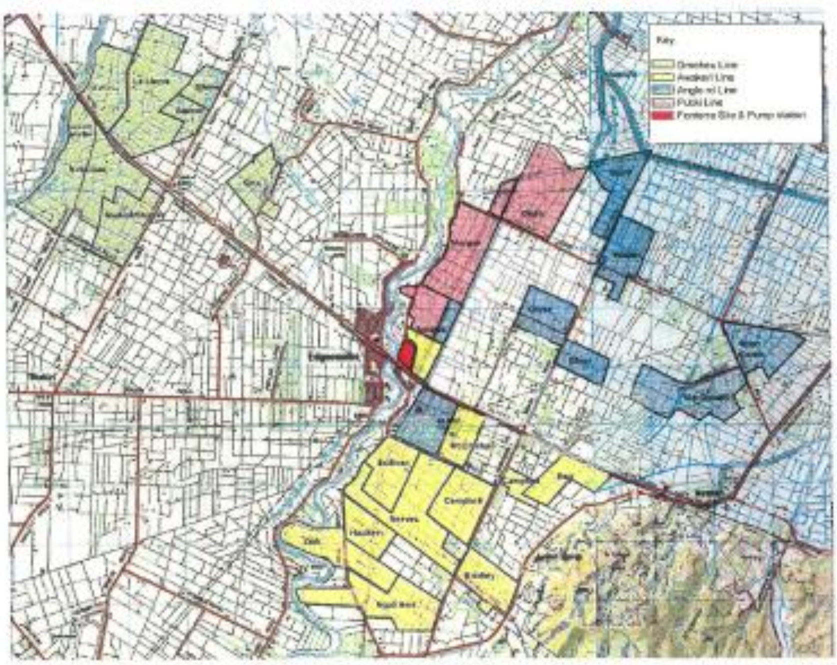


B.O.P.R.C. PLAN No.
RC 65800/2

Appendix 2
Pasture burning record sheets

PART 1: Record of the Event: When pasture damage is observed the following will be recorded:		
WHERE: Location of Damage	Farm	
	Paddock Number	
	Whole paddock burnt or patchy?	
	Run number / start & finish time of run	
	Burning at start, middle or end of run?	
	Line	
	Irrigator Operator	
	Irrigator Unit Number	
WHEN	Date of damage observed	
	Date of Irrigation (last application, and time since last irrigated	
Weather Conditions	Sunny, Cloudy/Overcast/Rain	
	Wind Speed and Direction	
Burning Assessment	1 – yellow before irrigation?	
	2 - brown wheel tracks	
	3 – slight browning of tips	
	4- slight browning	
	5 –severe browning	
	6- complete grass die-off	
	Ponding after irrigation?	
	Describe burning on 1st/2nd/3rd day etc.	
Assign ID to Event	Identification e.g. 17_PB_001_McD-20	
Record event and ID in Comms Log		
Photographs	Photographs to be sent to ETL	
Notifications	Steve Morrissey & Leigh Old ETL to notify Bram Berger /Kelli Paterson (Masters Research)	

Appendix 3
Pasture burning records

Event 1

Burning on Barr's farm was noticed on the 14th of September 2016 in paddock 3. Burning was moderate with tip burning on both the clover and ryegrass. Burning was observed where the paddock had hollows and ponding occurred, pasture burning was more severe. The Barr farm is supplied effluent via the Awakeri effluent line.

Event 2

On the 14th of September 2016 on McDonalds farm in paddock 3 there was moderate patchy burns to parts of the recently irrigated paddocks. The tip of the clover, ryegrass and dock were burnt in strips following the irrigator. There were also hollow presents causing the effluent to pond and kill the grass. Irrigation occurred on the 12th of September 2016.

Event 3

On the 20th of September 2016, light tip burning of clover and ryegrass was noticed on McDonalds farm in paddock 77. Paddock 77 was irrigated on the 18th of September 2016. Run one, two and three showed tip burning of both clover and ryegrass. McDonalds farm is supplied with effluent from the Angle road effluent line.

Event 4

On the 20th of September 2016, burning was noticed on McDonalds farm in paddock 22a. Irrigation of paddock 22a occurred on the 17th and 18th of September 2016. Patches of ponding of the effluent on run one, two and three after irrigation was thought to be the cause of the burning as anoxic conditions were created killing the pasture. McDonalds farm is supplied with effluent from the Angle road effluent line.

The soil where burning occurred on the McDonalds farm was compact with a peat layer at the top and sand deeper down.

A white substance found on the surface of the soil in paddock 22a suggested that the effluent ponded on the surface causing microbes to create a seal preventing the effluent from soaking into the soil.

Event 5

On the 21th of September 2016, burning was noticed on Ngakauroa farm in paddock 48. Irrigation of paddock 48 occurred on the 15th to the 19th of September 2016. Tip burning occurred on run one, two, three, four, five and six. Ngakauroa farm is supplied with effluent from the Awaroa effluent line.

Event 6

On the 21th of September 2016, tip burning of clover and ryegrass was noticed on Rowlands farm in paddock 48. The effluent was observed to change in smell from sweet to sour suggesting microbial activity. Irrigation of paddock 28 occurred on the 17th to the 19th of September 2016. Tip burning occurred on run two and three. Rowlands farm is supplied with effluent from the Angle road effluent line.

Event 7

On the 25th of September 2016, burning was noticed on McDonalds farm in paddock 71. Irrigation of paddock 71 occurred on the 25th of September 2016. Tip burning occurred on run three. McDonalds farm is supplied with effluent from the Angle road effluent line.

Event 8

On the 28th of September 2016, burning was noticed on Barr farm in paddock 16. Irrigation of paddock 16 occurred on the 24th of October 2016. Tip burn occurred in the middle of the paddock at the end of the run. Barr farm is supplied with effluent from the Awakeri effluent line.

Event 9

On the 28th of September 2016, tip burning was noticed on Rowlands farm in paddock 3. Irrigation of paddock 3 occurred on the 24th of October 2016. Rowlands farm is supplied with effluent from the Angle effluent line.

Event 10

On the 28th of September 2016, tip burning of clover and ryegrass was noticed on Rowlands farm in paddock 4. The clover that stood tall was burnt the worst. Irrigation of paddock 4 occurred on the 24th of October 2016. Rowlands farm is supplied with effluent from the Angle effluent line.

Event 11

On the 28th of September 2016, tip burning of clover and ryegrass was noticed on Rowlands farm in paddock 15. Irrigation of paddock 15 occurred on the 24th of October 2016. Rowlands farm is supplied with effluent from the Angle effluent line.

Event 12

On the 7th of November 2016, tip burning of clover and ryegrass was noticed on McDonalds (B) farm in paddock 75, run two. Irrigation of paddock 75 occurred on the 6th of November 2016. Rowlands farm is supplied with effluent from the Angle effluent line.

Event 13

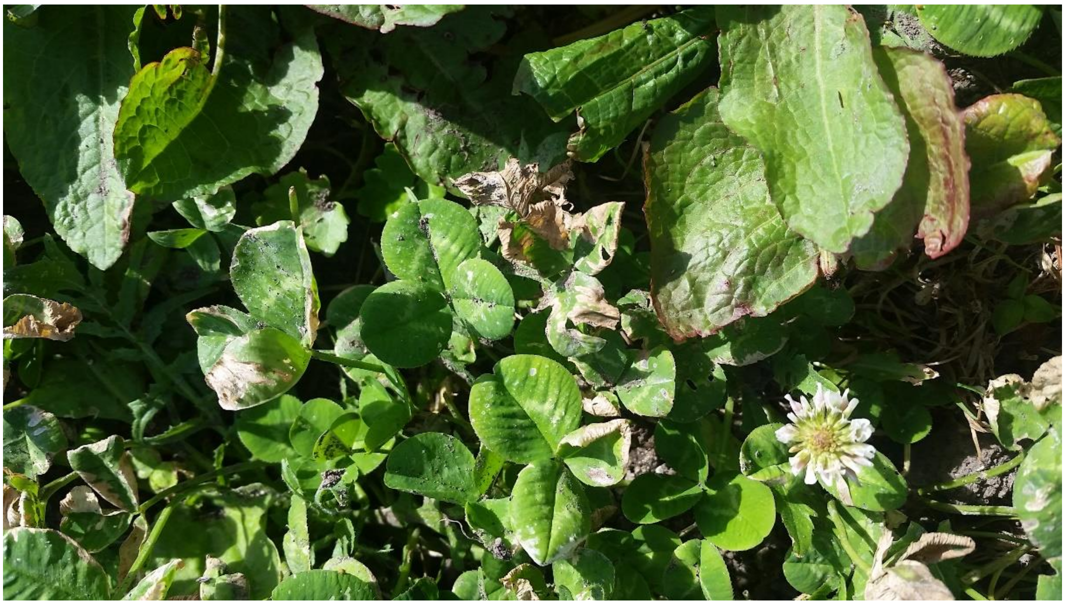
On the 9th of November 2016, tip burning of clover and ryegrass was noticed on Campbells farm in paddock 95, run two (7am to 3pm), three (4.05pm to late) and four (7.30am to 3.30pm). Irrigation of paddock 95 occurred on the 6th and 7th of November 2016. Immediately after irrigation the clover leaves were starting to curl over towards the end of run two. The day after irrigation a white substance was covering the pasture and the wheel tracks from the irrigator was burnt. The weather was very hot and sunny on the day of irrigation. Campbells farm is supplied with effluent from the Awakeri effluent line.

Event 14

On the 9th of November 2016, tip burning of clover and ryegrass was noticed on Ngakauroa farm in the middle of paddock 40. Irrigation of paddock 40 occurred on the 8th of November 2016. Ngakauroa farm is supplied with effluent from the Awakeri effluent line.

Event 15

On the 9th of November 2016, tip burning of clover and ryegrass was noticed on Awaroa farm in paddock 33, runs one (2.14pm to 6.30pm), two (6.50am to 1pm), three (12.15pm to 5pm), four (7pm to late), five (6.41am to 12pm), six (1.30pm to late) and seven (6.45am to 12.45pm). Burning was in strips following the irrigator. Irrigation of paddock 33 occurred on the 5th to 6th of November 2016. Awaroa farm is supplied with effluent from the Putiki effluent line.



Event 16

On the 9th of November 2016, tip burning of clover and ryegrass was noticed on Law farm in paddock 19 in the middle to the end of run one (9.30am to 2pm) and two (2.45pm to late). Irrigation of paddock 19 occurred on the 7th of November 2016. Law farm is supplied with effluent from the Angle road effluent line.

Event 17

On the 10th of November 2016, light tip burning of clover and ryegrass was noticed on McDonalds (C) farm in paddock 9 in the middle of run one (8.50am to 5pm). Burning was also in the lower spots in the paddock suggesting small amounts of ponding occurred. Irrigation of paddock 9 occurred on the 9th of November 2016. The weather was sunny on the day of irrigation. McDonalds (C) farm is supplied with effluent from the Angle road effluent line.

Event 18

On the 15th of November 2016, tip burning of ryegrass was noticed on Barr farm in paddock 1 in the middle of run four (1pm to late). Clover burning was lighter compared to the ryegrass burn. Irrigation of paddock 1 occurred on the 13th of November 2016. Barr farm is supplied with effluent from the Awakeri road effluent line.

Event 19

On the 14th of November 2016, tip burning of clover and ryegrass was noticed on Ngakauroa farm in paddock 6 in the middle of run three (6.45am to 1pm). The burning was patchy throughout run three. Irrigation of paddock 6 occurred on the 10th of November 2016. Ngakauroa farm is supplied with effluent from the Awaroa road effluent line.

Event 20

On the 14th of November 2016, tip burning of clover and ryegrass was noticed on Awaroa farm in paddock 15 in the middle of run two (9.15am to 4pm) and four (6.30am to 4pm). The burning ran the full length of occurred run three and four but was light. Irrigation of paddock 15 occurred on the 12th of November 2016. Awaroa farm is supplied with effluent from the Putiki effluent line.

Event 21

On the 14th of November 2016, tip burning of clover and ryegrass was noticed on Laws farm in paddock 33, run one (8.50am to late). The burning ran the full length of run one but was light and followed the irrigator tire tracks. Irrigation of paddock 33 occurred on the 11th of November 2016. Awaroa farm is supplied with effluent from the Angle road effluent line.

Event 22

On the 13th of November 2016, tip burning of clover and ryegrass was noticed on Awaroa farm in paddock 14, run three (8.50am to 5pm) and six (7.50am to 5pm). The burning ran down most of run one and six. Irrigation of paddock 14 occurred on the 10th of November 2016. Awaroa farm is supplied with effluent from the Angle road effluent line.

Event 23 and 24

On the 13th of November 2016, tip burning of clover and ryegrass was noticed on Awaroa farm in paddock 15 and 16. There was minimal information on the burning that occurred in both paddocks. Awaroa farm is supplied with effluent from the Putiki road effluent line.

Event 25

On the 23rd of November 2016, burning of clover and ryegrass was noticed on Sullivan’s farm in paddock 24. The burning was more severe and ran down most of run one and six. Date of irrigation of paddock 24 is unknown as the run that burnt was not reported. Sullivan’s farm is supplied with effluent from the Awakeri effluent line.

Event 26

On the 24th of November 2016, burning of clover and ryegrass was noticed on the Barr farm in paddock 29, run one and six. Burning occurred along most of run one and run six. Ponding was thought to be the cause of this burning event however, nitrogen was applied to the paddock the day after irrigation occurred. The Barr farm is supplied with effluent from the Awakeri effluent line.

Event 27

On the 25th of November 2016, tip burning of clover, ryegrass and dock was noticed on the McDonald farm in paddock 45, run one (8.10am to 4.10pm) and two (5pm to late). Burning occurred along the whole right side of the paddock where run one and two had overlapped due to an operator mistake in measurements. Irrigation of paddock 45 occurred on the 23th of November 2016. McDonalds farm is supplied with effluent from the Angle road effluent line.

Event 28 and 29

On the 8th of December 2016, tip burning of clover and ryegrass was noticed on Rowlands farm in the all of the runs in paddock 3 and run one in paddock 4 (Figure 4-30; 4-31.). Irrigation of paddock 3 occurred on the 4th and 5th of December 2016. Rowlands farm is supplied with effluent from the Angle road effluent line.

Event 30

On the 7th of December 2016, severe burning of clover and ryegrass was noticed on Ngakauroa farm in paddock 15, runs one, five, six and seven. (Figure 4-32; 4-33;4-34.). Irrigation of paddock 3 occurred on the 3rd to the 6th of December 2016. Burning was in strips that followed where the irrigator travelled. Ngakauroa farm is supplied with effluent from the Angle road effluent line.

Event 31, 32 and 33

On the 7th of December 2016, tip burning of clover and ryegrass was noticed on the Kokshaun farm in paddock 25, paddock 29 and paddock 30. In paddock 25 run one (7.13am to 11.30am) and two (11.30am to 2pm) were burnt. In paddock 29 run one (1.30pm to 4.30pm), two (1.30pm to 4.30pm) and three (6.50am to 11am) burnt and in paddock 30 run one (8pm to late), two (unknown) and three (unknown) also burnt. In paddock 25, 29 and 30 burning occurred as patchy strips where mostly clover burnt. Irrigation of paddock 25, 29 and 30 occurred on the 4th and 7th of December 2016. The Kokshaun farm is supplied with effluent from the Awakeri effluent line.

Event 34

On the 9th of December 2016, tip burning of clover and ryegrass was noticed on the Reeves farm in paddock 19, run two (7.25am to 4pm). The burning of run two was patchy and in strips following the pattern of the irrigator. Irrigation of paddock 19 occurred on the 6th of December 2016. The Reeves farm is supplied with effluent from the Awakeri effluent line.

Event 35

On the 10th of December 2016, tip burning of clover and ryegrass was noticed on the Rowlands farm in paddock 16, run one (12.40pm to 6pm). The whole of run one was burnt lightly. Irrigation of paddock 16 occurred on the 7th of December 2016. The Rowlands farm is supplied with effluent from the Angle effluent line.

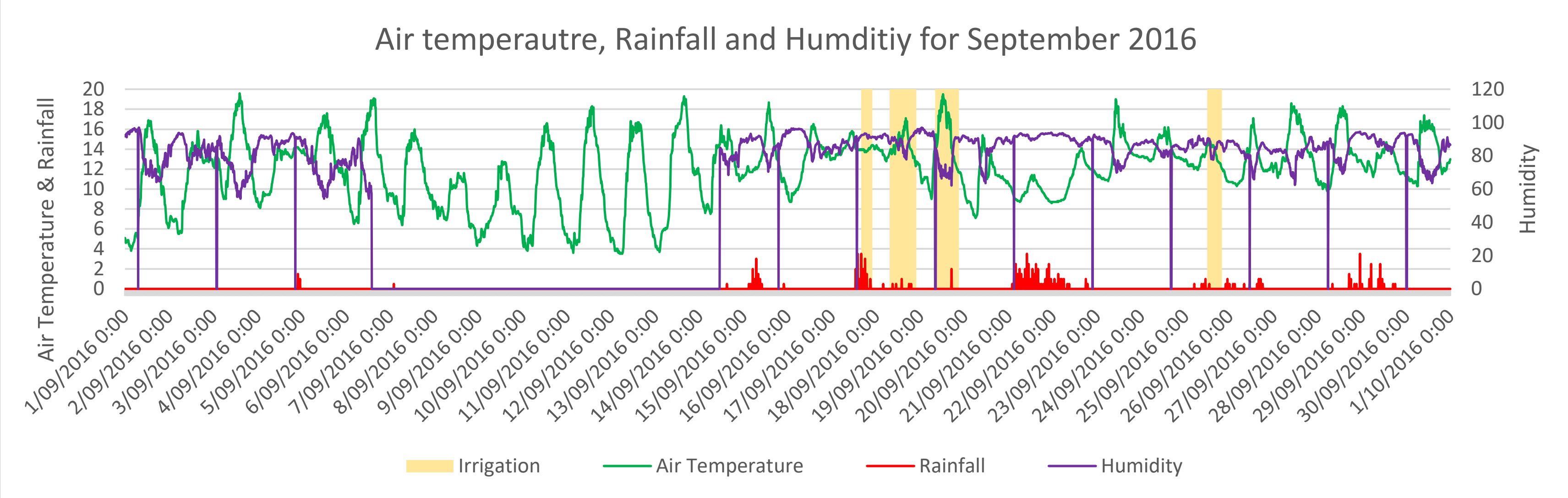
Event 36 and 37

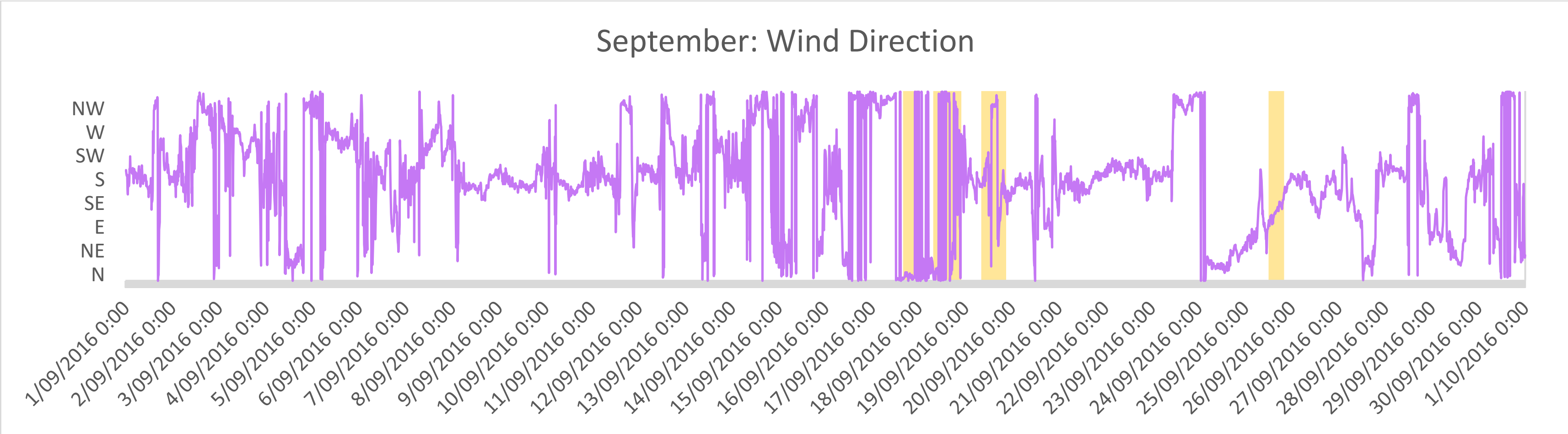
On the 10th of December 2016, tip burning of clover and ryegrass was noticed on the BDL East farm in paddock 14 and 15. In paddock 14, run one (9.10am to ?) was almost all burnt. In paddock 15, both run one (5.50pm to late) and two (11.45am to ?) burnt the whole run also. Irrigation of paddock 14 occurred on the 7th of December 2016 and the irrigation of paddock 15 occurred on the 8th and 9th of December 2016. The BDL East farm is supplied with effluent from the Angle effluent line.

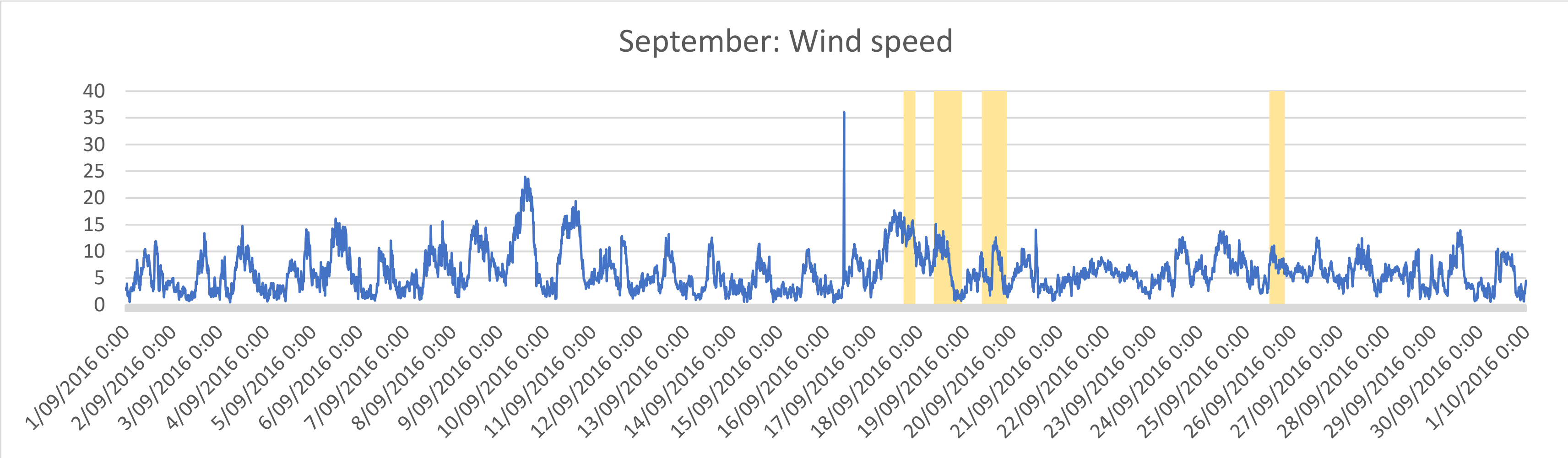
Event 38

On the 10th of December 2016, light tip burning of clover and ryegrass was noticed on the Rowlands farm in paddock 15, run one (9.30am to ?). The most of run one was burnt lightly. Irrigation of paddock 15 occurred on the 9th of December 2016. The Rowlands farm is supplied with effluent from the Angle effluent line.

Appendix 4
Weather Data






September: Wind speed
40
35
30
25
20
15
10
5
0
1/09/2016 0:00
2/09/2016 0:00
3/09/2016 0:00
4/09/2016 0:00
5/09/2016 0:00
6/09/2016 0:00
7/09/2016 0:00
8/09/2016 0:00
9/09/2016 0:00
10/09/2016 0:00
11/09/2016 0:00
12/09/2016 0:00
13/09/2016 0:00
14/09/2016 0:00
15/09/2016 0:00
16/09/2016 0:00
17/09/2016 0:00
18/09/2016 0:00
19/09/2016 0:00
20/09/2016 0:00
21/09/2016 0:00
22/09/2016 0:00
23/09/2016 0:00
24/09/2016 0:00
25/09/2016 0:00
26/09/2016 0:00
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28/09/2016 0:00
29/09/2016 0:00
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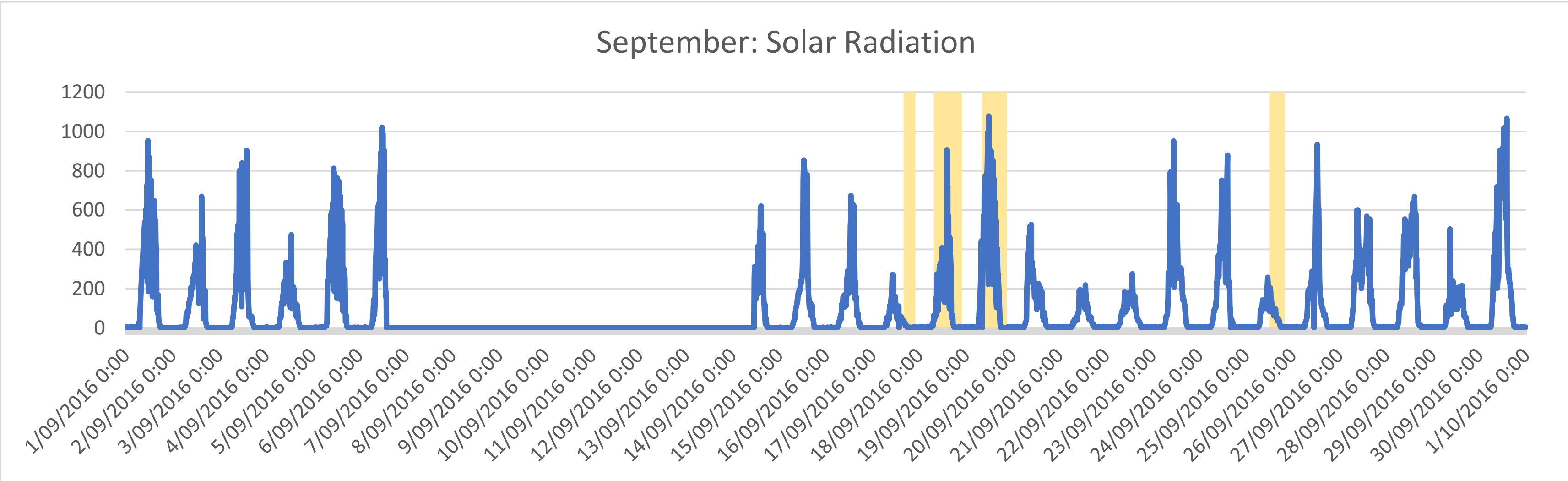
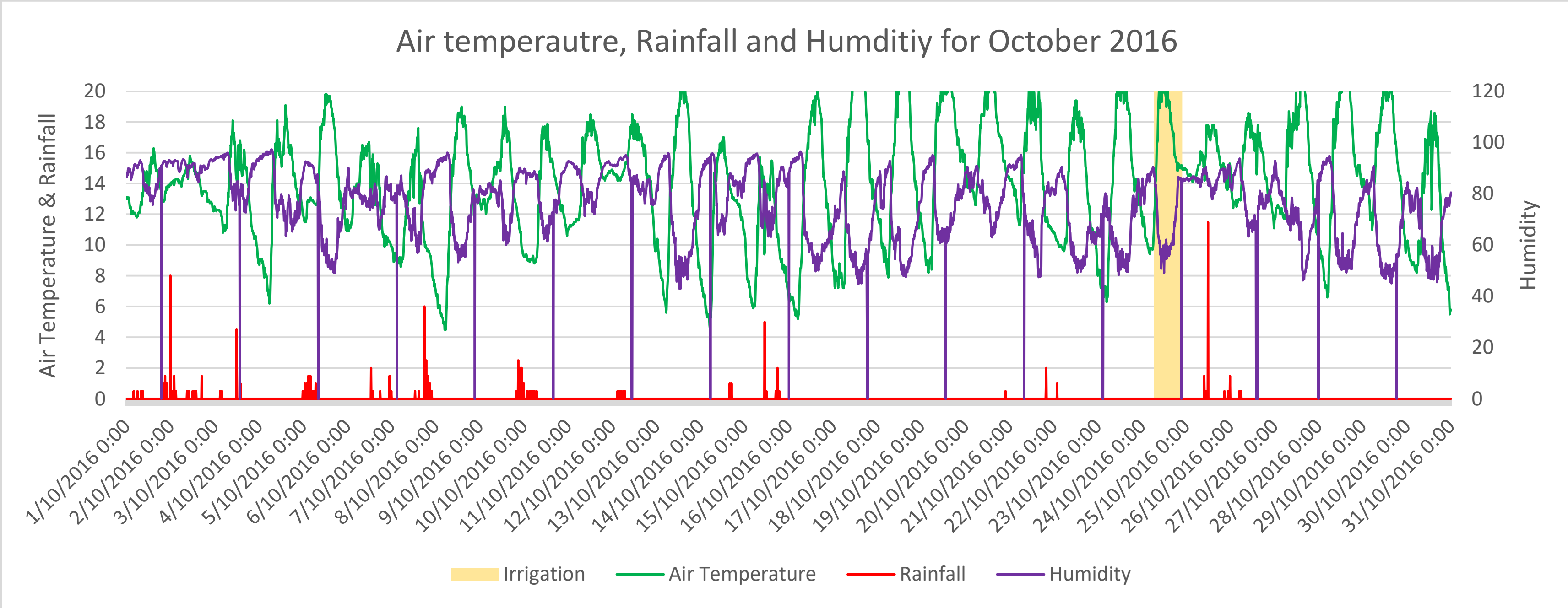
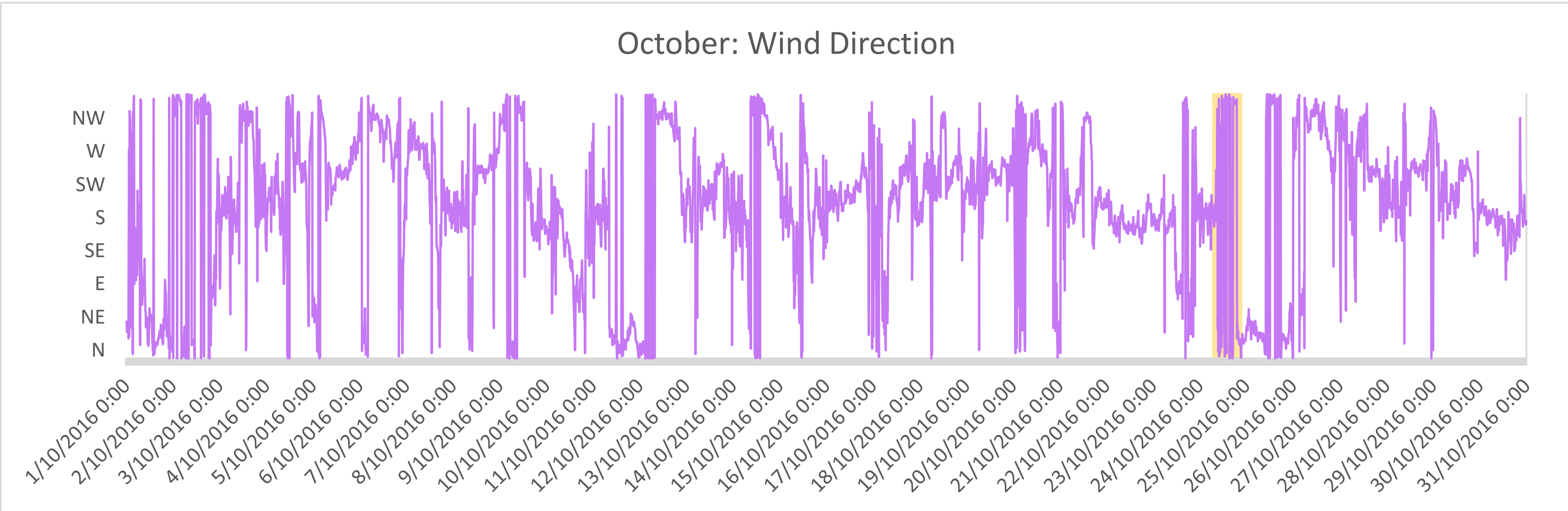
1/10/2016 0:00


September: Solar Radiation
1200
1000
800
600
400
200
0
1/09/2016 0:00
2/09/2016 0:00
3/09/2016 0:00
4/09/2016 0:00
5/09/2016 0:00
6/09/2016 0:00
7/09/2016 0:00
8/09/2016 0:00
9/09/2016 0:00
10/09/2016 0:00
11/09/2016 0:00
12/09/2016 0:00
13/09/2016 0:00
14/09/2016 0:00
15/09/2016 0:00
16/09/2016 0:00
17/09/2016 0:00
18/09/2016 0:00
19/09/2016 0:00
20/09/2016 0:00
21/09/2016 0:00
22/09/2016 0:00
23/09/2016 0:00
24/09/2016 0:00
25/09/2016 0:00
26/09/2016 0:00
27/09/2016 0:00
28/09/2016 0:00
29/09/2016 0:00
30/09/2016 0:00
1/10/2016 0:00


Air temperautre, Rainfall and Humditiy for October 2016
Air Temperature & Rainfall
Humidity
0
2
4
6
8
10
12
14
16
18
20
0
20
40
60
80
100
120
1/10/2016 0:00
2/10/2016 0:00
3/10/2016 0:00
4/10/2016 0:00
5/10/2016 0:00
6/10/2016 0:00
7/10/2016 0:00
8/10/2016 0:00
9/10/2016 0:00
10/10/2016 0:00
11/10/2016 0:00
12/10/2016 0:00
13/10/2016 0:00
14/10/2016 0:00
15/10/2016 0:00
16/10/2016 0:00
17/10/2016 0:00
18/10/2016 0:00
19/10/2016 0:00
20/10/2016 0:00
21/10/2016 0:00
22/10/2016 0:00
23/10/2016 0:00
24/10/2016 0:00
25/10/2016 0:00
26/10/2016 0:00
27/10/2016 0:00
28/10/2016 0:00
29/10/2016 0:00
30/10/2016 0:00
31/10/2016 0:00
Irrigation
Air Temperature
Rainfall
Humidity


October: Wind Direction
NW
W
SW
S
SE
E
NE
N
1/10/2016 0:00
2/10/2016 0:00
3/10/2016 0:00
4/10/2016 0:00
5/10/2016 0:00
6/10/2016 0:00
7/10/2016 0:00
8/10/2016 0:00
9/10/2016 0:00
10/10/2016 0:00
11/10/2016 0:00
12/10/2016 0:00
13/10/2016 0:00
14/10/2016 0:00
15/10/2016 0:00
16/10/2016 0:00
17/10/2016 0:00
18/10/2016 0:00
19/10/2016 0:00
20/10/2016 0:00
21/10/2016 0:00
22/10/2016 0:00
23/10/2016 0:00
24/10/2016 0:00
25/10/2016 0:00
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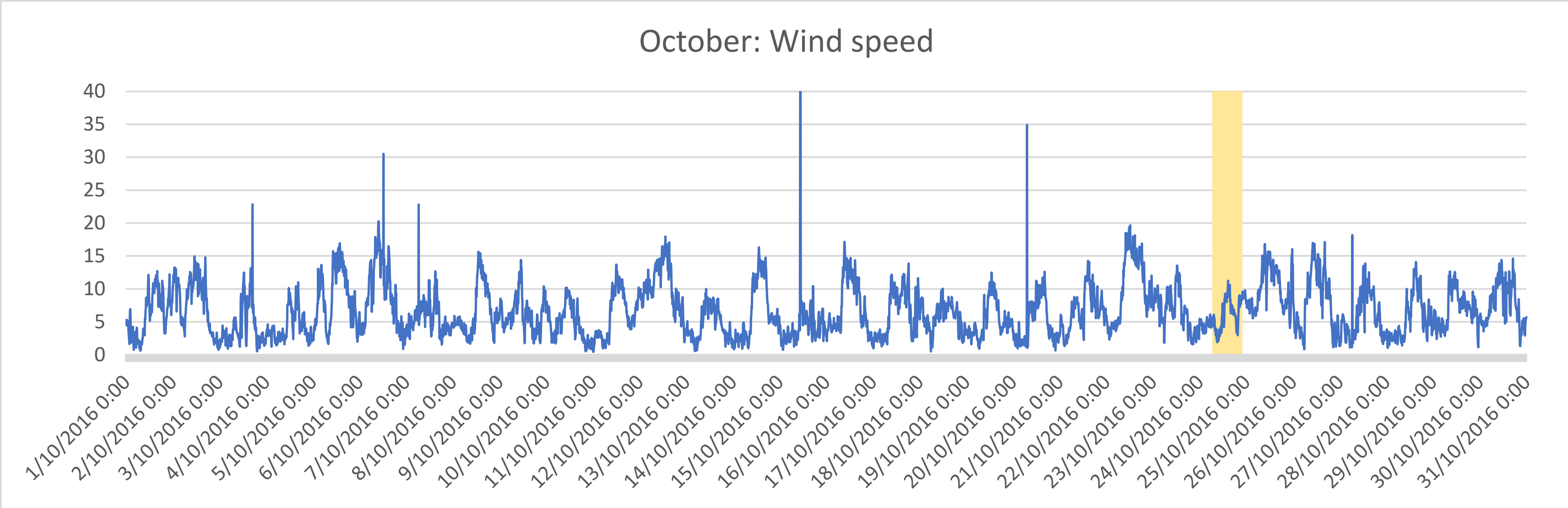
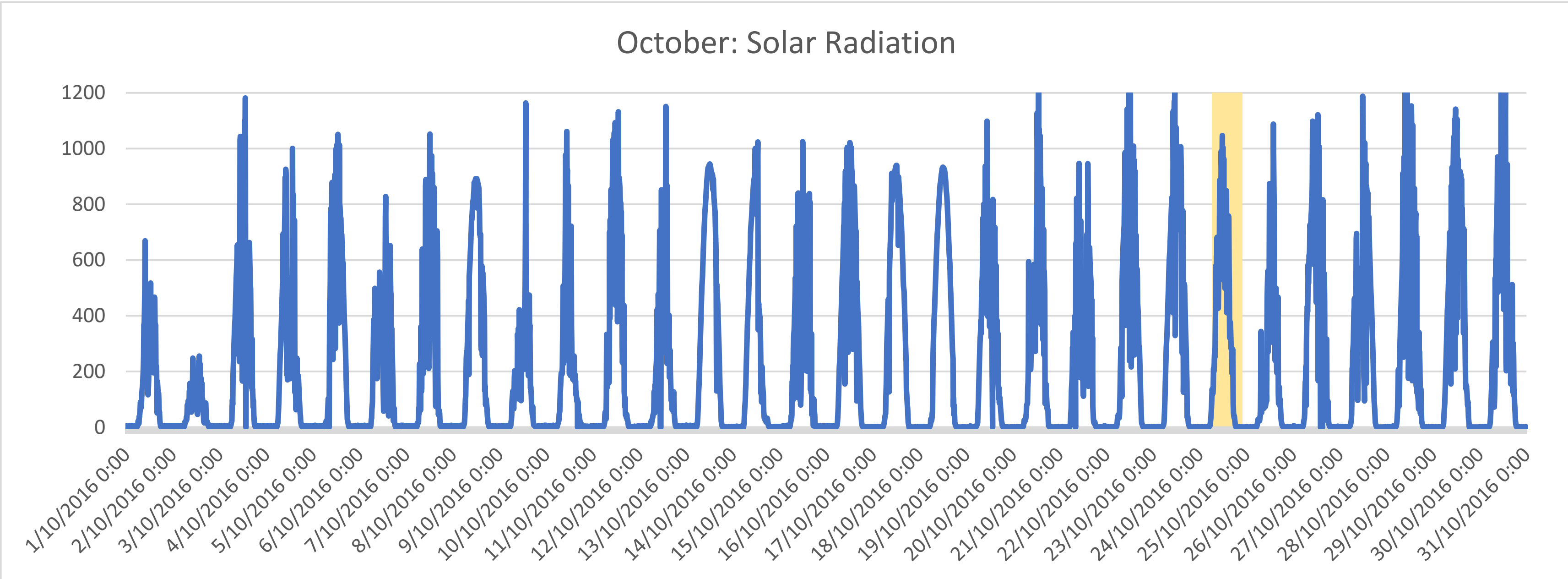
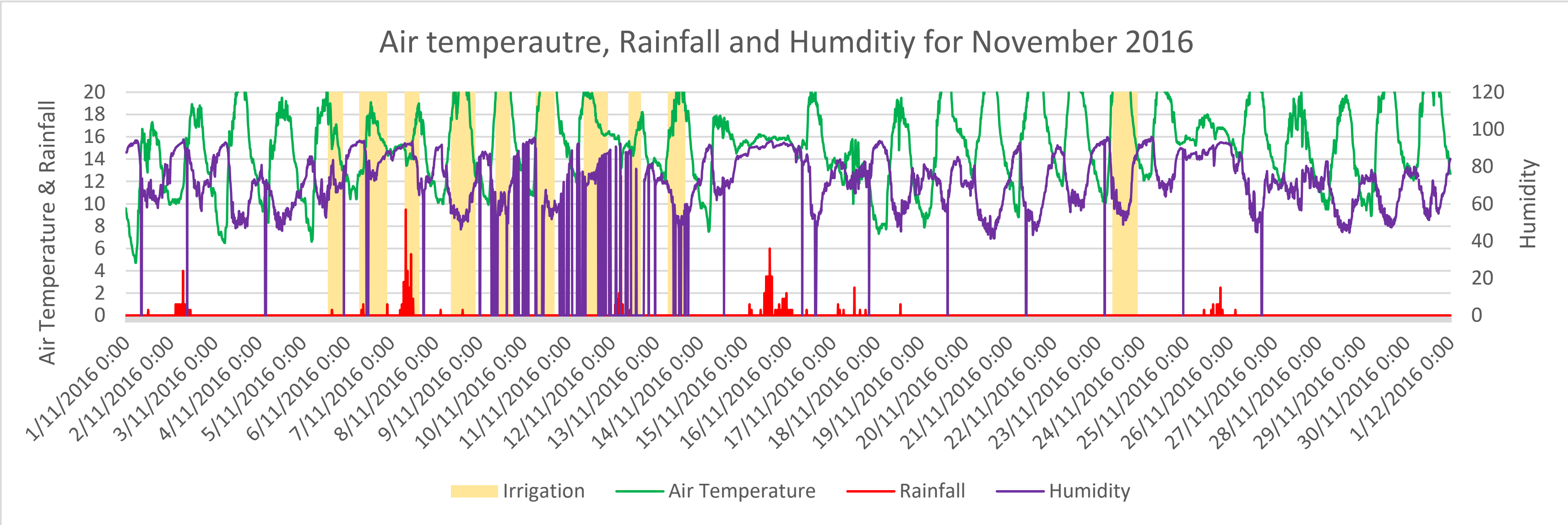
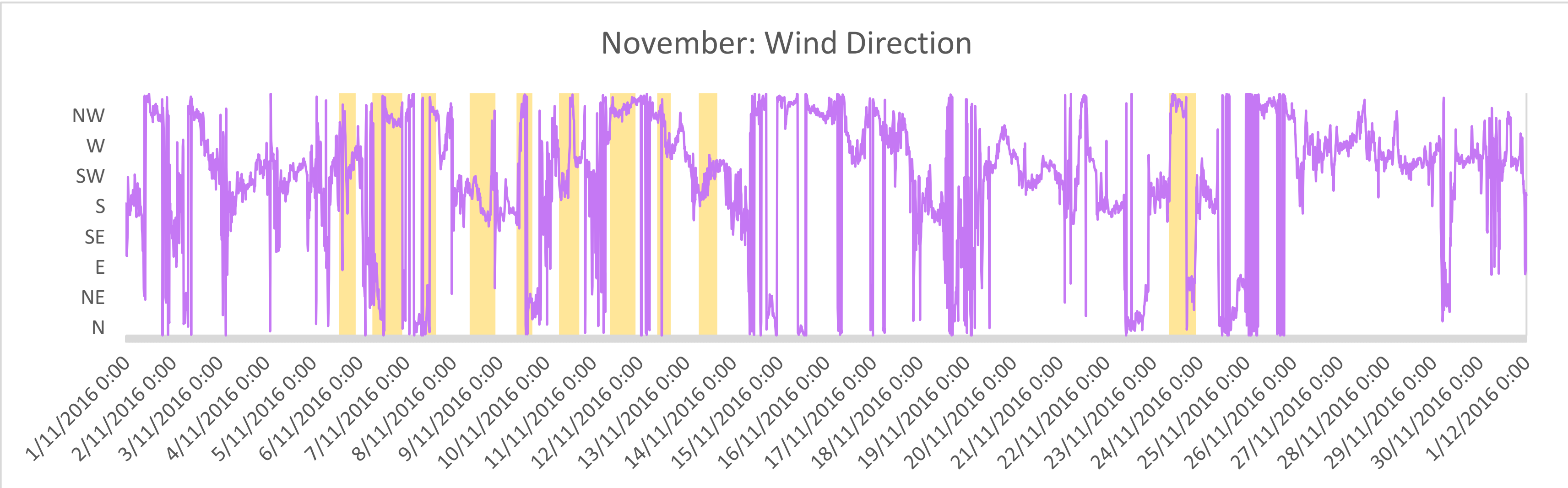
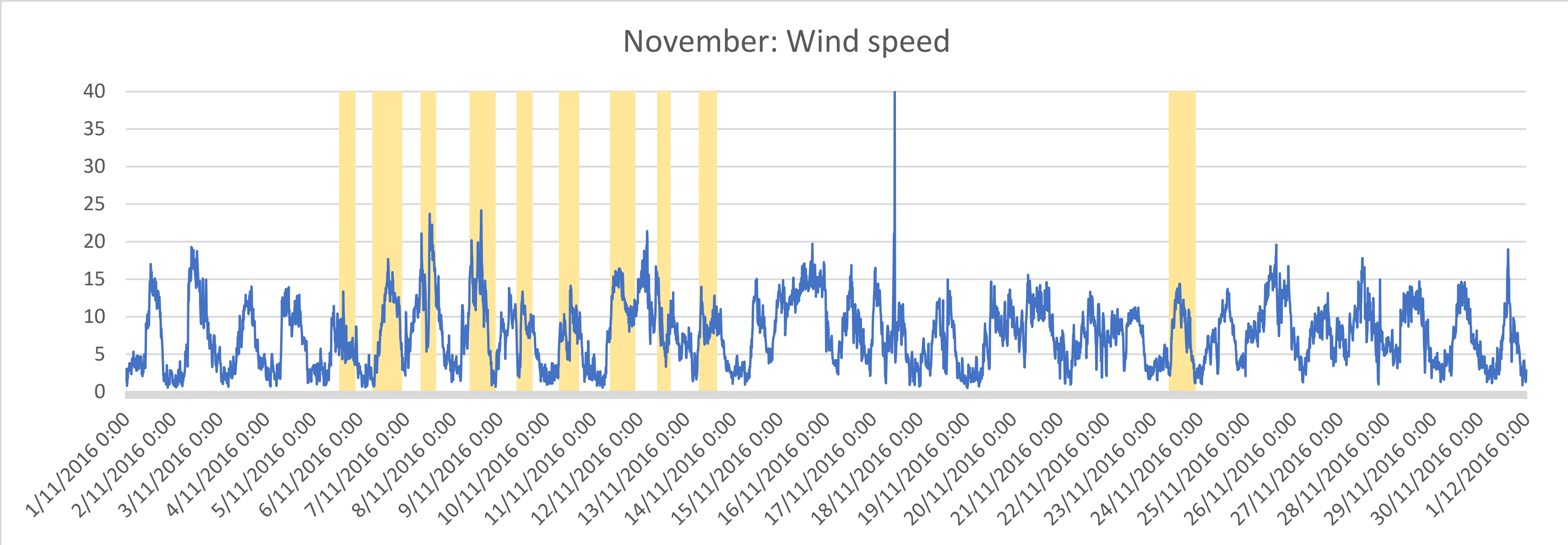
28/10/2016 0:00
29/10/2016 0:00
30/10/2016 0:00
31/10/2016 0:00


October: Wind speed
40
35
30
25
20
15
10
5
0
1/10/2016 0:00
2/10/2016 0:00
3/10/2016 0:00
4/10/2016 0:00
5/10/2016 0:00
6/10/2016 0:00
7/10/2016 0:00
8/10/2016 0:00
9/10/2016 0:00
10/10/2016 0:00
11/10/2016 0:00
12/10/2016 0:00
13/10/2016 0:00
14/10/2016 0:00
15/10/2016 0:00
16/10/2016 0:00
17/10/2016 0:00
18/10/2016 0:00
19/10/2016 0:00
20/10/2016 0:00
21/10/2016 0:00
22/10/2016 0:00
23/10/2016 0:00
24/10/2016 0:00
25/10/2016 0:00
26/10/2016 0:00
27/10/2016 0:00
28/10/2016 0:00
29/10/2016 0:00
30/10/2016 0:00
31/10/2016 0:00


October: Solar Radiation
1200
1000
800
600
400
200
0
1/10/2016 0:00
2/10/2016 0:00
3/10/2016 0:00
4/10/2016 0:00
5/10/2016 0:00
6/10/2016 0:00
7/10/2016 0:00
8/10/2016 0:00
9/10/2016 0:00
10/10/2016 0:00
11/10/2016 0:00
12/10/2016 0:00
13/10/2016 0:00
14/10/2016 0:00
15/10/2016 0:00
16/10/2016 0:00
17/10/2016 0:00
18/10/2016 0:00
19/10/2016 0:00
20/10/2016 0:00
21/10/2016 0:00
22/10/2016 0:00
23/10/2016 0:00
24/10/2016 0:00
25/10/2016 0:00
26/10/2016 0:00
27/10/2016 0:00
28/10/2016 0:00
29/10/2016 0:00
30/10/2016 0:00
31/10/2016 0:00


Air temperautre, Rainfall and Humditiy for November 2016
Air Temperature & Rainfall
Humidity
20
18
16
14
12
10
8
6
4
2
0
120
100
80
60
40
20
0
1/11/2016 0:00
2/11/2016 0:00
3/11/2016 0:00
4/11/2016 0:00
5/11/2016 0:00
6/11/2016 0:00
7/11/2016 0:00
8/11/2016 0:00
9/11/2016 0:00
10/11/2016 0:00
11/11/2016 0:00
12/11/2016 0:00
13/11/2016 0:00
14/11/2016 0:00
15/11/2016 0:00
16/11/2016 0:00
17/11/2016 0:00
18/11/2016 0:00
19/11/2016 0:00
20/11/2016 0:00
21/11/2016 0:00
22/11/2016 0:00
23/11/2016 0:00
24/11/2016 0:00
25/11/2016 0:00
26/11/2016 0:00
27/11/2016 0:00
28/11/2016 0:00
29/11/2016 0:00
30/11/2016 0:00
1/12/2016 0:00
Irrigation
Air Temperature
Rainfall
Humidity


November: Wind Direction
NW
W
SW
S
SE
E
NE
N
1/11/2016 0:00
2/11/2016 0:00
3/11/2016 0:00
4/11/2016 0:00
5/11/2016 0:00
6/11/2016 0:00
7/11/2016 0:00
8/11/2016 0:00
9/11/2016 0:00
10/11/2016 0:00
11/11/2016 0:00
12/11/2016 0:00
13/11/2016 0:00
14/11/2016 0:00
15/11/2016 0:00
16/11/2016 0:00
17/11/2016 0:00
18/11/2016 0:00
19/11/2016 0:00
20/11/2016 0:00
21/11/2016 0:00
22/11/2016 0:00
23/11/2016 0:00
24/11/2016 0:00
25/11/2016 0:00
26/11/2016 0:00
27/11/2016 0:00
28/11/2016 0:00
29/11/2016 0:00
30/11/2016 0:00
1/12/2016 0:00


November: Wind speed
40
35
30
25
20
15
10
5
0
1/11/2016 0:00
2/11/2016 0:00
3/11/2016 0:00
4/11/2016 0:00
5/11/2016 0:00
6/11/2016 0:00
7/11/2016 0:00
8/11/2016 0:00
9/11/2016 0:00
10/11/2016 0:00
11/11/2016 0:00
12/11/2016 0:00
13/11/2016 0:00
14/11/2016 0:00
15/11/2016 0:00
16/11/2016 0:00
17/11/2016 0:00
18/11/2016 0:00
19/11/2016 0:00
20/11/2016 0:00
21/11/2016 0:00
22/11/2016 0:00
23/11/2016 0:00
24/11/2016 0:00
25/11/2016 0:00
26/11/2016 0:00
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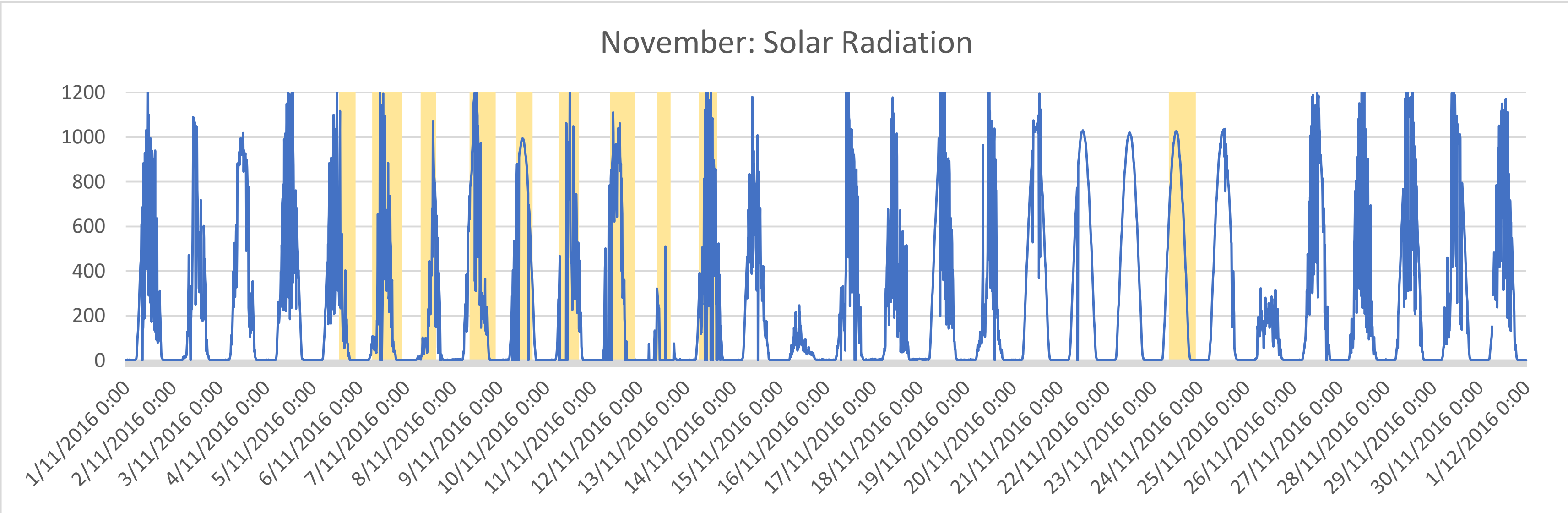
1/12/2016 0:00


November: Solar Radiation
1200
1000
800
600
400
200
0
1/11/2016 0:00
2/11/2016 0:00
3/11/2016 0:00
4/11/2016 0:00
5/11/2016 0:00
6/11/2016 0:00
7/11/2016 0:00
8/11/2016 0:00
9/11/2016 0:00
10/11/2016 0:00
11/11/2016 0:00
12/11/2016 0:00
13/11/2016 0:00
14/11/2016 0:00
15/11/2016 0:00
16/11/2016 0:00
17/11/2016 0:00
18/11/2016 0:00
19/11/2016 0:00
20/11/2016 0:00
21/11/2016 0:00
22/11/2016 0:00
23/11/2016 0:00
24/11/2016 0:00
25/11/2016 0:00
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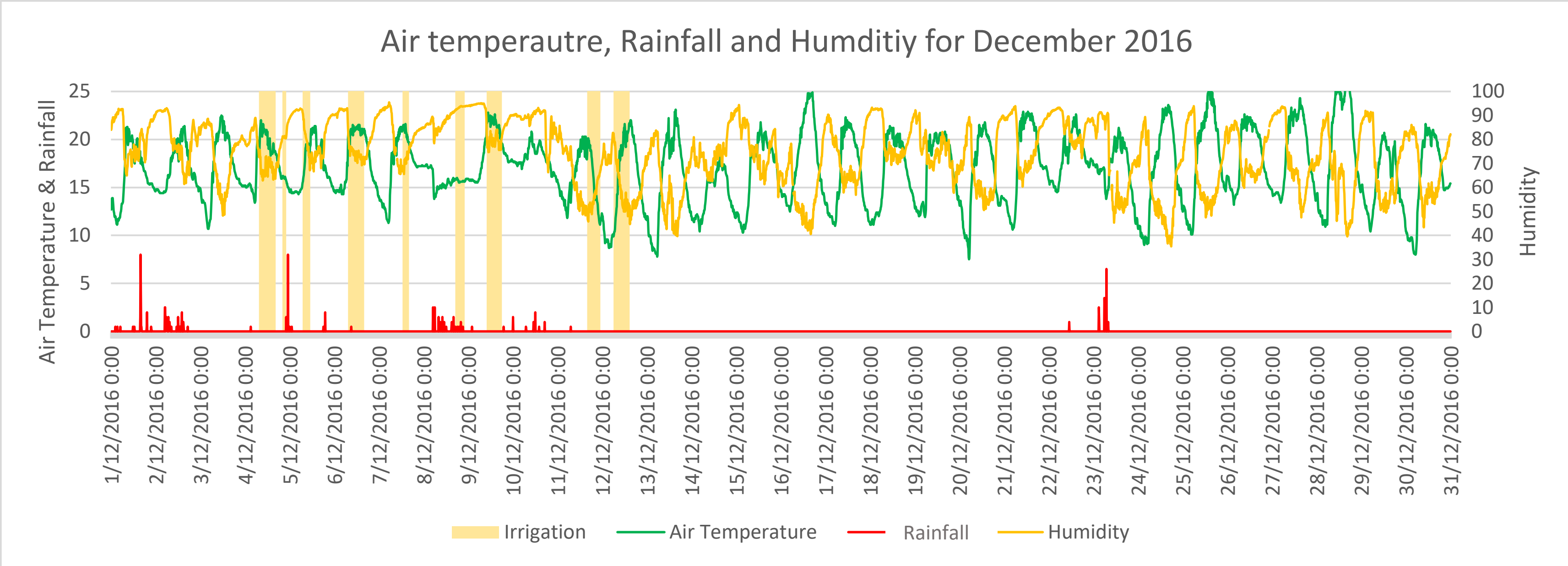
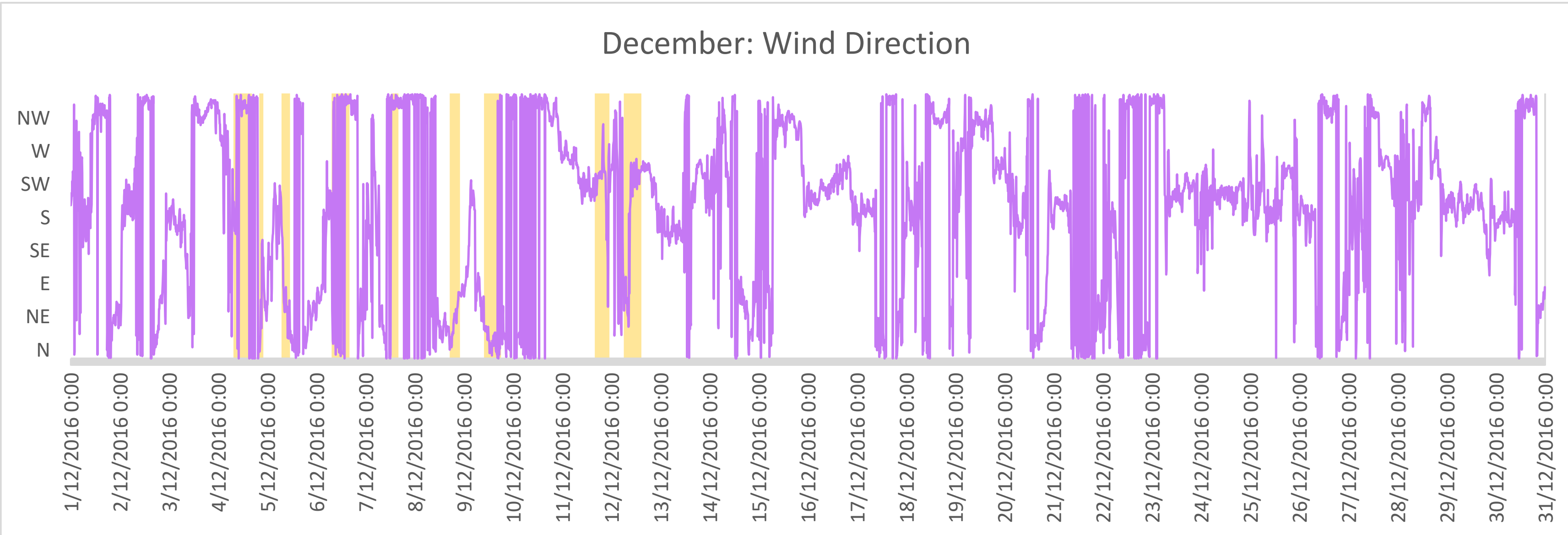
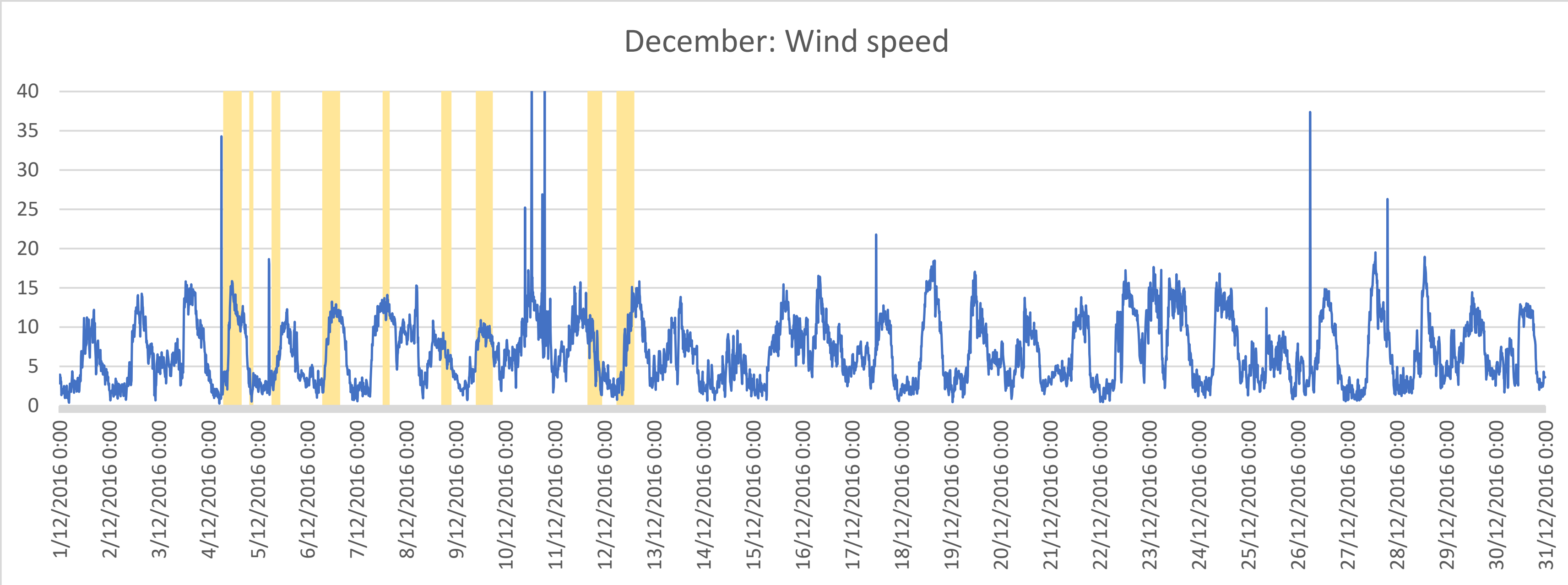
1/12/2016 0:00


Air temperautre, Rainfall and Humditiy for December 2016
Air Temperature & Rainfall
Humidity
25
20
15
10
5
0
100
90
80
70
60
50
40
30
20
10
0
1/12/2016 0:00
2/12/2016 0:00
3/12/2016 0:00
4/12/2016 0:00
5/12/2016 0:00
6/12/2016 0:00
7/12/2016 0:00
8/12/2016 0:00
9/12/2016 0:00
10/12/2016 0:00
11/12/2016 0:00
12/12/2016 0:00
13/12/2016 0:00
14/12/2016 0:00
15/12/2016 0:00
16/12/2016 0:00
17/12/2016 0:00
18/12/2016 0:00
19/12/2016 0:00
20/12/2016 0:00
21/12/2016 0:00
22/12/2016 0:00
23/12/2016 0:00
24/12/2016 0:00
25/12/2016 0:00
26/12/2016 0:00
27/12/2016 0:00
28/12/2016 0:00
29/12/2016 0:00
30/12/2016 0:00
31/12/2016 0:00
Irrigation
Air Temperature
Rainfall
Humidity


December: Wind Direction
NW
W
SW
S
SE
E
NE
N
1/12/2016 0:00
2/12/2016 0:00
3/12/2016 0:00
4/12/2016 0:00
5/12/2016 0:00
6/12/2016 0:00
7/12/2016 0:00
8/12/2016 0:00
9/12/2016 0:00
10/12/2016 0:00
11/12/2016 0:00
12/12/2016 0:00
13/12/2016 0:00
14/12/2016 0:00
15/12/2016 0:00
16/12/2016 0:00
17/12/2016 0:00
18/12/2016 0:00
19/12/2016 0:00
20/12/2016 0:00
21/12/2016 0:00
22/12/2016 0:00
23/12/2016 0:00
24/12/2016 0:00
25/12/2016 0:00
26/12/2016 0:00
27/12/2016 0:00
28/12/2016 0:00
29/12/2016 0:00
30/12/2016 0:00
31/12/2016 0:00


December: Wind speed
0
5
10
15
20
25
30
35
40
1/12/2016 0:00
2/12/2016 0:00
3/12/2016 0:00
4/12/2016 0:00
5/12/2016 0:00
6/12/2016 0:00
7/12/2016 0:00
8/12/2016 0:00
9/12/2016 0:00
10/12/2016 0:00
11/12/2016 0:00
12/12/2016 0:00
13/12/2016 0:00
14/12/2016 0:00
15/12/2016 0:00
16/12/2016 0:00
17/12/2016 0:00
18/12/2016 0:00
19/12/2016 0:00
20/12/2016 0:00
21/12/2016 0:00
22/12/2016 0:00
23/12/2016 0:00
24/12/2016 0:00
25/12/2016 0:00
26/12/2016 0:00
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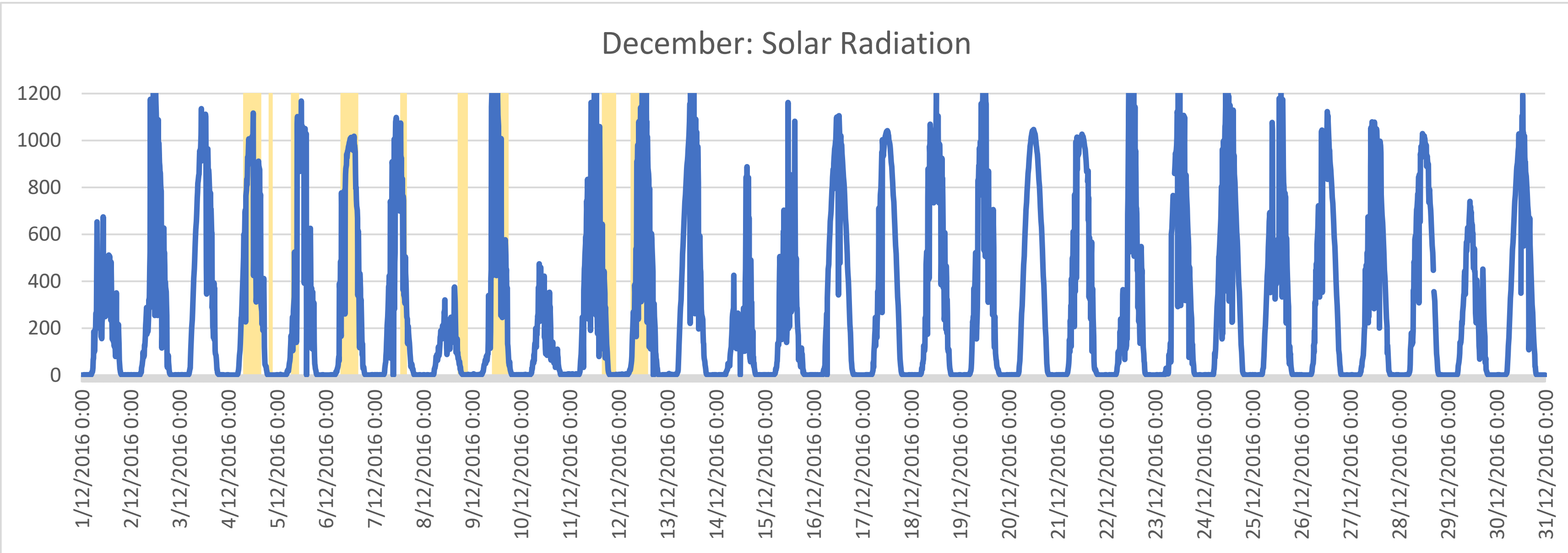
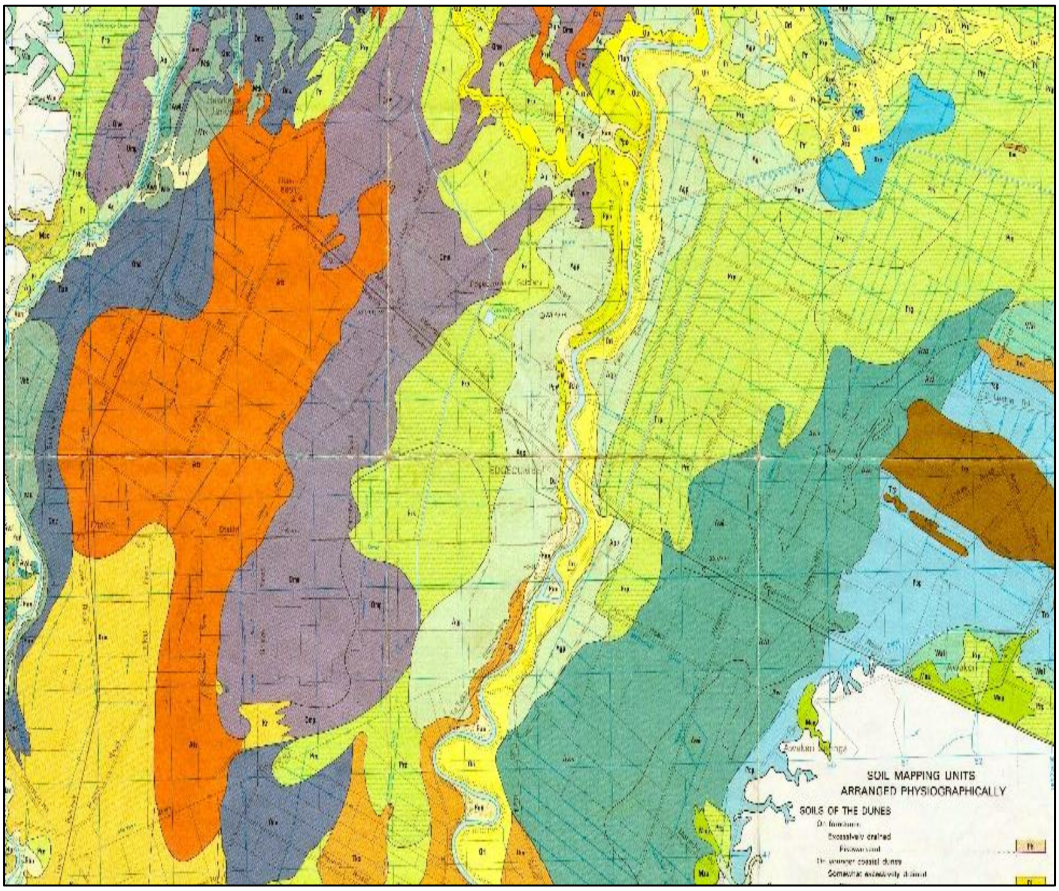
29/12/2016 0:00
30/12/2016 0:00
31/12/2016 0:00


December: Solar Radiation
0
200
400
600
800
1000
1200
1/12/2016 0:00
2/12/2016 0:00
3/12/2016 0:00
4/12/2016 0:00
5/12/2016 0:00
6/12/2016 0:00
7/12/2016 0:00
8/12/2016 0:00
9/12/2016 0:00
10/12/2016 0:00
11/12/2016 0:00
12/12/2016 0:00
13/12/2016 0:00
14/12/2016 0:00
15/12/2016 0:00
16/12/2016 0:00
17/12/2016 0:00
18/12/2016 0:00
19/12/2016 0:00
20/12/2016 0:00
21/12/2016 0:00
22/12/2016 0:00
23/12/2016 0:00
24/12/2016 0:00
25/12/2016 0:00
26/12/2016 0:00
27/12/2016 0:00
28/12/2016 0:00
29/12/2016 0:00
30/12/2016 0:00
31/12/2016 0:00

Appendix 5
Soil Map of Area



Legend:

- Te Rahu loamy sand, peaty subsoil variant
- Matata soils
- Pongakawa peaty soil
- Poroporo silt loam
- Kopeopeo loamy sand
- Awakeri sandy loam on shallow peat
- Awakaponga silt loam
- Te Teko sandy loam
- Omehue sandy loam
- Awaiti sandy loam
- Kawerau loamy coarse sand, motle varient
- Matuku silt loam

Appendix 6
Pilot Trial: Results

Extent of burn on clover and ryegrass on day 1 of pilot trial using visual damage scale.

Treatments	Clover burn (0 – 4)	Ryegrass burn (0 – 4)
Water only	0	0
Effluent only 216	0	0
Untreated	0	0
KCl 501	0	0
KCl 1194	0	0
Lactose solution 370	1	0
Lactose solution 1406	0	0
Lactose solution + KCl 464	0	0
Lactose solution + KCl 1311	0	0

Extent of burn on clover and ryegrass on day 2 of pilot trial using visual damage scale.

Treatments	Clover burn (0 – 4)	Ryegrass burn (0 – 4)
Water only	0	0
Effluent only 216	0	0
Untreated	0	0
KCl 501	1	0
KCl 1194	1	0
Lactose solution 370	0	0
Lactose solution 1406	0	1
Lactose solution + KCl 464	0	0
Lactose solution + KCl 1311	1	0

Extent of burn on clover and ryegrass on day 3 of pilot trial using visual damage scale.

Treatments	Clover burn (0 – 4)	Ryegrass burn (0 – 4)
Water only	0	0
Effluent only 216	1	0
Untreated	0	0
KCl 501	1	0
KCl 1194	2	0
Lactose solution 370	1	0
Lactose solution 1406	4	2
Lactose solution + KCl 464	1	0
Lactose solution + KCl 1311	4	1

Extent of burn on clover and ryegrass on day 4 of pilot trial using visual damage scale.

Treatments	Clover burn (0 – 4)	Ryegrass burn (0 – 4)
Water only	0	0
Effluent only 216	1	0
Untreated	0	0
KCl 501	1	0
KCl 1194	1	0
Lactose solution 370	1	0
Lactose solution 1406	4	2
Lactose solution + KCl 464	1	1
Lactose solution + KCl 1311	3	1

Extent of burn on clover and ryegrass on day 5 of pilot trial using visual damage scale.

Treatments	Clover burn (0 – 4)	Ryegrass burn (0 – 4)
Water only	0	0
Effluent only 216	1	0
Untreated	0	0
KCl 501	1	0
KCl 1194	3	1
Lactose solution 370	1	0
Lactose solution 1406	3	3
Lactose solution + KCl 464	1	1
Lactose solution + KCl 1311	3	2

Extent of burn on clover and ryegrass on day 6 of pilot trial using visual damage scale.

Treatments	Clover burn (0 – 4)	Ryegrass burn (0 – 4)
Water only	0	0
Effluent only 216	1	0
Untreated	0	0
KCl 501	2	0
KCl 1194	2	1
Lactose solution 370	2	0
Lactose solution 1406	4	3
Lactose solution + KCl 464	2	1
Lactose solution + KCl 1311	3	2

Extent of burn on clover and ryegrass on day 7 of pilot trial using visual damage scale.

Treatments	Clover burn (0 – 4)	Ryegrass burn (0 – 4)
Water only	0	0
Effluent only 216	1	0
Untreated	0	0
KCl 501	1	0
KCl 1194	4	2
Lactose solution 370	1	0
Lactose solution 1406	4	3
Lactose solution + KCl 464	1	1
Lactose solution + KCl 1311	3	2

Main Experiment Block 1: Results

Extent of burn on clover and ryegrass on day 1 of the main experiment; block 1 using visual damage scale.

Treatments	Clover burn (0 – 4)	Ryegrass burn (0 – 4)
Water only	0	0
Untreated	0	0
Effluent Only 233	0	0
KCL 382	1	0
KCL 570	1	0
KCL 818	1	0
KCL 1064	3	0
Lactose solution 356	0	0
Lactose solution 656	0	0
Lactose solution 803	0	0
Lactose solution 921	1	0
Lactose solution + KCl 395	0	0
Lactose solution + KCl 645	0	0
Lactose solution + KCl 847	0	0
Lactose solution + KCl 1095	1	0

Extent of burn on clover and ryegrass on day 2 of the main experiment; block 1 using visual damage scale.

Treatments	Clover burn (0 – 4)	Ryegrass burn (0 – 4)
Water only	0	0
Untreated	0	0
Effluent Only 233	0	0
KCL 382	2	0
KCL 570	2	0
KCL 818	2	0
KCL 1064	4	0
Lactose solution 356	0	0
Lactose solution 656	0	0
Lactose solution 803	0	0
Lactose solution 921	1	0
Lactose solution + KCl 395	0	0
Lactose solution + KCl 645	0	0
Lactose solution + KCl 847	0	0
Lactose solution + KCl 1095	1	0

Extent of burn on clover and ryegrass on day 3 of the main experiment; block 1 using visual damage scale.

Treatments	Clover burn (0 – 4)	Ryegrass burn (0 – 4)
Water only	1	0
Untreated	1	0
Effluent only 233	1	0
KCL 382	2	0
KCL 570	1	0
KCL 818	2	0
KCL 1064	4	0
Lactose solution 356	1	0
Lactose solution 656	1	0
Lactose solution 803	1	0
Lactose solution 921	1	0
Lactose solution + KCl 395	1	0
Lactose solution + KCl 645	1	0
Lactose solution + KCl 847	1	0
Lactose solution + KCl 1095	1	0

Extent of burn on clover and ryegrass on day 4 of the main experiment; block 1 using visual damage scale.

Treatments	Clover burn (0 – 4)	Ryegrass burn (0 – 4)
Water only	0	0
Untreated	0	0
Effluent only 233	0	0
KCL 382	2	1
KCL 570	2	0
KCL 818	2	0
KCL 1064	4	0
Lactose solution 356	0	0
Lactose solution 656	1	0
Lactose solution 803	1	0
Lactose solution 921	1	0
Lactose solution + KCl 395	1	0
Lactose solution + KCl 645	2	0
Lactose solution + KCl 847	1	0
Lactose solution + KCl 1095	1	0

Extent of burn on clover and ryegrass on day 5 of the main experiment; block 1 using visual damage scale.

Treatments	Clover burn (0 – 4)	Ryegrass burn (0 – 4)
Water only	0	0
Untreated	0	0
Effluent only 233	1	0
KCL 382	1	0
KCL 570	1	0
KCL 818	3	0
KCL 1064	4	1
Lactose solution 356	0	0
Lactose solution 656	1	0
Lactose solution 803	0	0
Lactose solution 921	0	1
Lactose solution + KCl 395	1	0
Lactose solution + KCl 645	1	0
Lactose solution + KCl 847	1	0
Lactose solution + KCl 1095	2	2

Extent of burn on clover and ryegrass on day 6 of the main experiment; block 1 using visual damage scale.

Treatments	Clover burn (0 – 4)	Ryegrass burn (0 – 4)
Water only	0	0
Untreated	0	0
Effluent only 233	1	0
KCL 382	1	0
KCL 570	2	0
KCL 818	1	0
KCL 1064	3	1
Lactose solution 356	0	0
Lactose solution 656	1	0
Lactose solution 803	0	0
Lactose solution 921	0	1
Lactose solution + KCl 395	1	0
Lactose solution + KCl 645	1	0
Lactose solution + KCl 847	1	0
Lactose solution + KCl 1095	2	2

Extent of burn on clover and ryegrass on day 8 of the main experiment; block 1 using visual damage scale.

Treatments	Clover burn (0 – 4)	Ryegrass burn (0 – 4)
Water only	0	0
Untreated	0	0
Effluent only 233	1	0
KCL 382	1	1
KCL 570	0	0
KCL 818	0	1
KCL 1064	0	0
Lactose solution 356	0	0
Lactose solution 656	0	1
Lactose solution 803	0	1
Lactose solution 921	0	1
Lactose solution + KCl 395	0	0
Lactose solution + KCl 645	0	0
Lactose solution + KCl 847	0	2
Lactose solution + KCl 1095	0	1

Extent of burn on clover and ryegrass on day 10 of the main experiment; block 1 using visual damage scale.

Treatments	Clover burn (0 – 4)	Ryegrass burn (0 – 4)
Water only	0	2
Untreated	0	1
Effluent only 233	0	1
KCL 382	0	1
KCL 570	0	1
KCL 818	0	0
KCL 1064	0	0
Lactose solution 356	0	1
Lactose solution 656	0	1
Lactose solution 803	0	2
Lactose solution 921	0	1
Lactose solution + KCl 395	0	1
Lactose solution + KCl 645	0	1
Lactose solution + KCl 847	0	0
Lactose solution + KCl 1095	0	2

Main Experiment Block 2: Results

Extent of burn on clover and ryegrass on day 1 of the main experiment; block 2 using visual damage scale.

Treatments	Clover burn (0 – 4)	Ryegrass burn (0 – 4)
Water only	0	0
Untreated	0	0
Effluent only 202	0	0
KCL 440	0	0
KCL 604	0	0
KCL 797	0	0
KCL 990	0	0
Lactose solution 365	0	0
Lactose solution 570	0	0
Lactose solution 768	0	0
Lactose solution 967	0	0
Lactose solution + KCl 370	0	0
Lactose solution + KCl 421	0	0
Lactose solution + KCl 876	0	0
Lactose solution + KCl 993	0	0

Extent of burn on clover and ryegrass on day 2 of the main experiment; block 2 using visual damage scale.

Treatments	Clover burn (0 – 4)	Ryegrass burn (0 – 4)
Water only	0	0
Untreated	0	0
Effluent only 202	1	0
KCL 440	1	0
KCL 604	1	0
KCL 797	1	0
KCL 990	1	0
Lactose solution 365	1	0
Lactose solution 570	1	0
Lactose solution 768	1	0
Lactose solution 967	1	0
Lactose solution + KCl 370	1	0
Lactose solution + KCl 421	0	0
Lactose solution + KCl 876	1	0
Lactose solution + KCl 993	1	0

Extent of burn on clover and ryegrass on day 3 of the main experiment; block 2 using visual damage scale.

Treatments	Clover burn (0 – 4)	Ryegrass burn (0 – 4)
Water only	0	0
Untreated	0	0
Effluent only 202	1	0
KCL 440	1	0
KCL 604	2	0
KCL 797	3	0
KCL 990	4	0
Lactose solution 365	1	0
Lactose solution 570	1	0
Lactose solution 768	1	0
Lactose solution 967	1	0
Lactose solution + KCl 370	1	0
Lactose solution + KCl 421	1	0
Lactose solution + KCl 876	1	0
Lactose solution + KCl 993	1	0

Extent of burn on clover and ryegrass on day 4 of the main experiment; block 2 using visual damage scale.

Treatments	Clover burn (0 – 4)	Ryegrass burn (0 – 4)
Water only	0	0
Untreated	0	0
Effluent only 202	1	0
KCL 440	1	0
KCL 604	2	2
KCL 797	3	0
KCL 990	4	3
Lactose solution 365	1	0
Lactose solution 570	1	0
Lactose solution 768	1	2
Lactose solution 967	1	0
Lactose solution + KCl 370	1	0
Lactose solution + KCl 421	1	0
Lactose solution + KCl 876	2	2
Lactose solution + KCl 993	1	0

Extent of burn on clover and ryegrass on day 5 of the main experiment; block 2 using visual damage scale.

Treatments	Clover burn (0 – 4)	Ryegrass burn (0 – 4)
Water only	0	0
Untreated	0	0
Effluent only 202	2	0
KCL 440	1	0
KCL 604	2	2
KCL 797	2	1
KCL 990	3	1
Lactose solution 365	1	1
Lactose solution 570	1	0
Lactose solution 768	1	2
Lactose solution 967	2	1
Lactose solution + KCl 370	1	0
Lactose solution + KCl 421	1	1
Lactose solution + KCl 876	2	1
Lactose solution + KCl 993	2	1

Extent of burn on clover and ryegrass on day 7 of the main experiment; block 2 using visual damage scale.

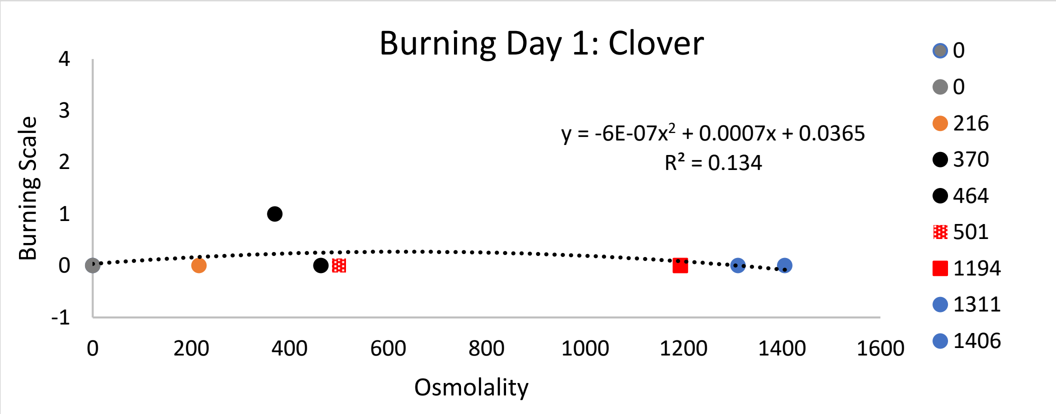
Treatments	Clover burn (0 – 4)	Ryegrass burn (0 – 4)
Water only	0	1
Untreated	0	0
Effluent	0	0
KCL 440	2	2
KCL 604	2	0
KCL 797	0	0
KCL 990	2	2
Lactose solution 365	1	1
Lactose solution 570	0	1
Lactose solution 768	1	0
Lactose solution 967	1	0
Lactose solution + KCl 370	0	0
Lactose solution + KCl 421	0	1
Lactose solution + KCl 876	2	2
Lactose solution + KCl 993	1	2

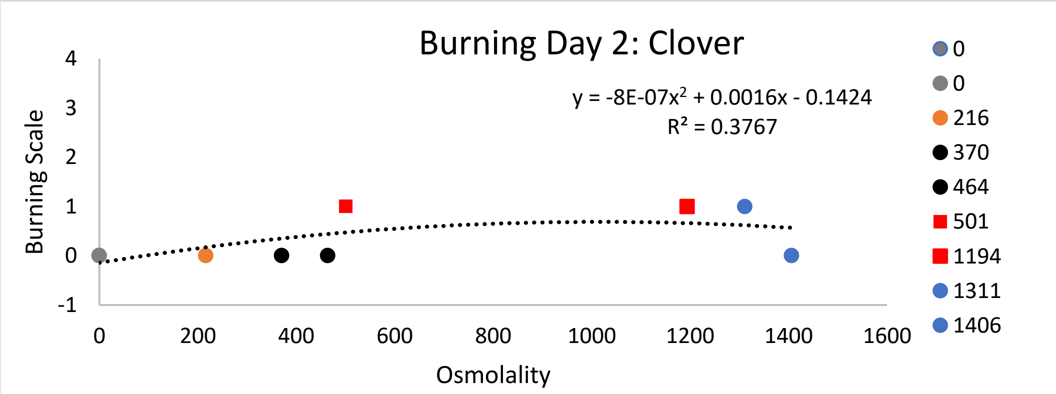
Extent of burn on clover and ryegrass on day 9 of the main experiment; block 2 using visual damage scale.

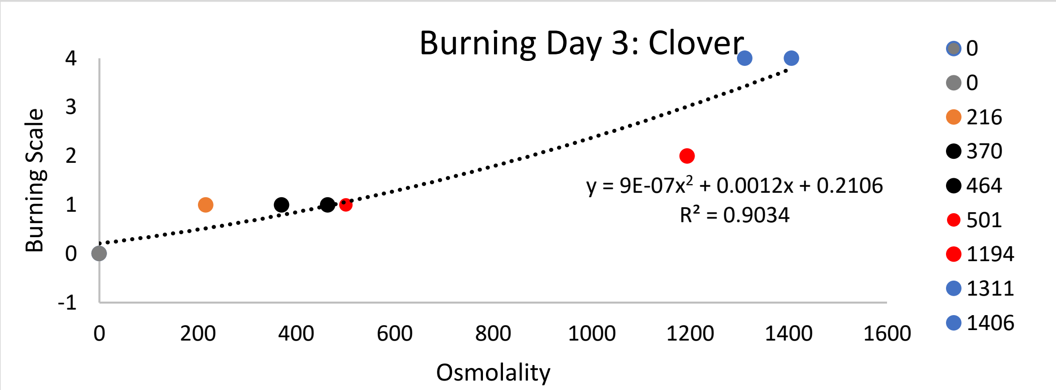
Treatments	Clover burn (0 – 4)	Ryegrass burn (0 – 4)
Water only	0	0
Untreated	0	0
Effluent	0	0
KCL 440	1	1
KCL 604	0	0
KCL 797	0	0
KCL 990	1	2
Lactose solution 365	1	0
Lactose solution 570	0	0
Lactose solution 768	1	0
Lactose solution 967	0	0
Lactose solution + KCl 370	0	0
Lactose solution + KCl 421	0	0
Lactose solution + KCl 876	0	1
Lactose solution + KCl 993	0	0

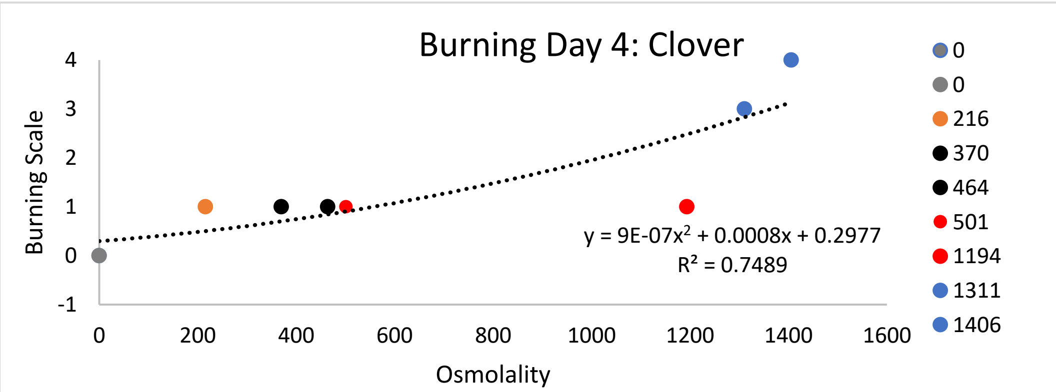
Appendix 7

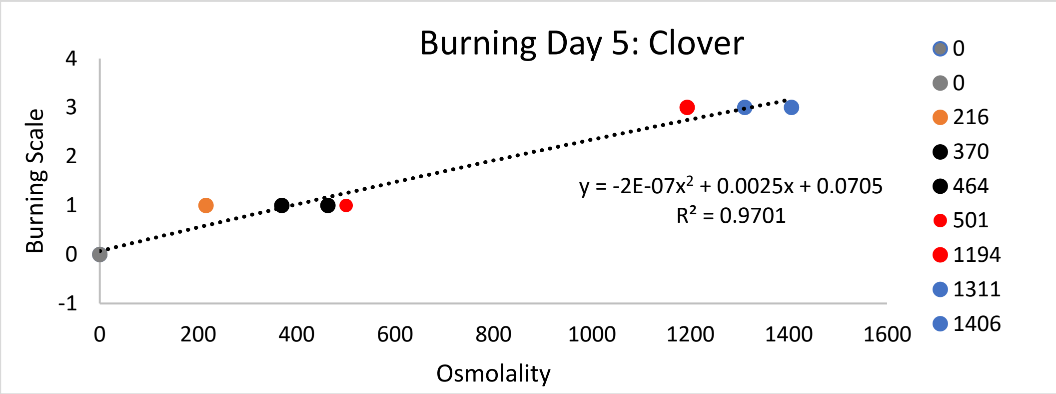
Pilot Experiment: Results

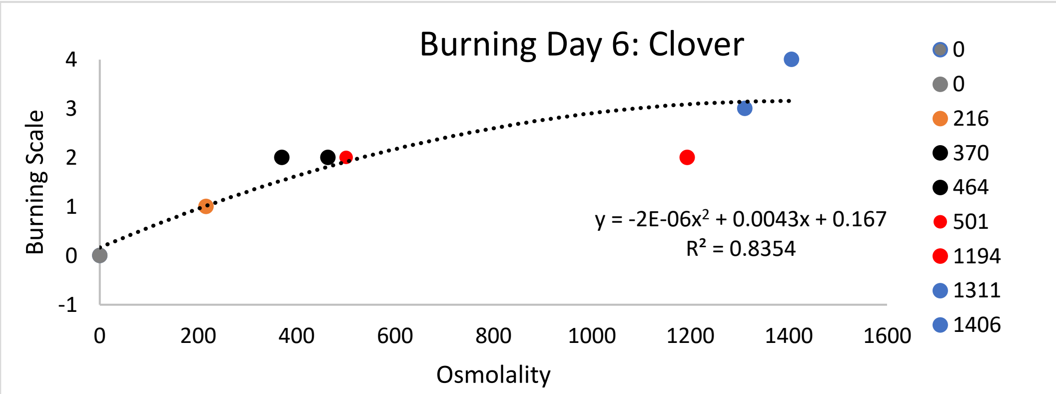


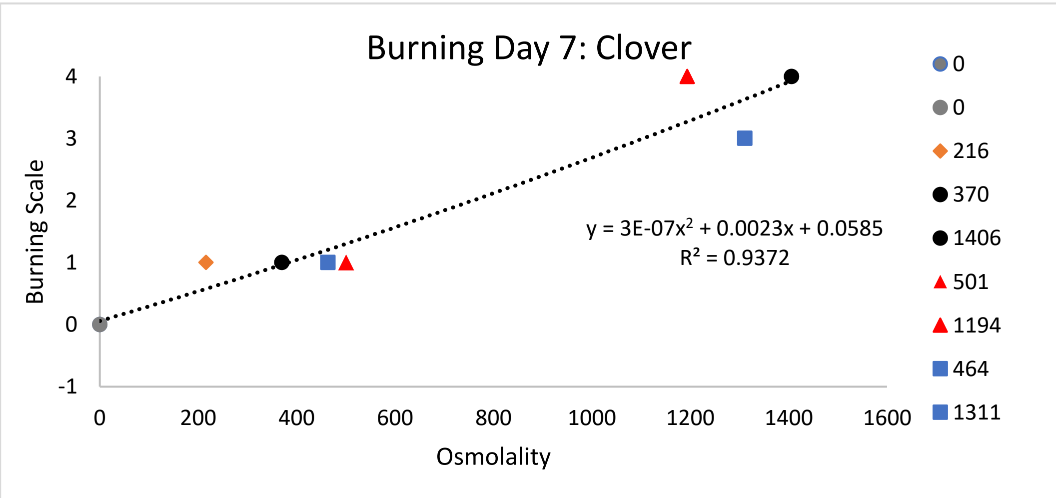


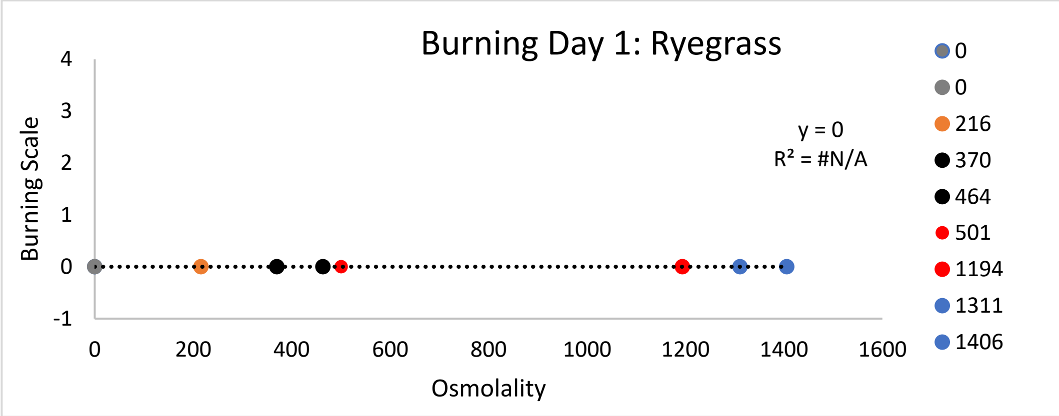


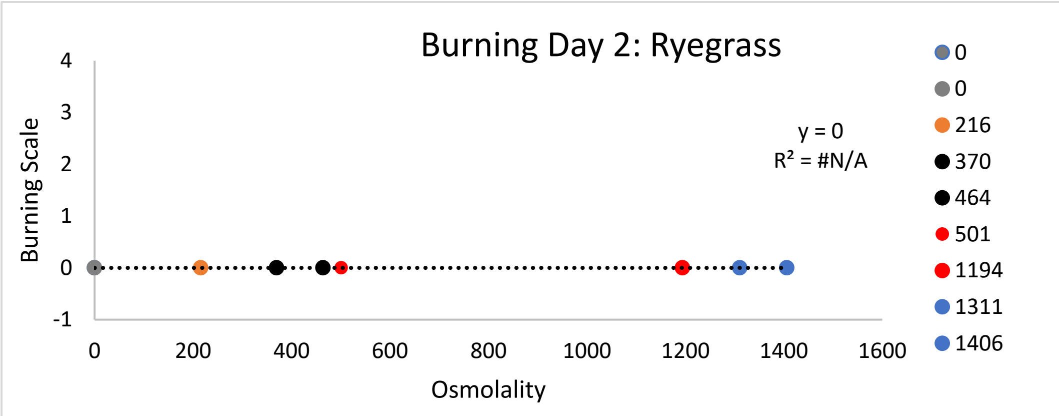


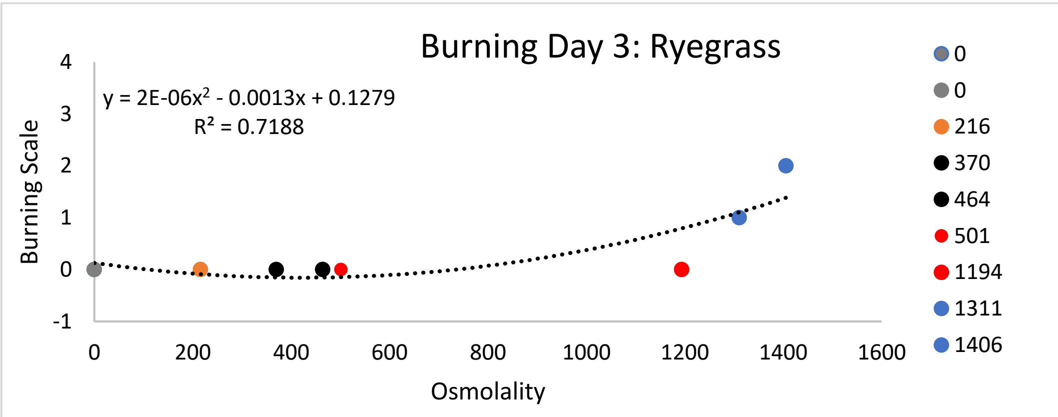

Burning Day 5: Clover
Burning Scale
Osmolality
y = -2E-07x² + 0.0025x + 0.0705
R² = 0.9701
4
3
2
1
0
-1
0
200
400
600
800
1000
1200
1400
1600
0
0
216
370
464
501
1194
1311
1406

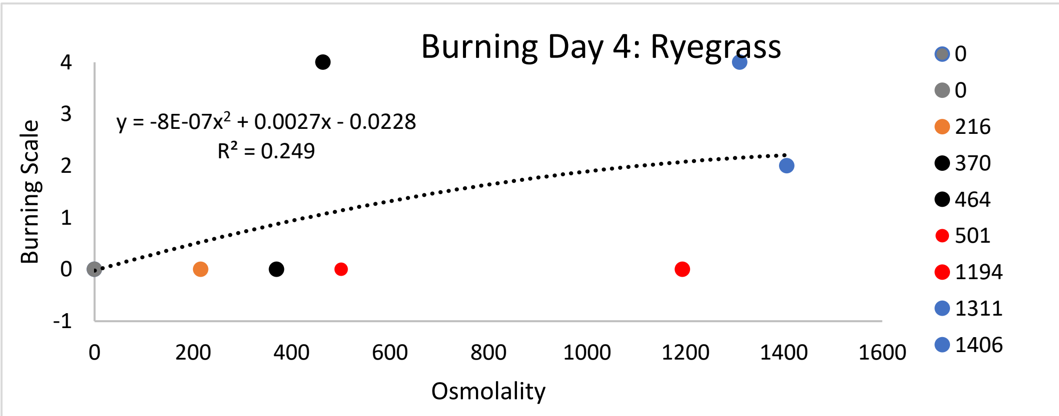

Burning Day 6: Clover
Burning Scale
Osmolality
y = -2E-06x² + 0.0043x + 0.167
R² = 0.8354
4
3
2
1
0
-1
0
200
400
600
800
1000
1200
1400
1600
0
0
216
370
464
501
1194
1311
1406

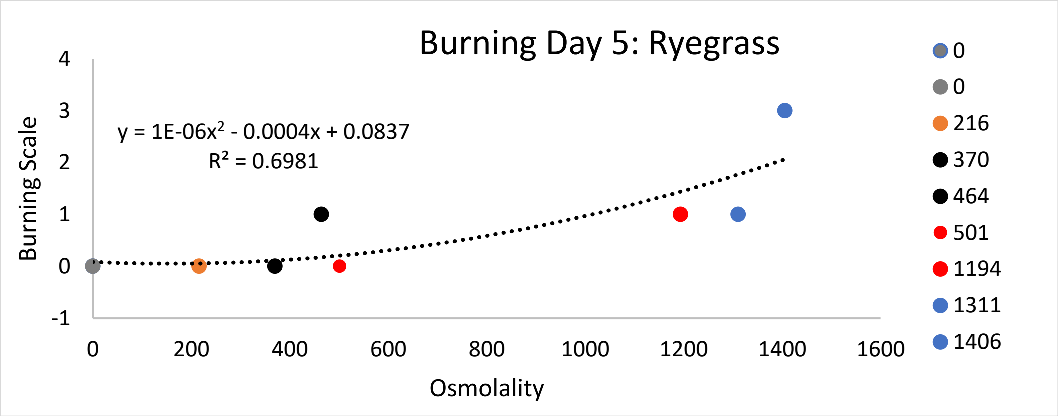

Burning Day 7: Clover
Burning Scale
Osmolality
y = 3E-07x² + 0.0023x + 0.0585
R² = 0.9372
4
3
2
1
0
-1
0
200
400
600
800
1000
1200
1400
1600
0
0
216
370
1406
501
1194
464
1311

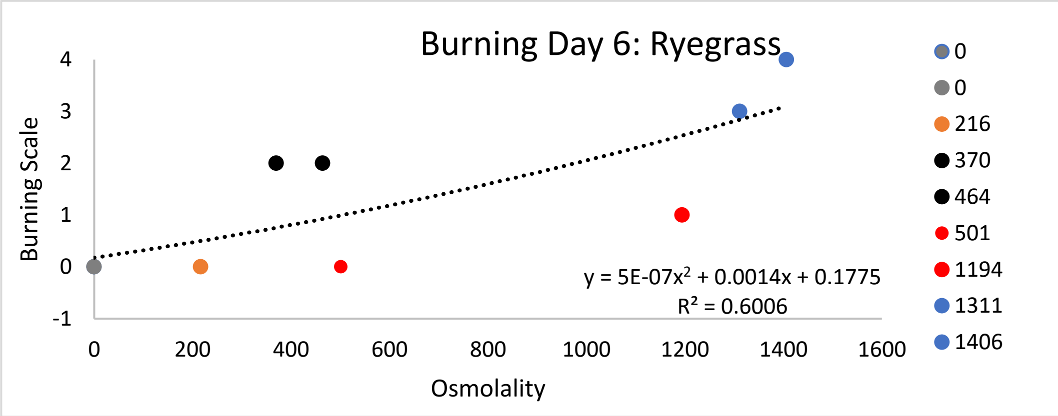

Burning Day 1: Ryegrass
y = 0
R² = #N/A
Burning Scale
Osmolality
0
0
216
370
464
501
1194
1311
1406

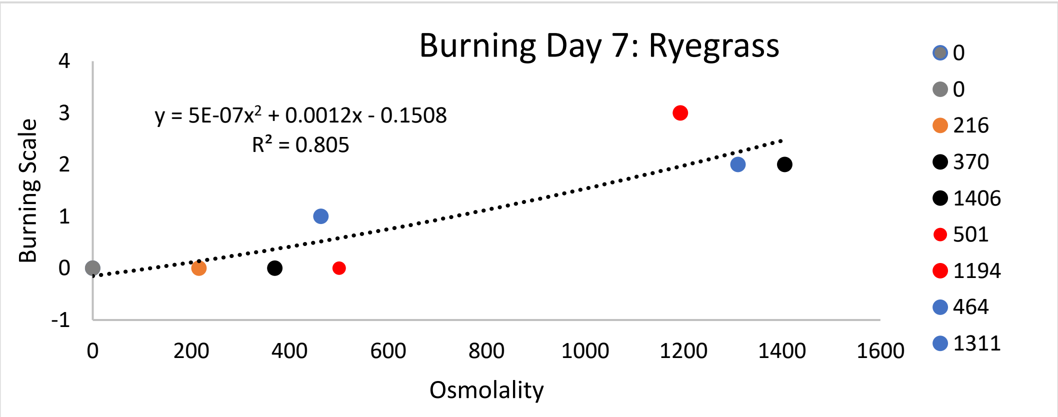

Burning Day 2: Ryegrass
y = 0
R² = #N/A
Burning Scale
Osmolality
0
0
216
370
464
501
1194
1311
1406

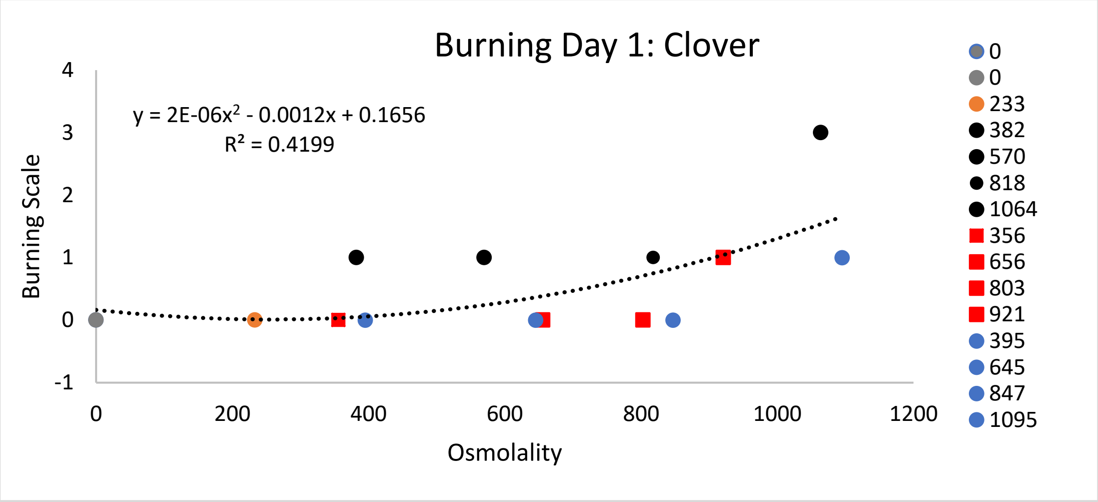

Burning Day 3: Ryegrass
y = 2E-06x² - 0.0013x + 0.1279
R² = 0.7188
Burning Scale
Osmolality
0
0
216
370
464
501
1194
1311
1406

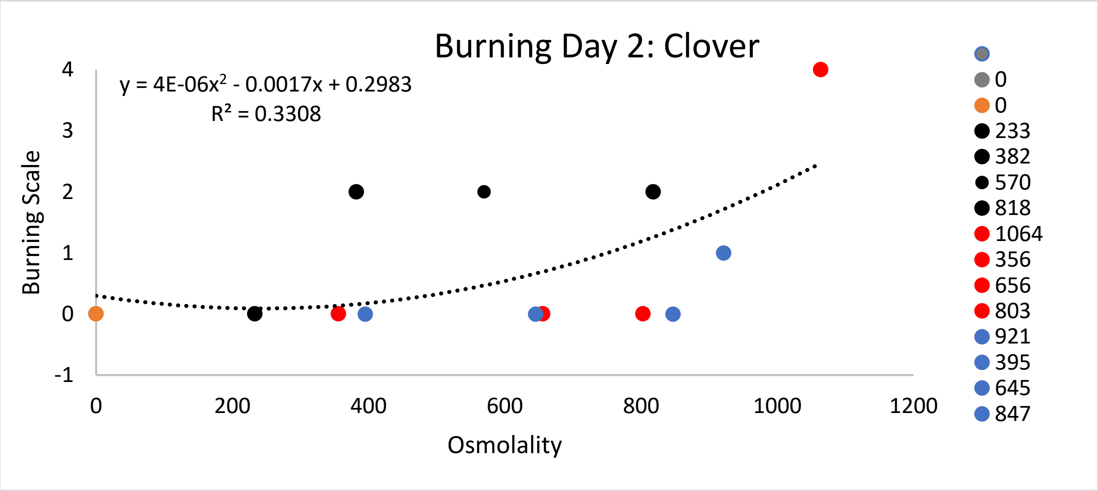

Burning Day 4: Ryegrass
y = -8E-07x² + 0.0027x - 0.0228
R² = 0.249
Burning Scale
Osmolality
0
0
216
370
464
501
1194
1311
1406

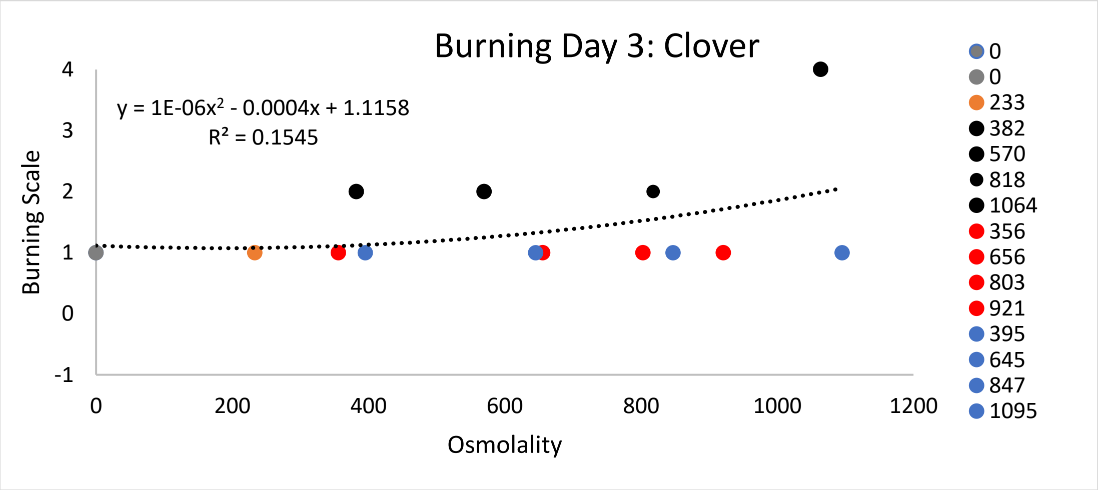

Burning Day 5: Ryegrass
y = 1E-06x² - 0.0004x + 0.0837
R² = 0.6981
Burning Scale
Osmolality
4
3
2
1
0
-1
0
200
400
600
800
1000
1200
1400
1600
0
0
216
370
464
501
1194
1311
1406

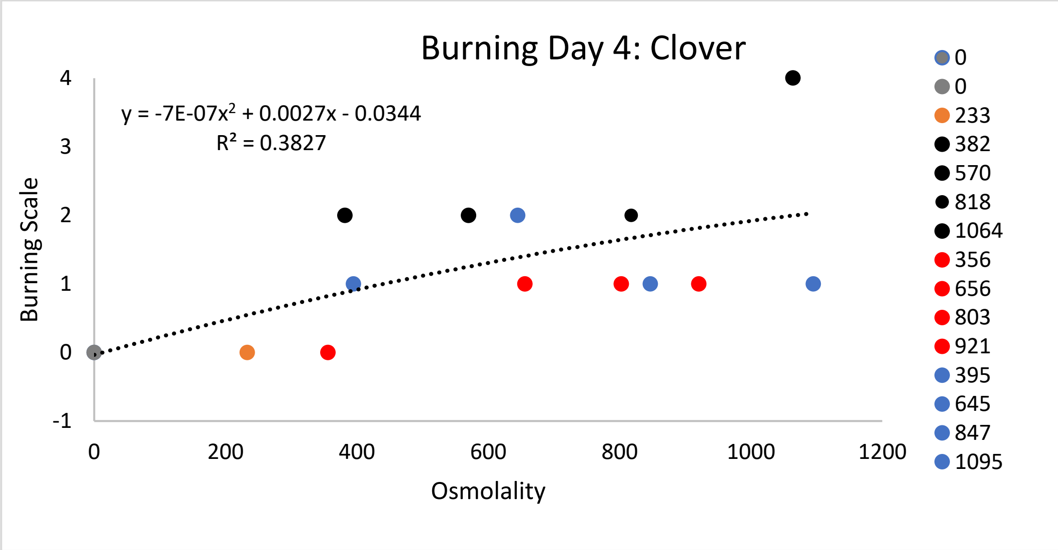

Burning Day 6: Ryegrass
y = 5E-07x² + 0.0014x + 0.1775
R² = 0.6006
Burning Scale
Osmolality
4
3
2
1
0
-1
0
200
400
600
800
1000
1200
1400
1600
0
0
216
370
464
501
1194
1311
1406

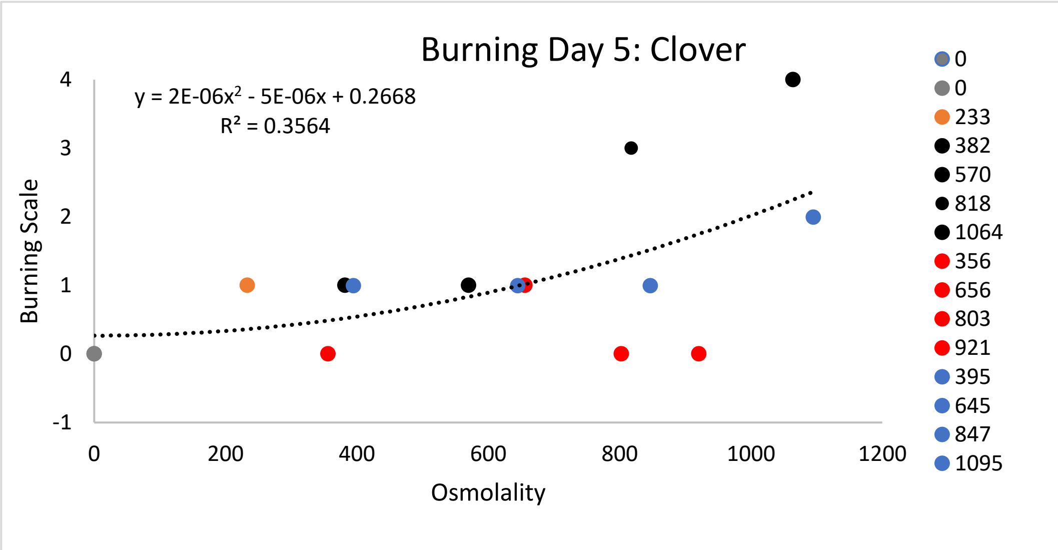

Burning Day 7: Ryegrass
y = 5E-07x² + 0.0012x - 0.1508
R² = 0.805
Burning Scale
Osmolality
4
3
2
1
0
-1
0
200
400
600
800
1000
1200
1400
1600
0
0
216
370
1406
501
1194
464
1311

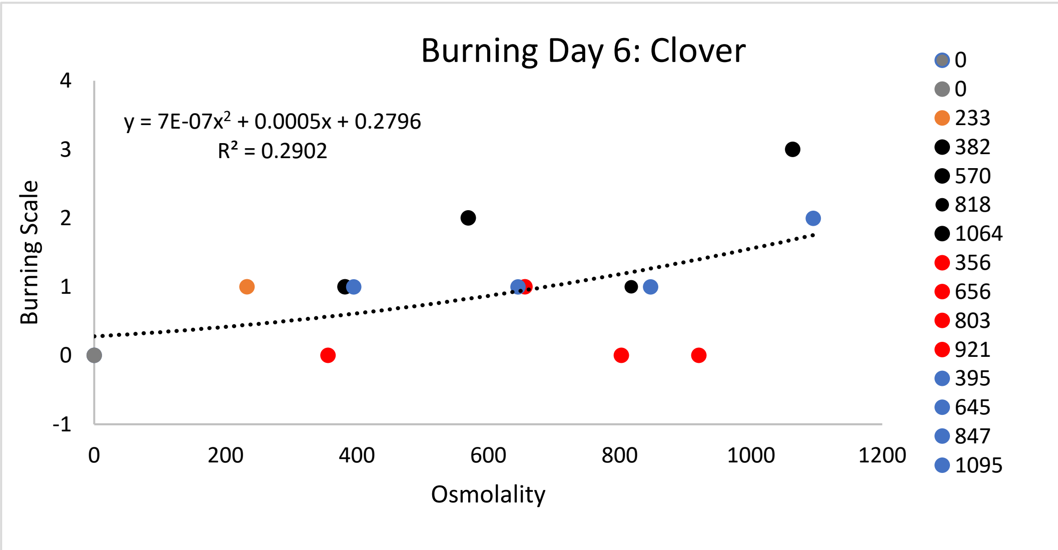

Burning Day 1: Clover
y = 2E-06x² - 0.0012x + 0.1656
R² = 0.4199
Burning Scale
Osmolality
0
0
233
382
570
818
1064
356
656
803
921
395
645
847
1095

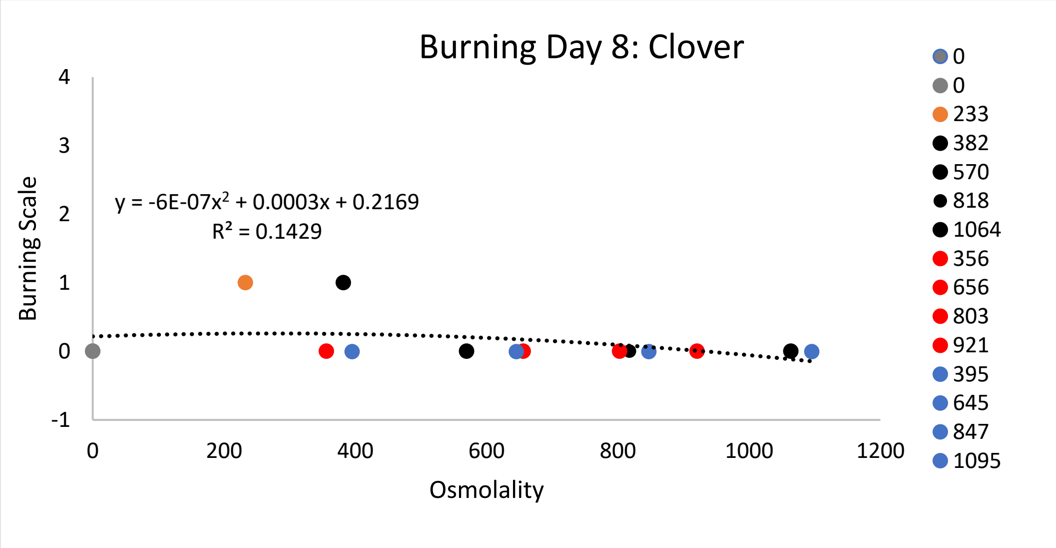

Burning Day 2: Clover
y = 4E-06x² - 0.0017x + 0.2983
R² = 0.3308
Burning Scale
Osmolality
0
0
233
382
570
818
1064
356
656
803
921
395
645
847

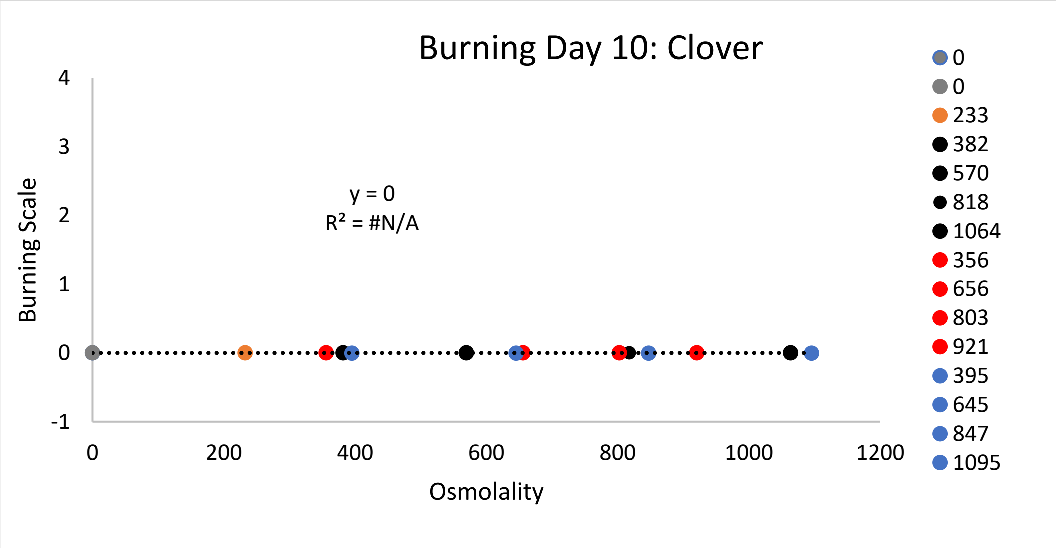

Burning Day 3: Clover
y = 1E-06x² - 0.0004x + 1.1158
R² = 0.1545
Burning Scale
Osmolality
0
0
233
382
570
818
1064
356
656
803
921
395
645
847
1095

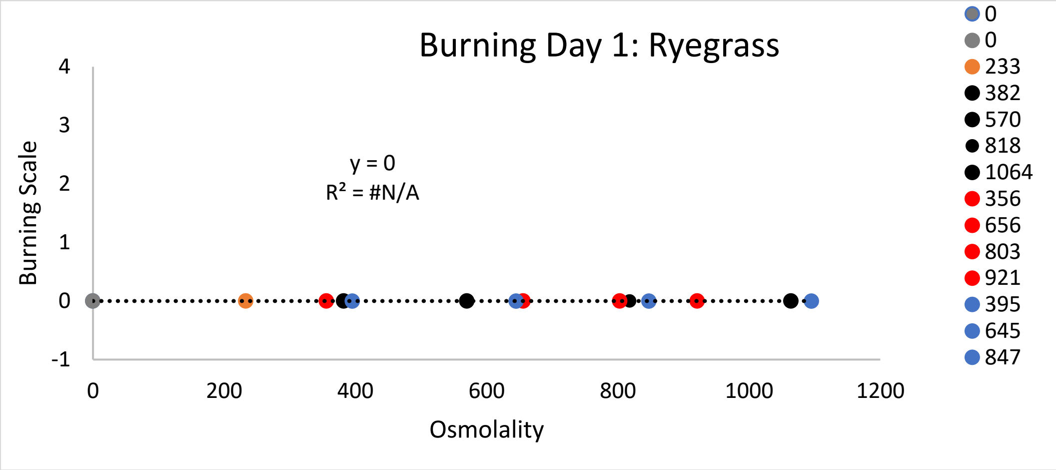

Burning Day 4: Clover
y = -7E-07x² + 0.0027x - 0.0344
R² = 0.3827
Burning Scale
Osmolality
4
3
2
1
0
-1
0
200
400
600
800
1000
1200
0
0
233
382
570
818
1064
356
656
803
921
395
645
847
1095

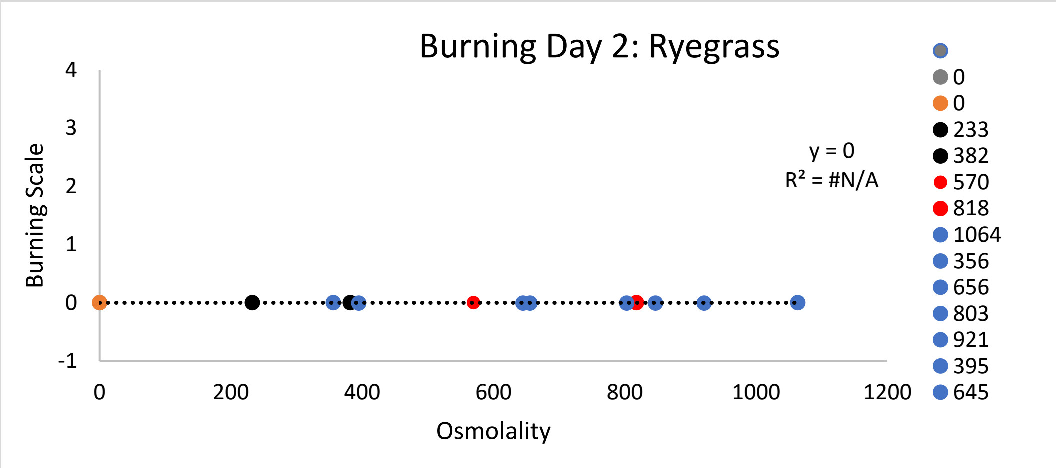

Burning Day 5: Clover
y = 2E-06x² - 5E-06x + 0.2668
R² = 0.3564
Burning Scale
Osmolality
4
3
2
1
0
-1
0
200
400
600
800
1000
1200
0
0
233
382
570
818
1064
356
656
803
921
395
645
847
1095

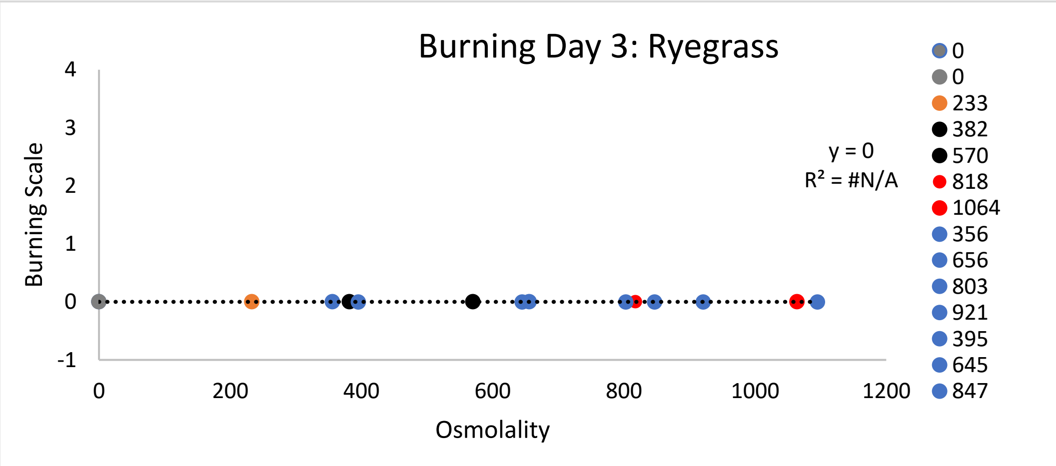

Burning Day 6: Clover
y = 7E-07x² + 0.0005x + 0.2796
R² = 0.2902
Burning Scale
Osmolality
4
3
2
1
0
-1
0
200
400
600
800
1000
1200
0
0
233
382
570
818
1064
356
656
803
921
395
645
847
1095

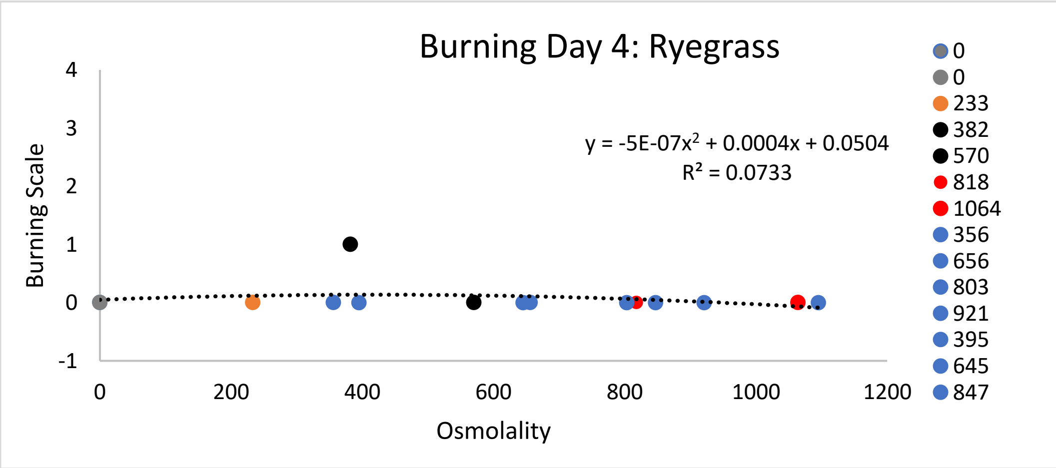

Burning Day 8: Clover
Burning Scale
4
3
2
1
0
-1
y = -6E-07x² + 0.0003x + 0.2169
R² = 0.1429
0
200
400
600
800
1000
1200
Osmolality
0
0
233
382
570
818
1064
356
656
803
921
395
645
847
1095

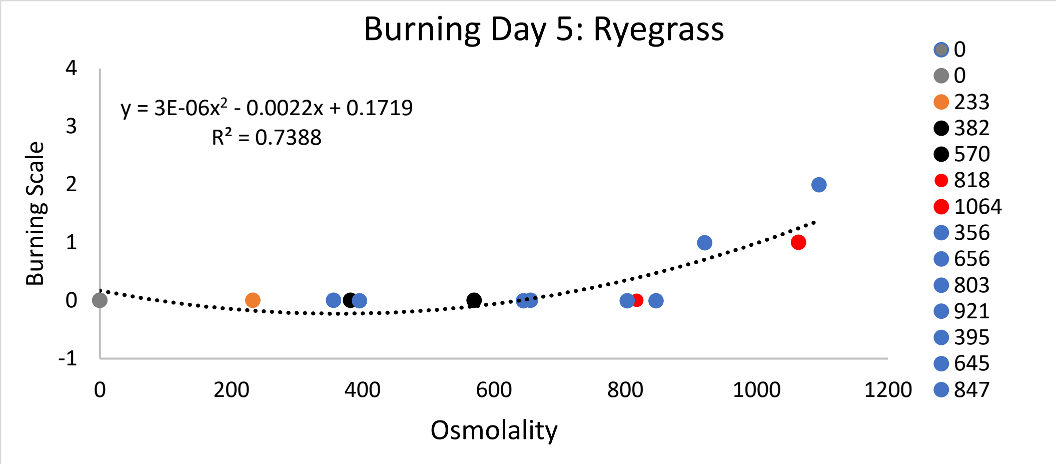

Burning Day 10: Clover
Burning Scale
4
3
2
1
0
-1
y = 0
R² = #N/A
0
200
400
600
800
1000
1200
Osmolality
0
0
233
382
570
818
1064
356
656
803
921
395
645
847
1095

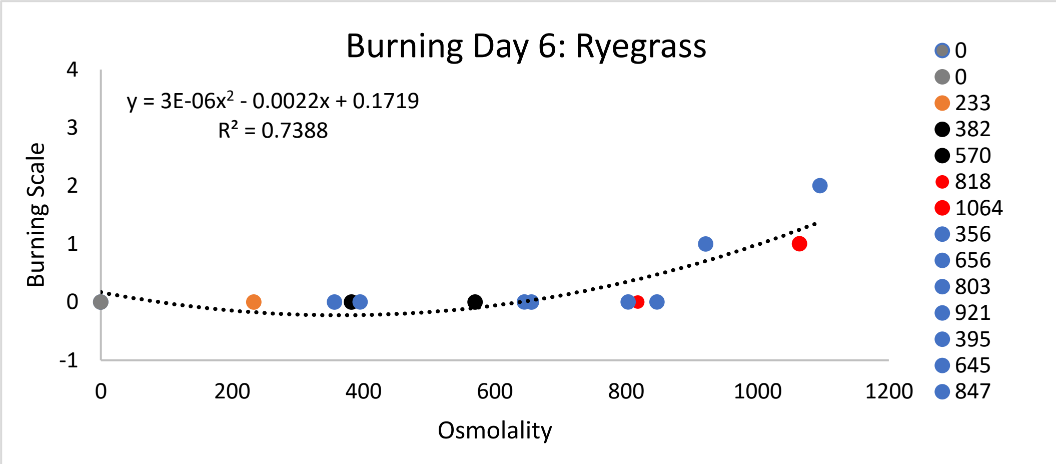

Burning Day 1: Ryegrass
y = 0
R² = #N/A
Burning Scale
Osmolality
4
3
2
1
0
-1
0
200
400
600
800
1000
1200
0
0
233
382
570
818
1064
356
656
803
921
395
645
847

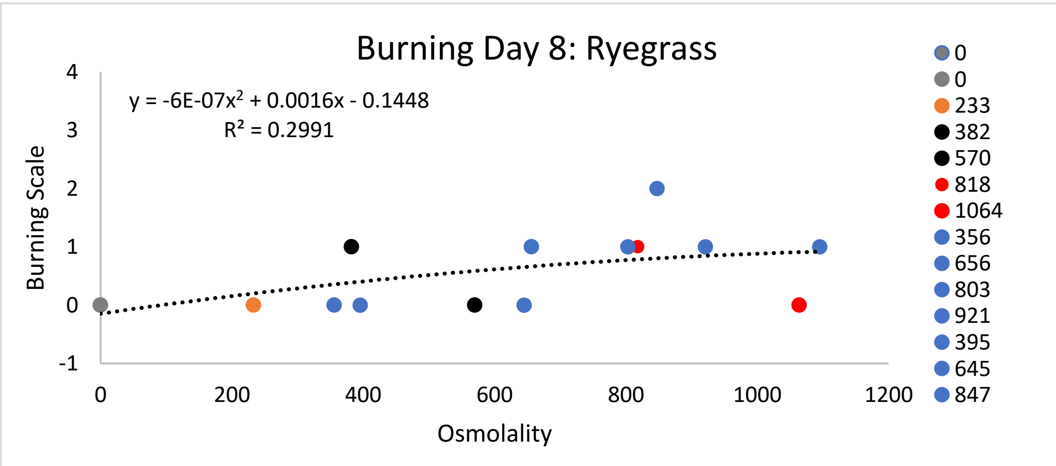

Burning Day 2: Ryegrass
y = 0
R² = #N/A
Burning Scale
Osmolality
4
3
2
1
0
-1
0
200
400
600
800
1000
1200
0
0
233
382
570
818
1064
356
656
803
921
395
645

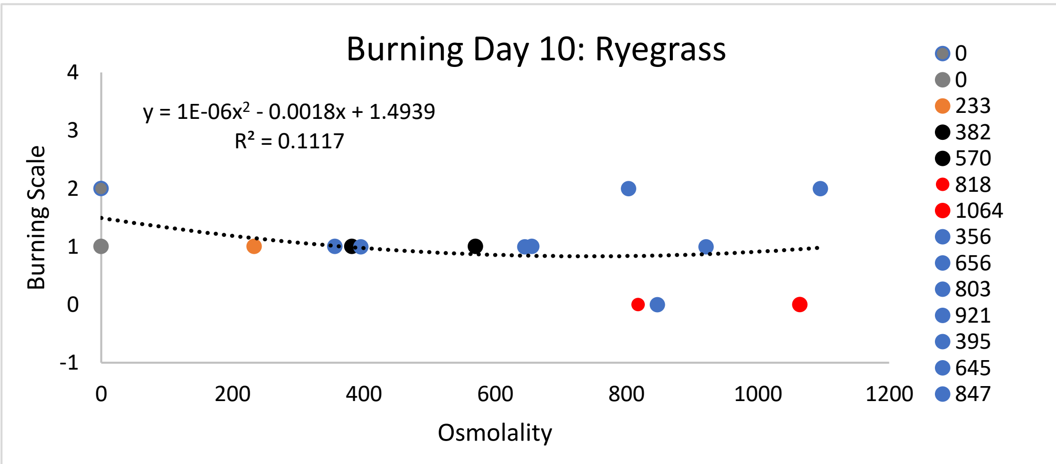

Burning Day 3: Ryegrass
y = 0
R² = #N/A
Burning Scale
Osmolality
4
3
2
1
0
-1
0
200
400
600
800
1000
1200
0
0
233
382
570
818
1064
356
656
803
921
395
645
847


Burning Day 4: Ryegrass
y = -5E-07x² + 0.0004x + 0.0504
R² = 0.0733
Burning Scale
Osmolality
4
3
2
1
0
-1
0
200
400
600
800
1000
1200
0
0
233
382
570
818
1064
356
656
803
921
395
645
847

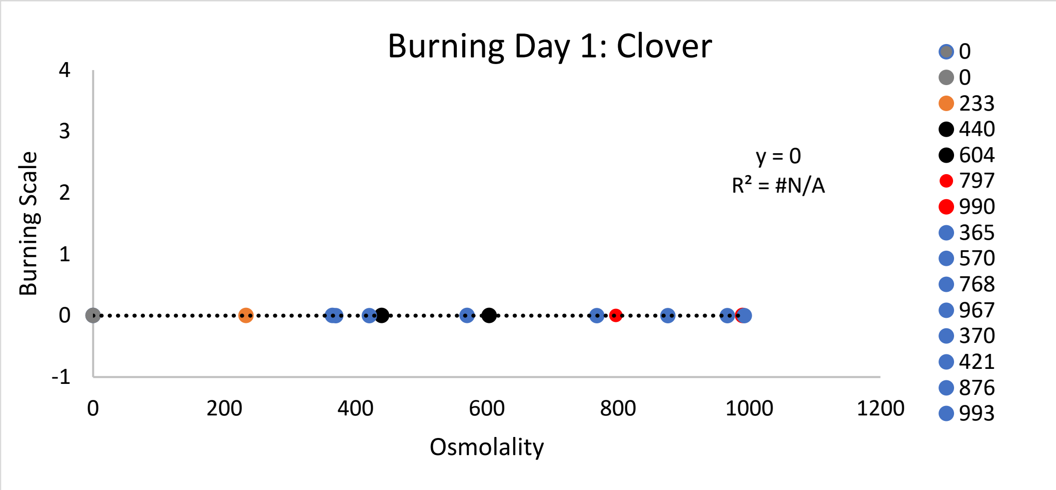

Burning Day 5: Ryegrass
y = 3E-06x² - 0.0022x + 0.1719
R² = 0.7388
Burning Scale
Osmolality
4
3
2
1
0
-1
0
200
400
600
800
1000
1200
0
0
233
382
570
818
1064
356
656
803
921
395
645
847

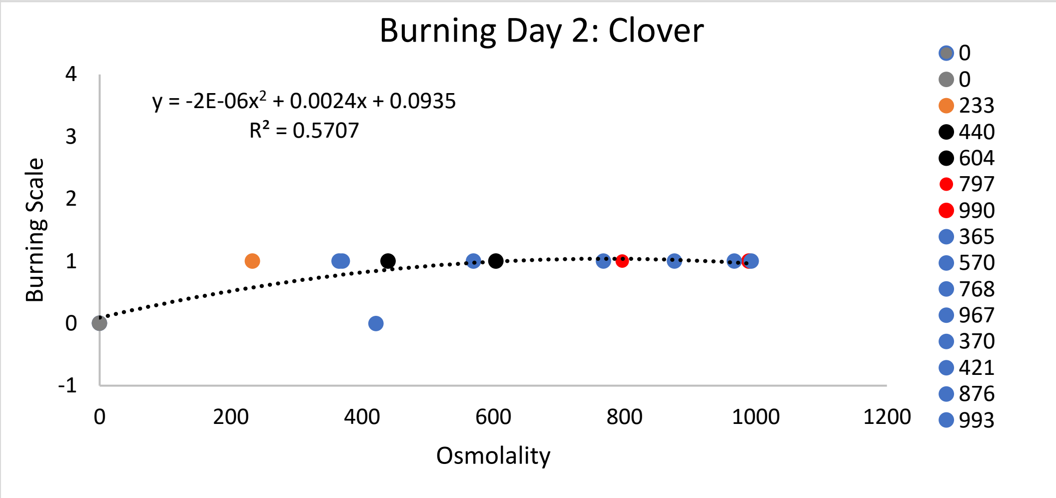

Burning Day 6: Ryegrass
y = 3E-06x² - 0.0022x + 0.1719
R² = 0.7388
Burning Scale
Osmolality
4
3
2
1
0
-1
0
200
400
600
800
1000
1200
0
0
233
382
570
818
1064
356
656
803
921
395
645
847

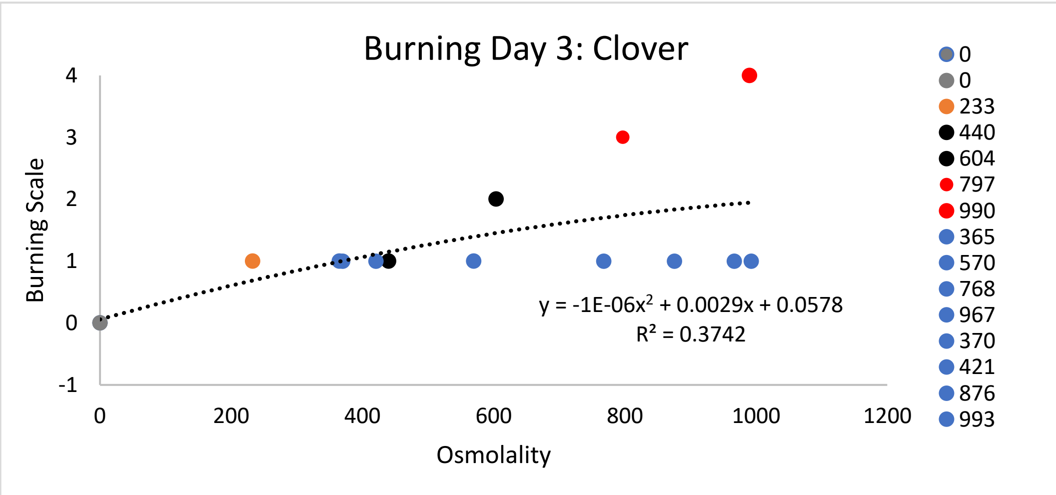

Burning Day 8: Ryegrass
y = -6E-07x² + 0.0016x - 0.1448
R² = 0.2991
Burning Scale
Osmolality
4
3
2
1
0
-1
0
200
400
600
800
1000
1200
0
0
233
382
570
818
1064
356
656
803
921
395
645
847

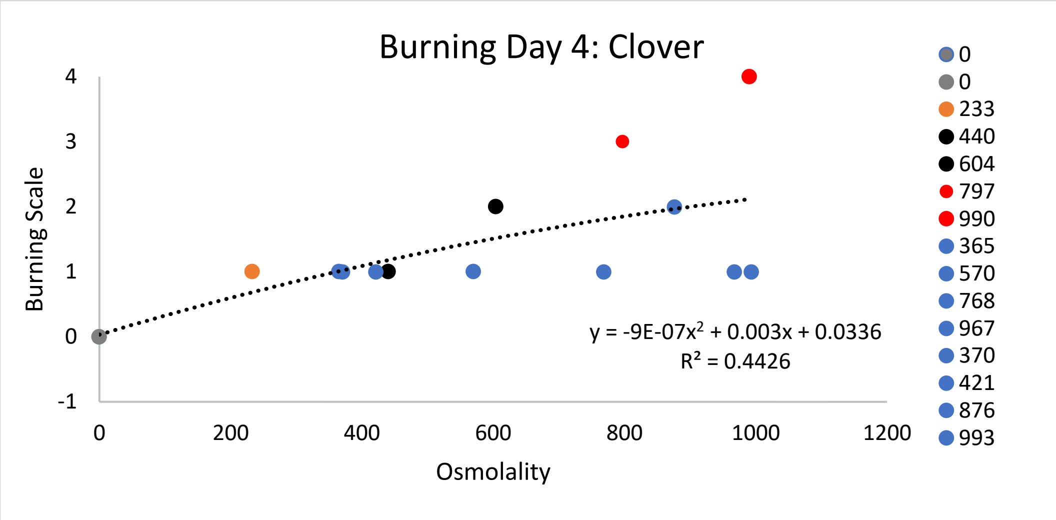

Burning Day 10: Ryegrass
y = 1E-06x² - 0.0018x + 1.4939
R² = 0.1117
Burning Scale
Osmolality
4
3
2
1
0
-1
0
200
400
600
800
1000
1200
0
0
233
382
570
818
1064
356
656
803
921
395
645
847

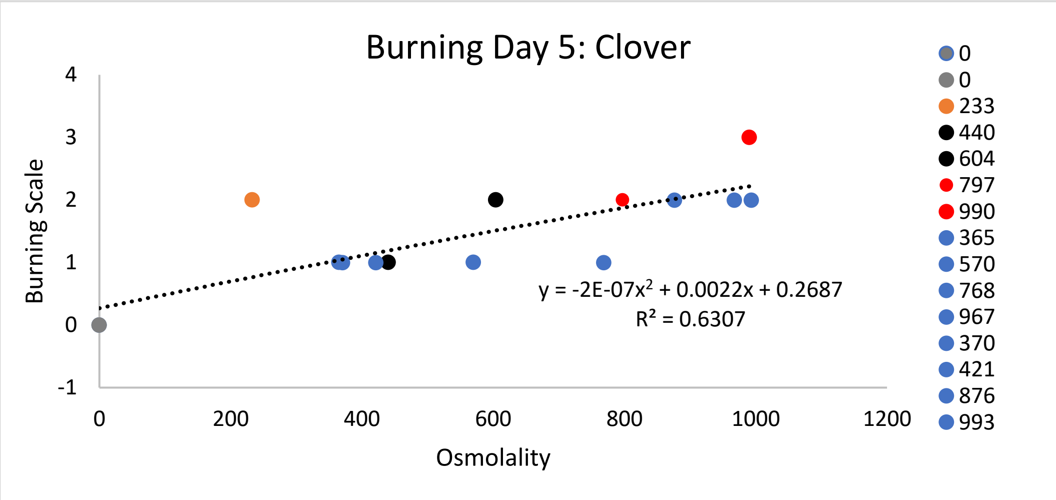
Main experiment 2: Results

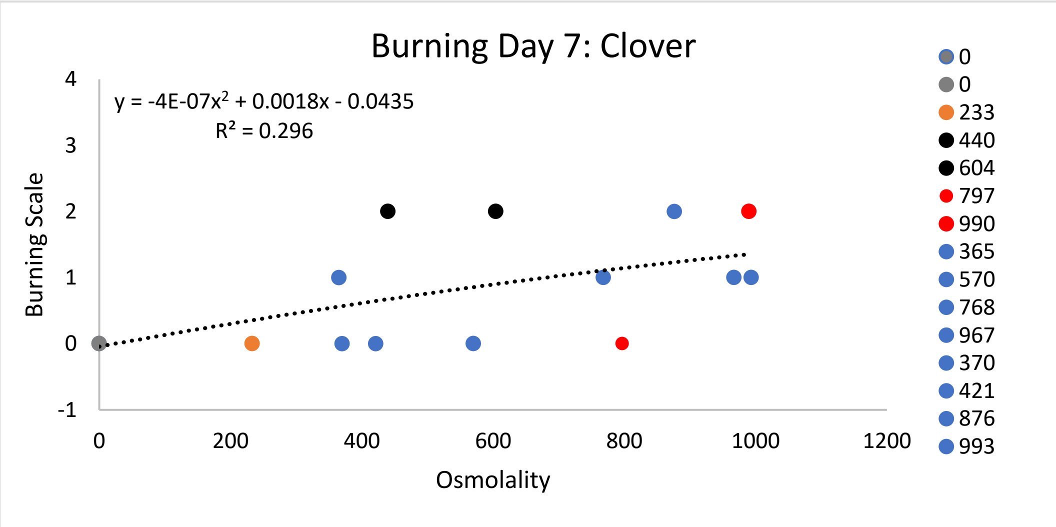


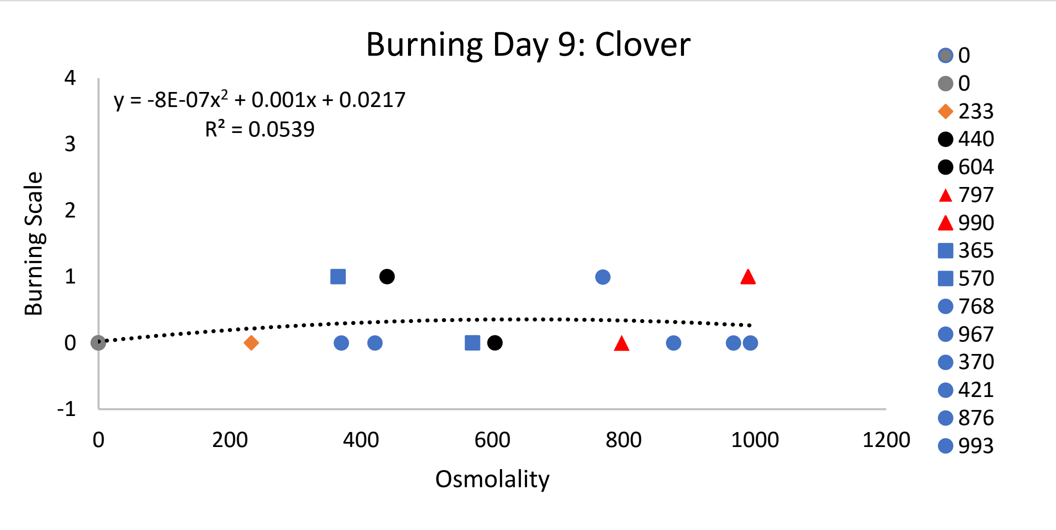


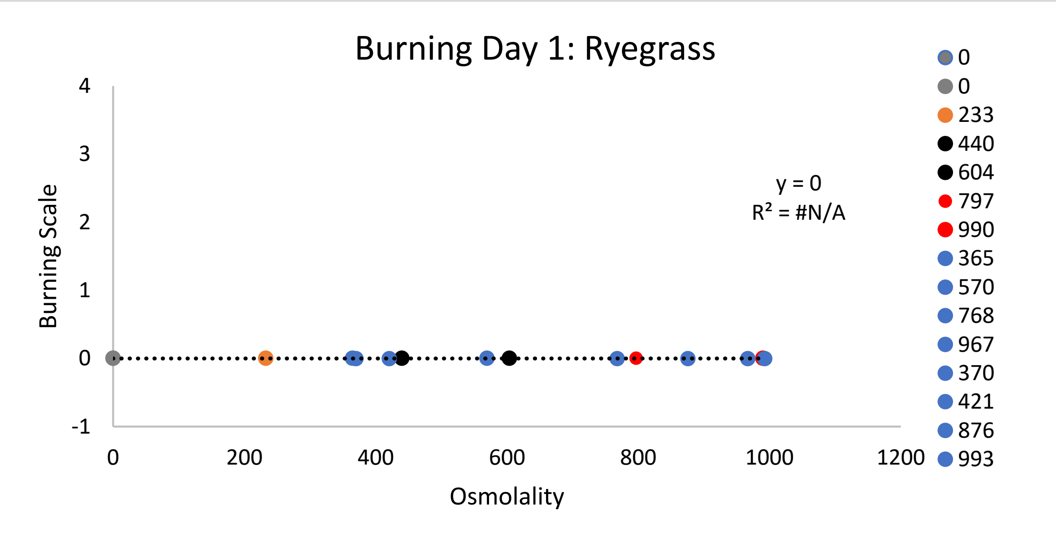


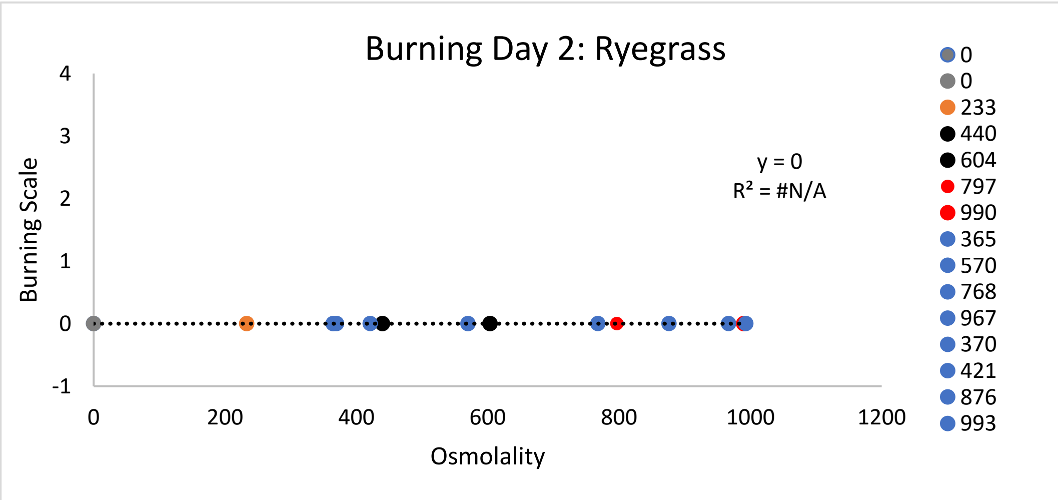

Burning Day 4: Clover
Burning Scale
Osmolality
y = -9E-07x² + 0.003x + 0.0336
R² = 0.4426
4
3
2
1
0
-1
0
200
400
600
800
1000
1200
0
0
233
440
604
797
990
365
570
768
967
370
421
876
993

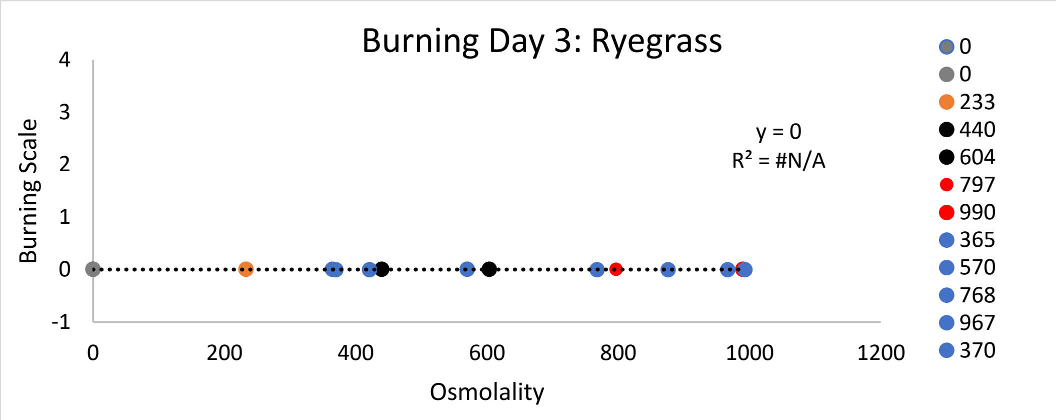

Burning Day 5: Clover
Burning Scale
Osmolality
y = -2E-07x² + 0.0022x + 0.2687
R² = 0.6307
4
3
2
1
0
-1
0
200
400
600
800
1000
1200
0
0
233
440
604
797
990
365
570
768
967
370
421
876
993

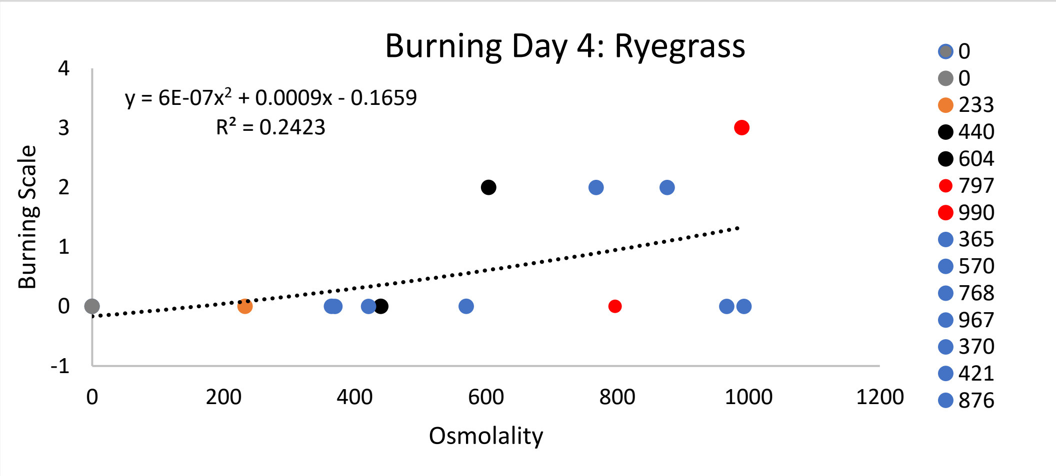

Burning Day 7: Clover
Burning Scale
Osmolality
y = -4E-07x² + 0.0018x - 0.0435
R² = 0.296
4
3
2
1
0
-1
0
200
400
600
800
1000
1200
0
0
233
440
604
797
990
365
570
768
967
370
421
876
993

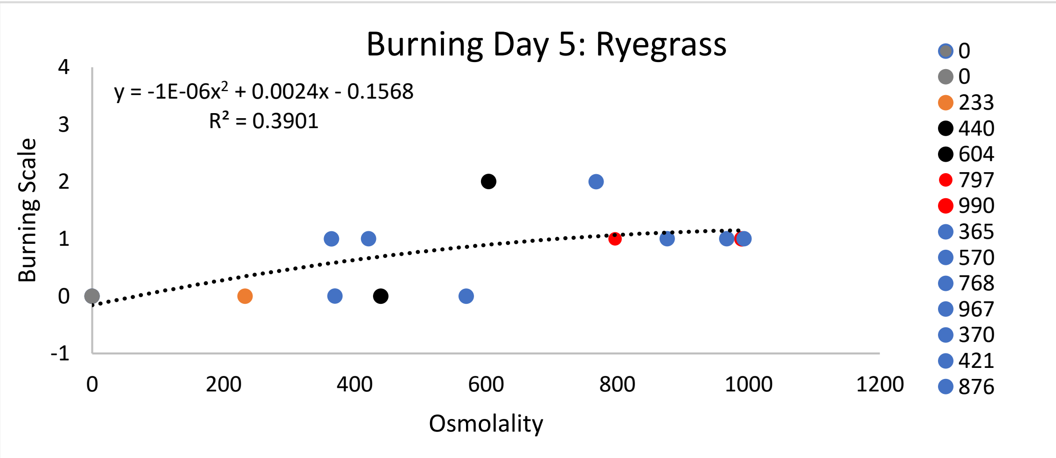

Burning Day 9: Clover
y = -8E-07x² + 0.001x + 0.0217
R² = 0.0539
Burning Scale
Osmolality
0
0
233
440
604
797
990
365
570
768
967
370
421
876
993

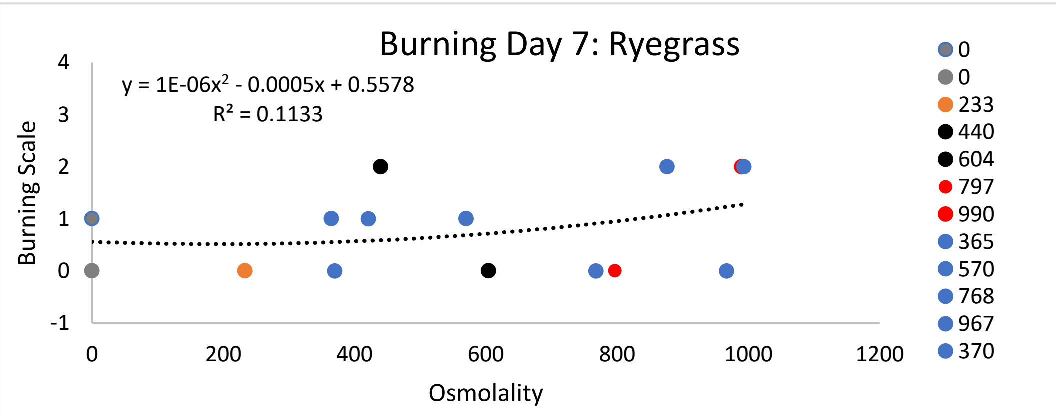

Burning Day 1: Ryegrass
y = 0
R² = #N/A
Burning Scale
Osmolality
0
0
233
440
604
797
990
365
570
768
967
370
421
876
993

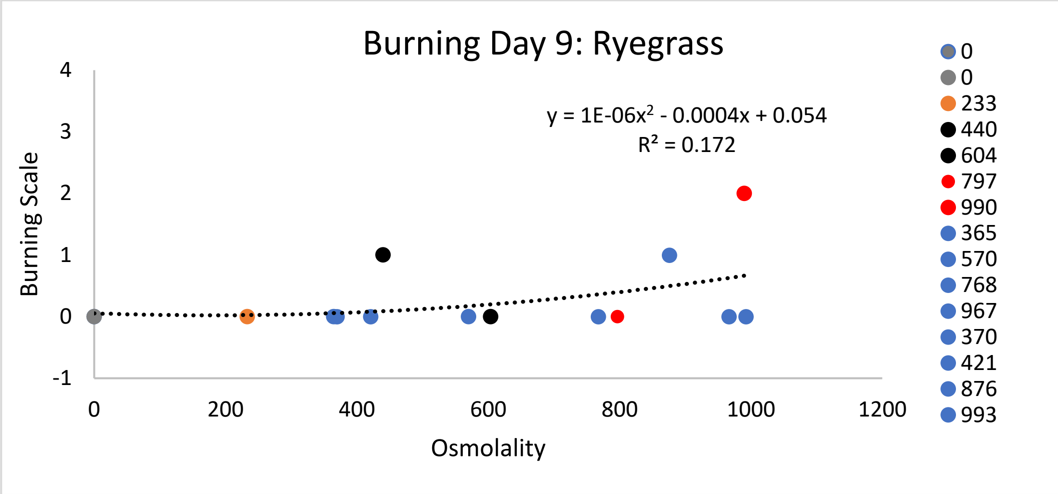

Burning Day 2: Ryegrass
y = 0
R² = #N/A
Burning Scale
Osmolality
0
0
233
440
604
797
990
365
570
768
967
370
421
876
993


Burning Day 3: Ryegrass
y = 0
R² = #N/A
Burning Scale
Osmolality
0
0
233
440
604
797
990
365
570
768
967
370


Burning Day 4: Ryegrass
y = 6E-07x² + 0.0009x - 0.1659
R² = 0.2423
Burning Scale
Osmolality
0
0
233
440
604
797
990
365
570
768
967
370
421
876

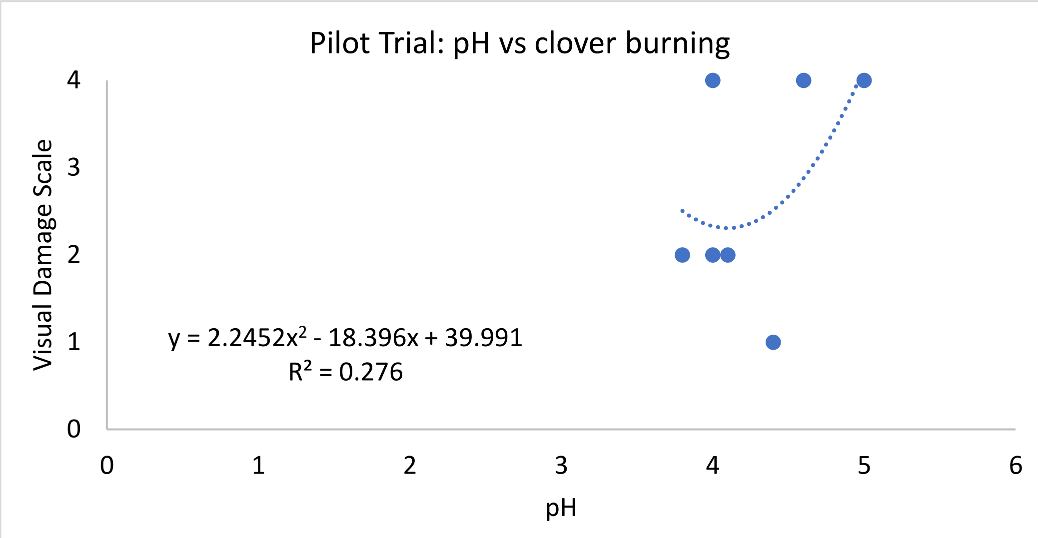

Burning Day 5: Ryegrass
y = -1E-06x² + 0.0024x - 0.1568
R² = 0.3901
Burning Scale
Osmolality
0
0
233
440
604
797
990
365
570
768
967
370
421
876

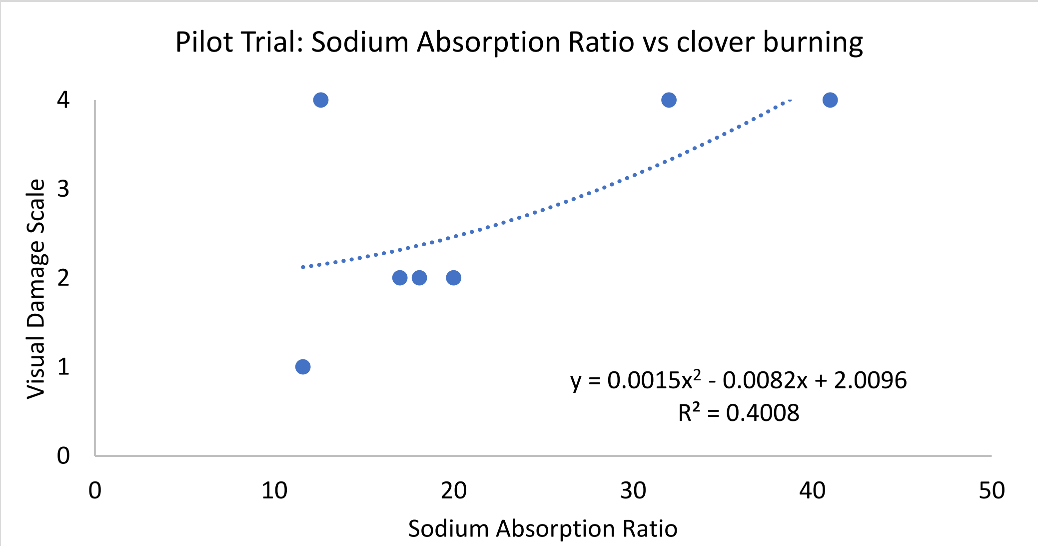

Burning Day 7: Ryegrass
y = 1E-06x² - 0.0005x + 0.5578
R² = 0.1133
Burning Scale
Osmolality
0
0
233
440
604
797
990
365
570
768
967
370

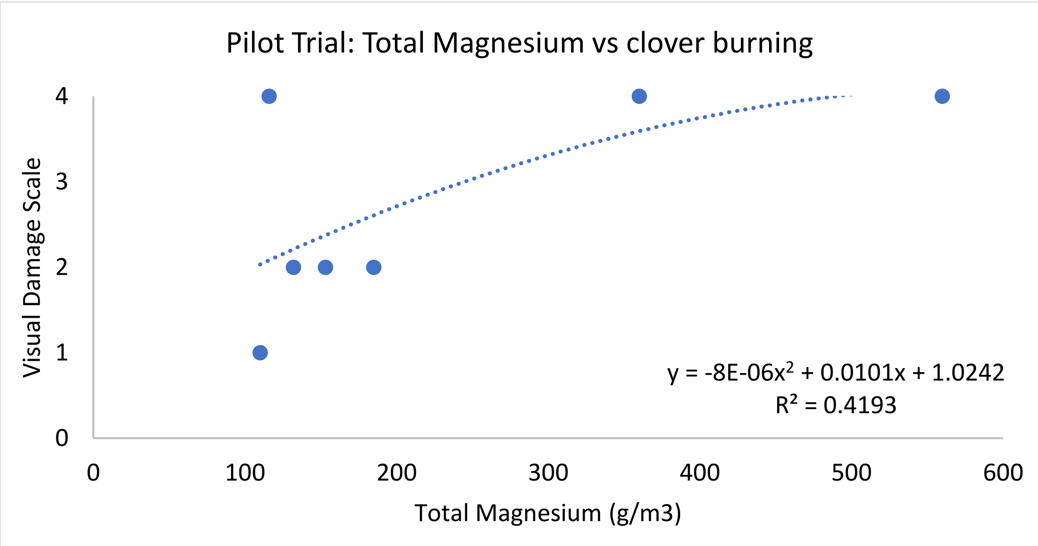

Burning Day 9: Ryegrass
y = 1E-06x² - 0.0004x + 0.054
R² = 0.172
Burning Scale
Osmolality
4
3
2
1
0
-1
0
200
400
600
800
1000
1200
0
0
233
440
604
797
990
365
570
768
967
370
421
876
993

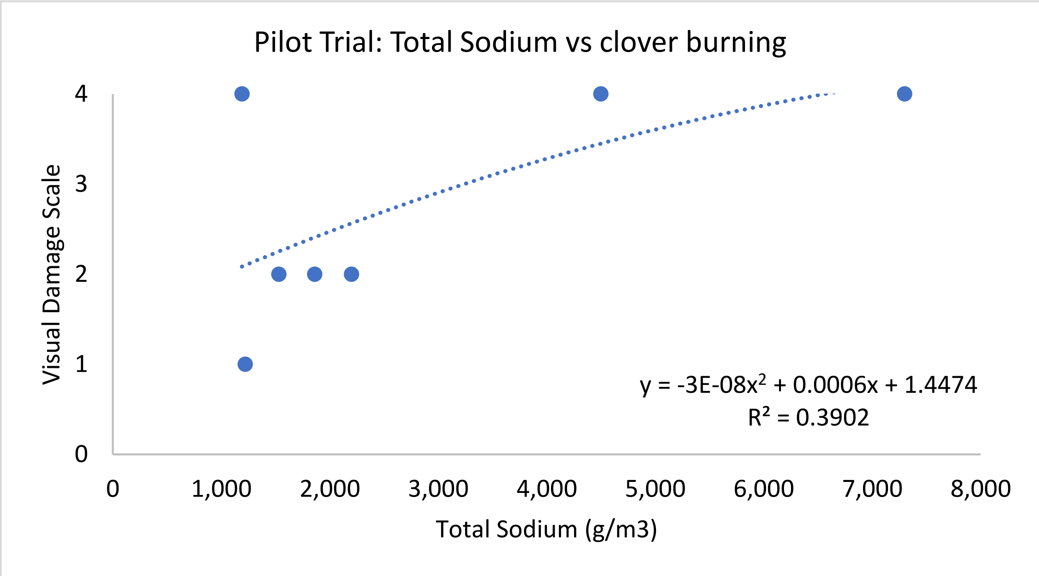
Appendix 8

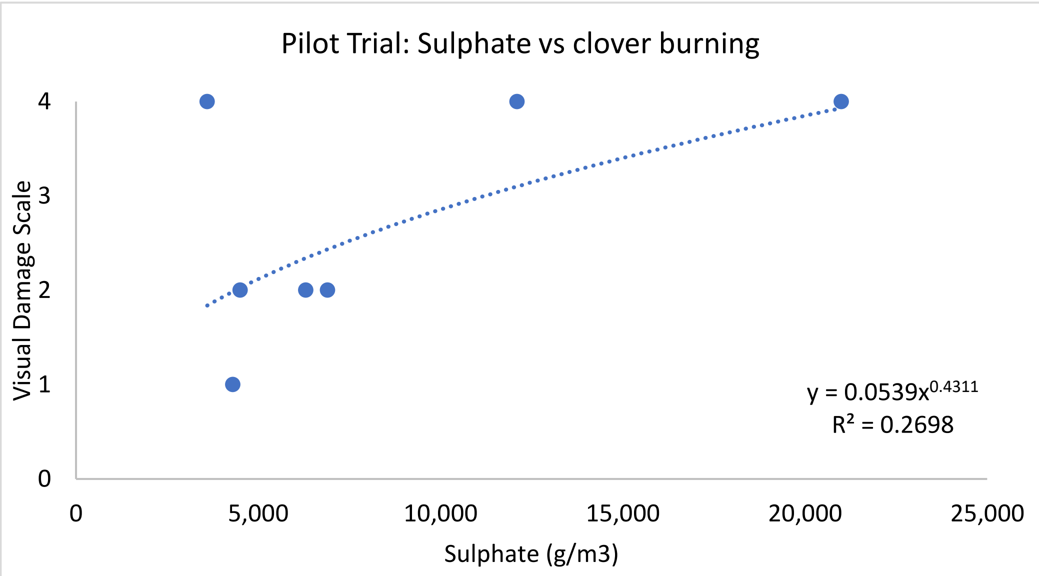
Pilot Trial: Results

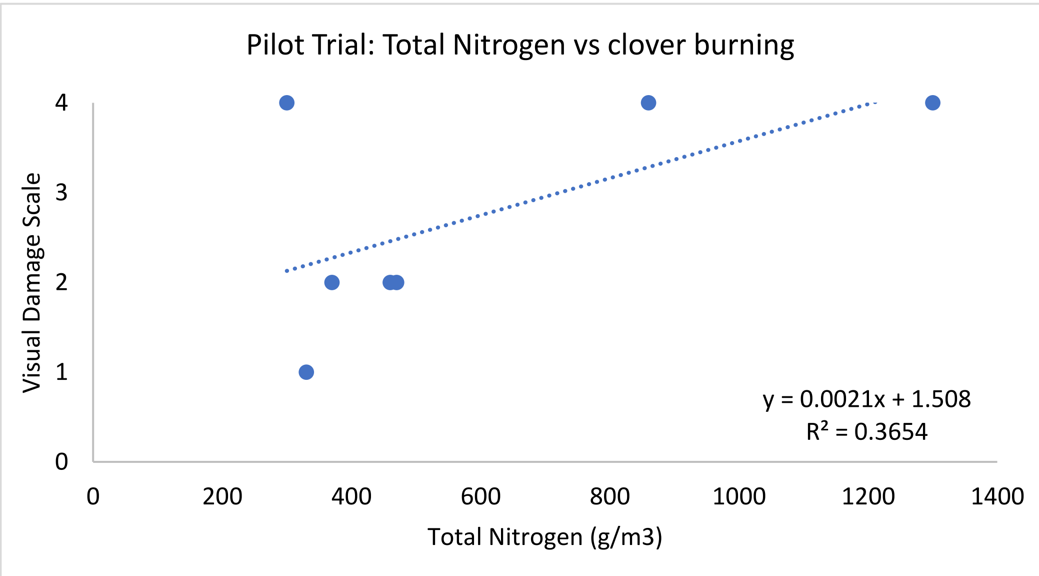


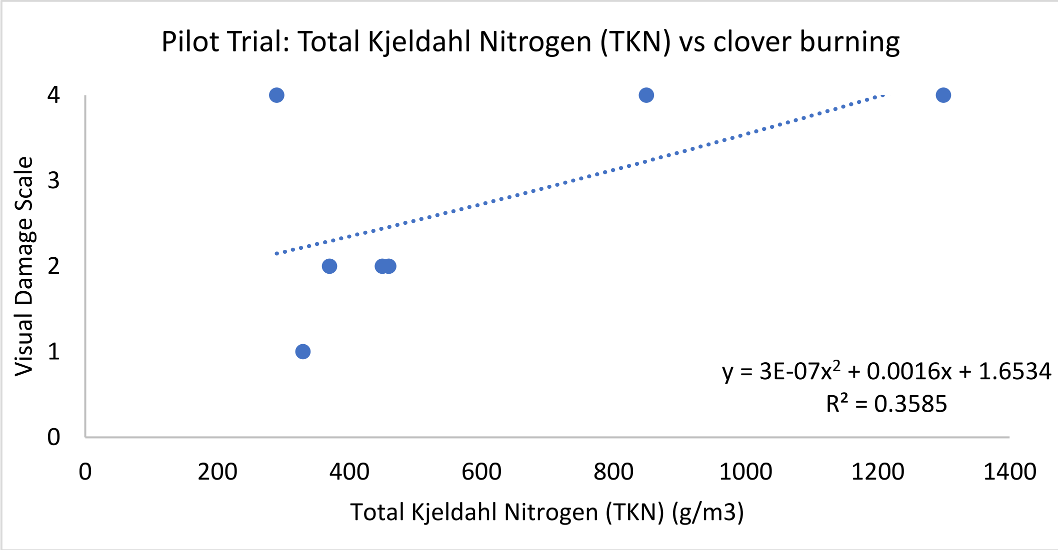


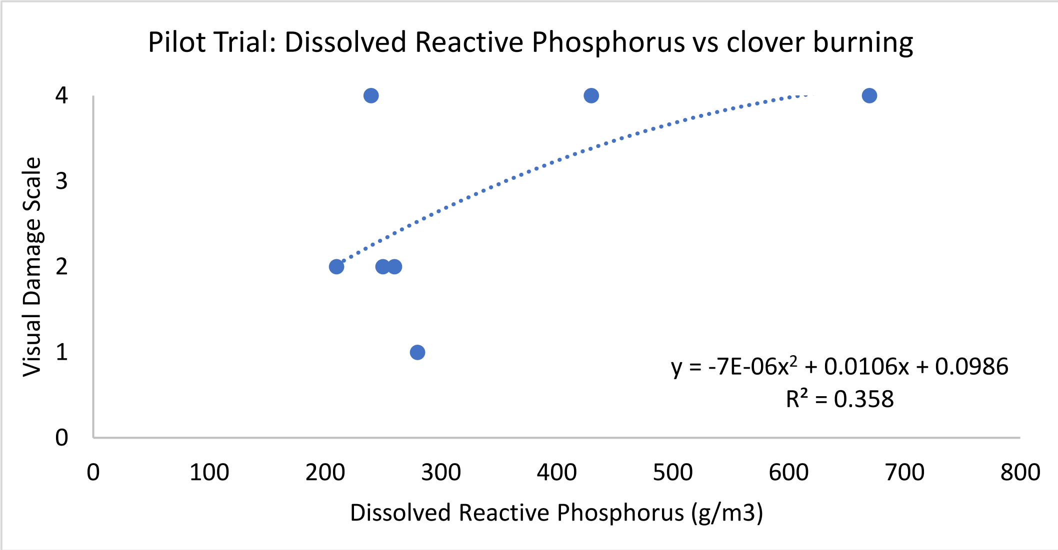


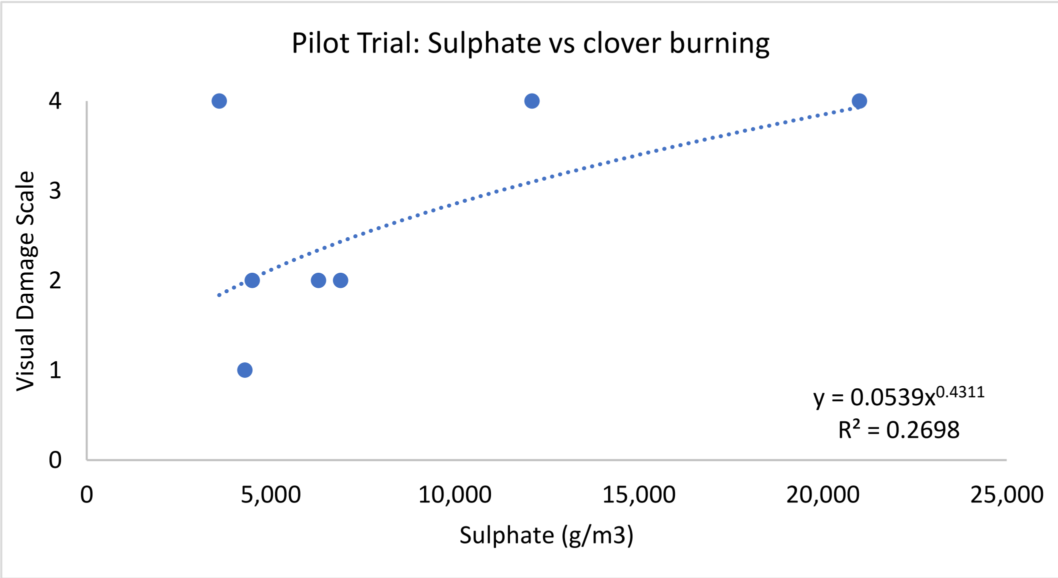

Pilot Trial: Total Sodium vs clover burning
Visual Damage Scale
4
3
2
1
0
0
1,000
2,000
3,000
4,000
5,000
6,000
7,000
8,000
Total Sodium (g/m3)
y = -3E-08x² + 0.0006x + 1.4474
R² = 0.3902

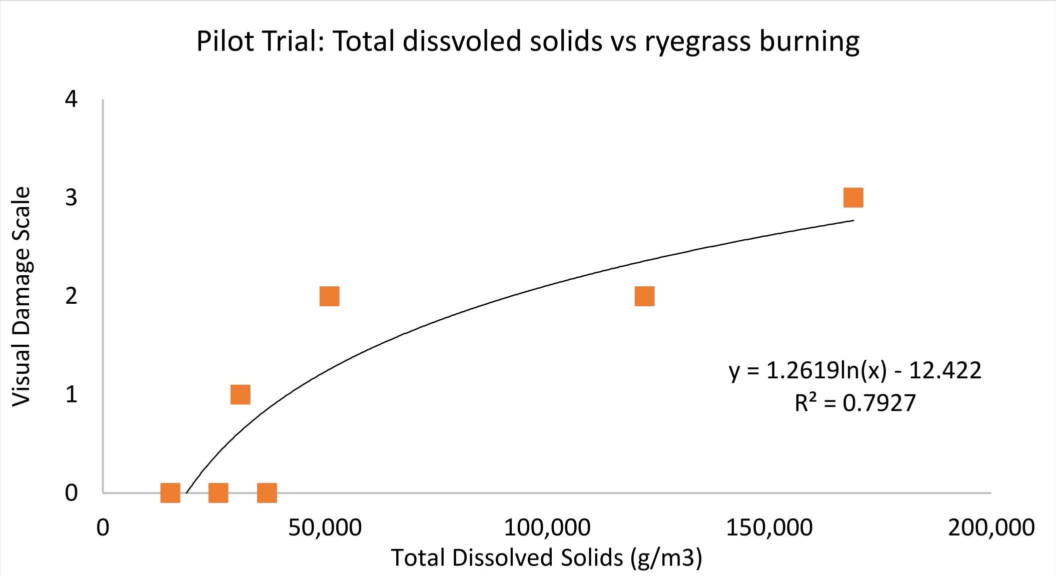

Pilot Trial: Sulphate vs clover burning
Visual Damage Scale
4
3
2
1
0
0
5,000
10,000
15,000
20,000
25,000
Sulphate (g/m3)
y = 0.0539x^0.4311
R² = 0.2698

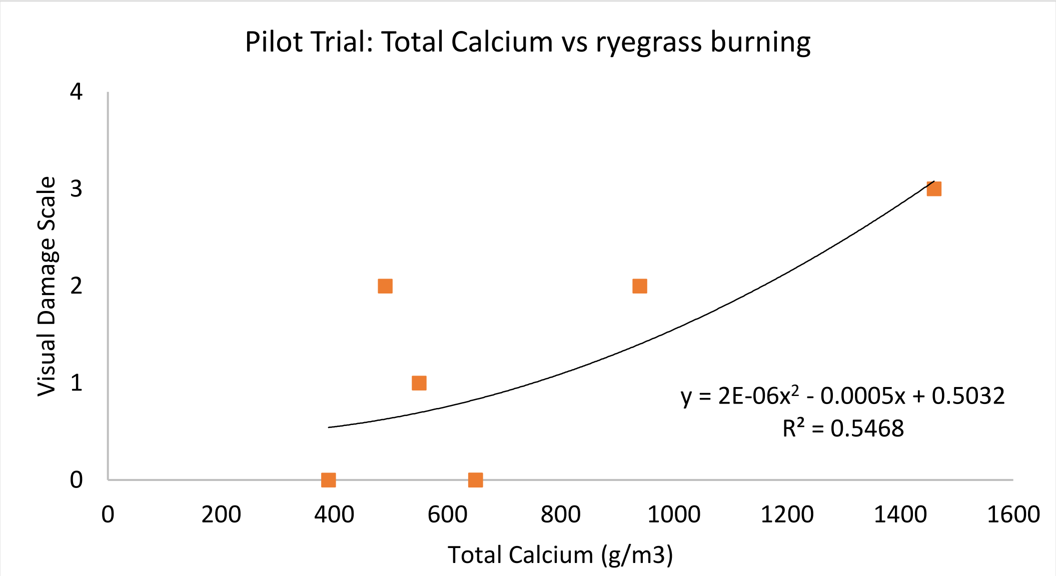

Pilot Trial: Total Nitrogen vs clover burning
Visual Damage Scale
4
3
2
1
0
0
200
400
600
800
1000
1200
1400
Total Nitrogen (g/m3)
y = 0.0021x + 1.508
R² = 0.3654

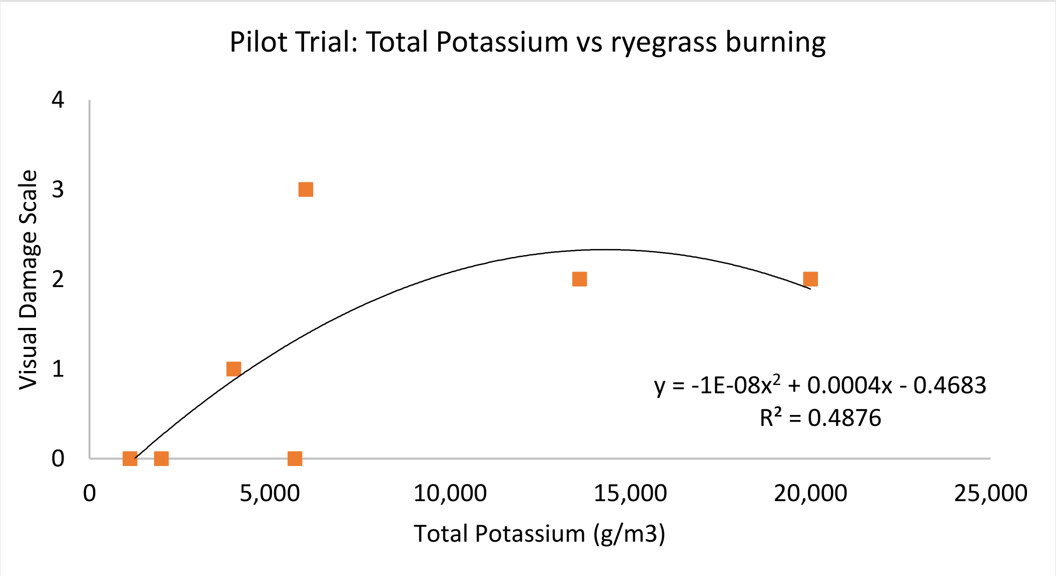

Pilot Trial: Total Kjeldahl Nitrogen (TKN) vs clover burning
Visual Damage Scale
0
1
2
3
4
0
200
400
600
800
1000
1200
1400
Total Kjeldahl Nitrogen (TKN) (g/m3)
y = 3E-07x² + 0.0016x + 1.6534
R² = 0.3585

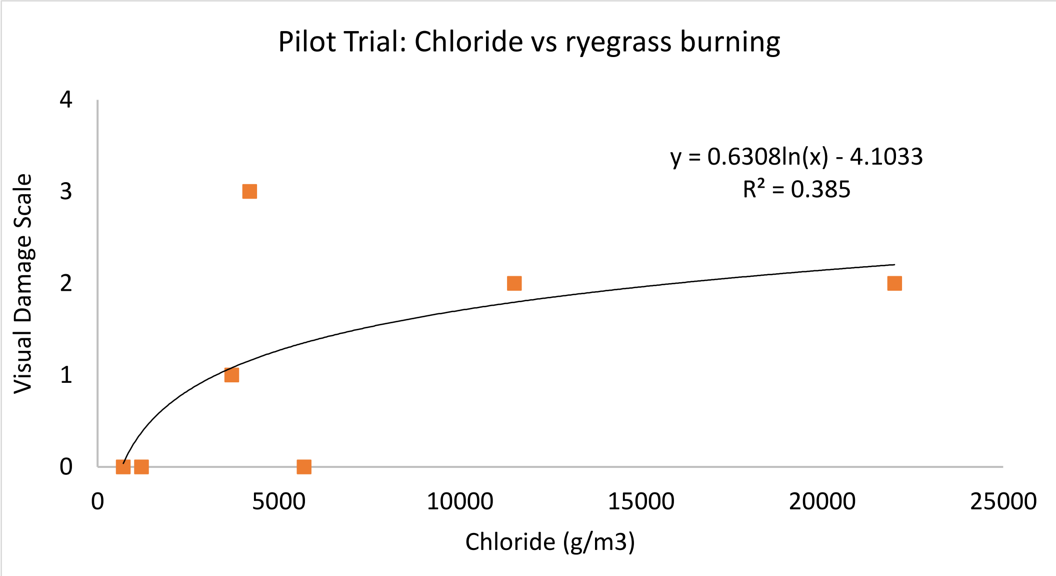

Pilot Trial: Dissolved Reactive Phosphorus vs clover burning
Visual Damage Scale
0
1
2
3
4
0
100
200
300
400
500
600
700
800
Dissolved Reactive Phosphorus (g/m3)
y = -7E-06x² + 0.0106x + 0.0986
R² = 0.358

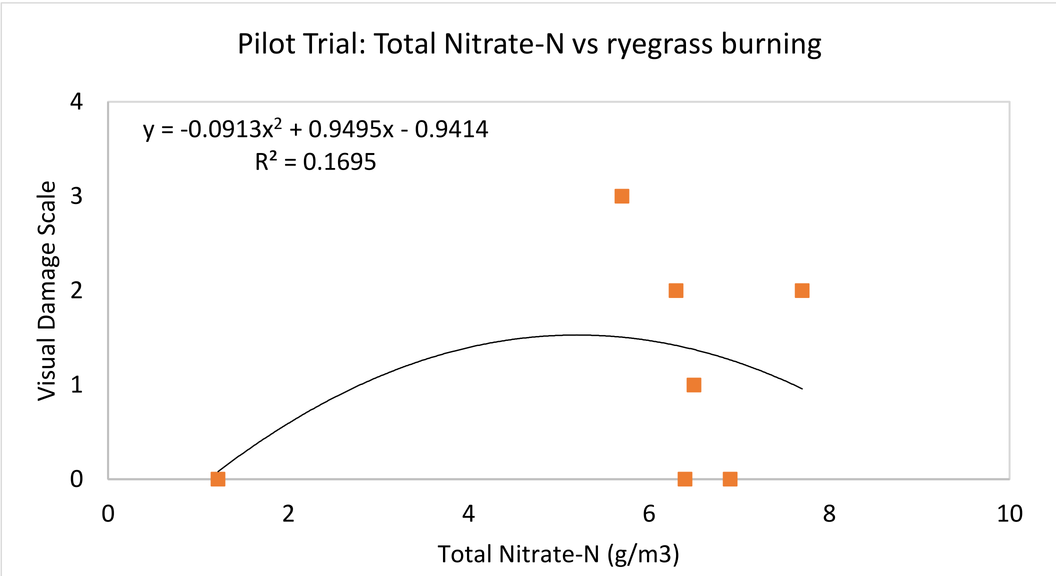

Pilot Trial: Sulphate vs clover burning
Visual Damage Scale
0
1
2
3
4
0
5,000
10,000
15,000
20,000
25,000
Sulphate (g/m3)
y = 0.0539x^0.4311
R² = 0.2698

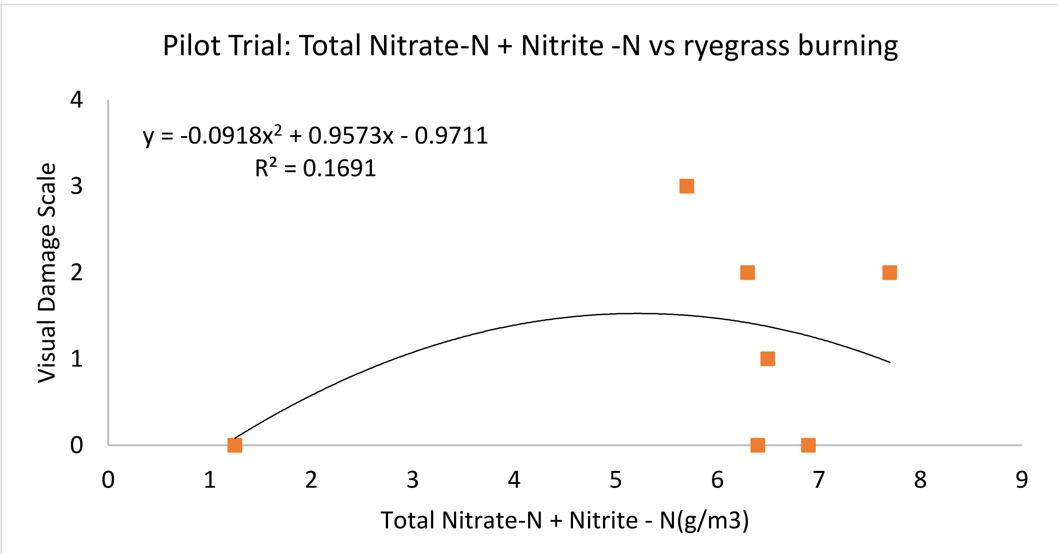

Pilot Trial: Total dissvoled solids vs ryegrass burning
Visual Damage Scale
4
3
2
1
0
y = 1.2619ln(x) - 12.422
R² = 0.7927
0
50,000
100,000
150,000
200,000
Total Dissolved Solids (g/m3)

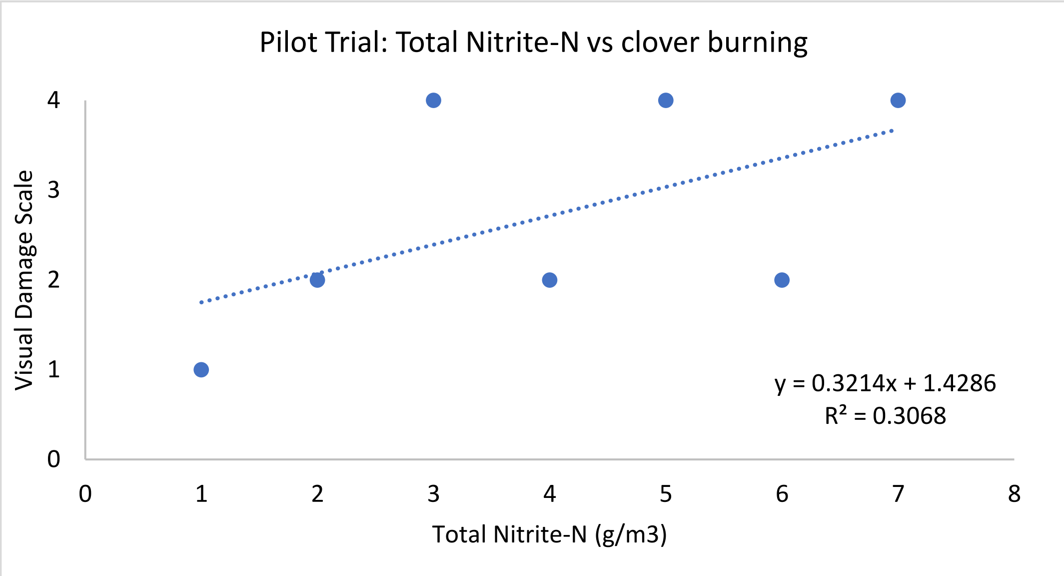

Pilot Trial: Total Calcium vs ryegrass burning
Visual Damage Scale
4
3
2
1
0
y = 2E-06x² - 0.0005x + 0.5032
R² = 0.5468
0
200
400
600
800
1000
1200
1400
1600
Total Calcium (g/m3)

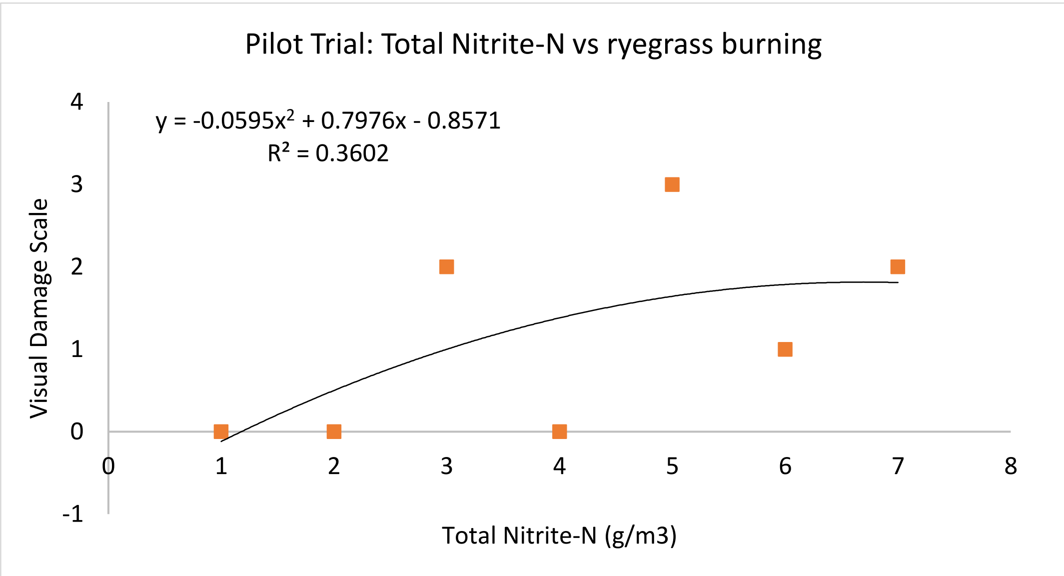

Pilot Trial: Total Potassium vs ryegrass burning
Visual Damage Scale
4
3
2
1
0
y = -1E-08x² + 0.0004x - 0.4683
R² = 0.4876
0
5,000
10,000
15,000
20,000
25,000
Total Potassium (g/m3)


Pilot Trial: Chloride vs ryegrass burning
y = 0.6308ln(x) - 4.1033
R² = 0.385
Visual Damage Scale
Chloride (g/m3)
0
1
2
3
4
0
5000
10000
15000
20000
25000

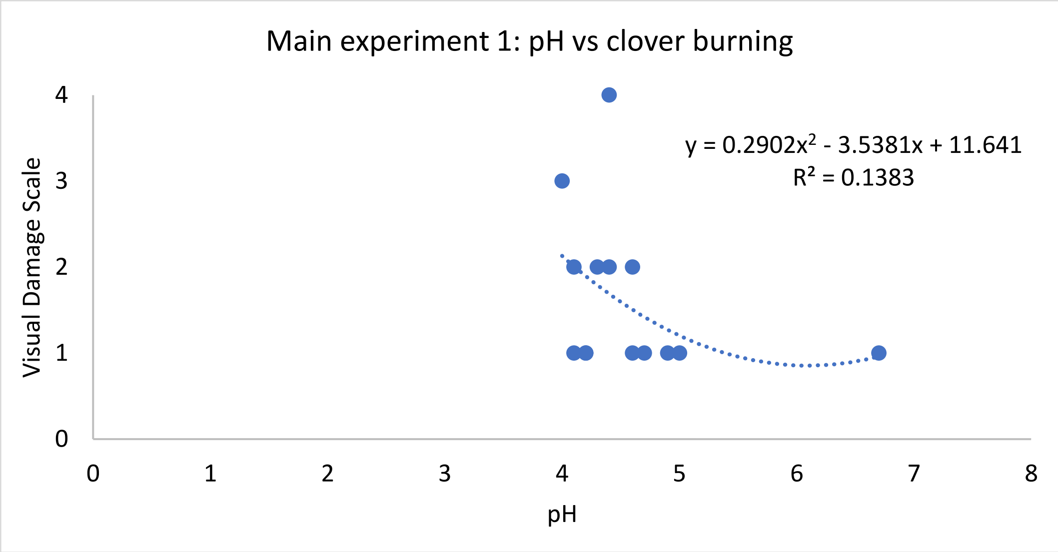

Pilot Trial: Total Nitrate-N vs ryegrass burning
y = -0.0913x² + 0.9495x - 0.9414
R² = 0.1695
Visual Damage Scale
Total Nitrate-N (g/m3)
0
1
2
3
4
0
2
4
6
8
10

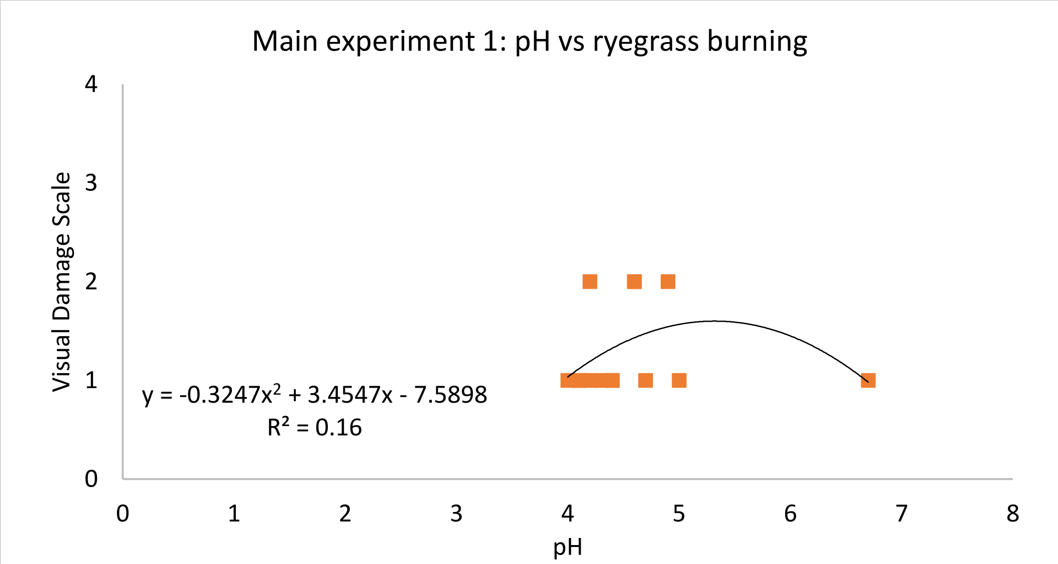

Pilot Trial: Total Nitrate-N + Nitrite -N vs ryegrass burning
y = -0.0918x² + 0.9573x - 0.9711
R² = 0.1691
Visual Damage Scale
Total Nitrate-N + Nitrite - N(g/m3)
0
1
2
3
4
0
1
2
3
4
5
6
7
8
9

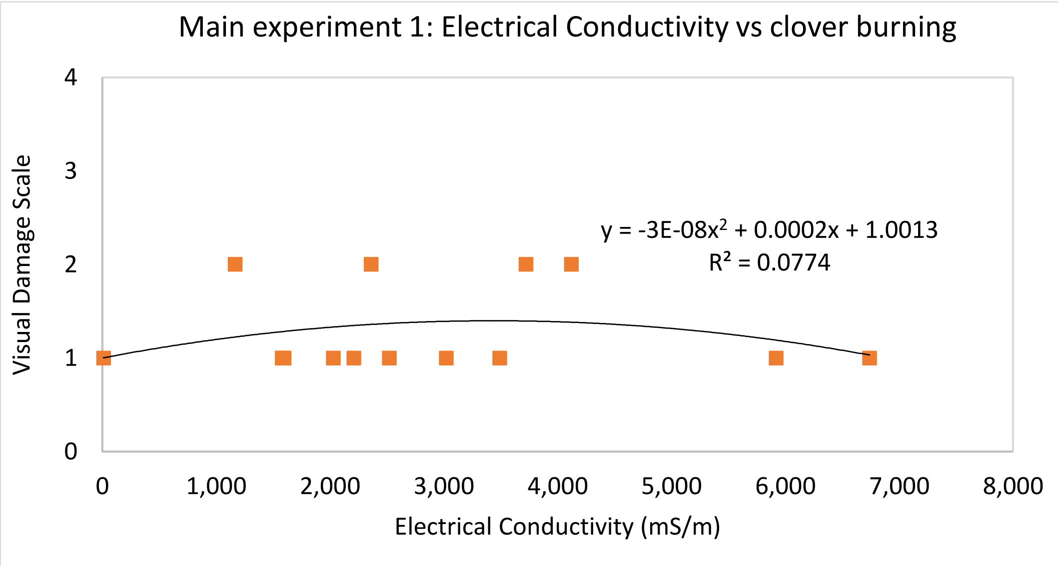

Pilot Trial: Total Nitrite-N vs clover burning
Visual Damage Scale
Total Nitrite-N (g/m3)
y = 0.3214x + 1.4286
R² = 0.3068
0
1
2
3
4
0
1
2
3
4
5
6
7
8

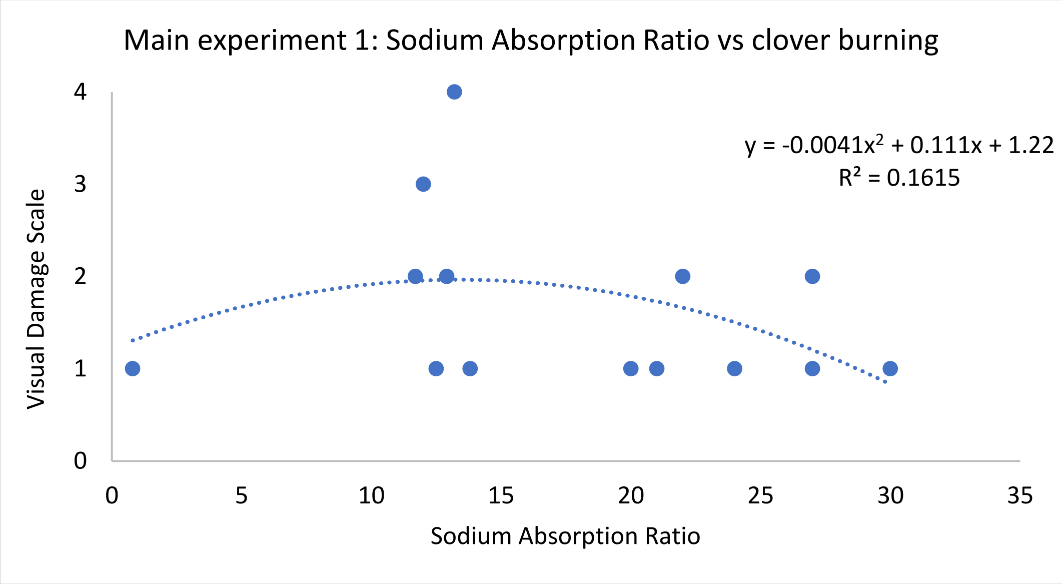

Pilot Trial: Total Nitrite-N vs ryegrass burning
Visual Damage Scale
Total Nitrite-N (g/m3)
y = -0.0595x² + 0.7976x - 0.8571
R² = 0.3602
-1
0
1
2
3
4
0
1
2
3
4
5
6
7
8

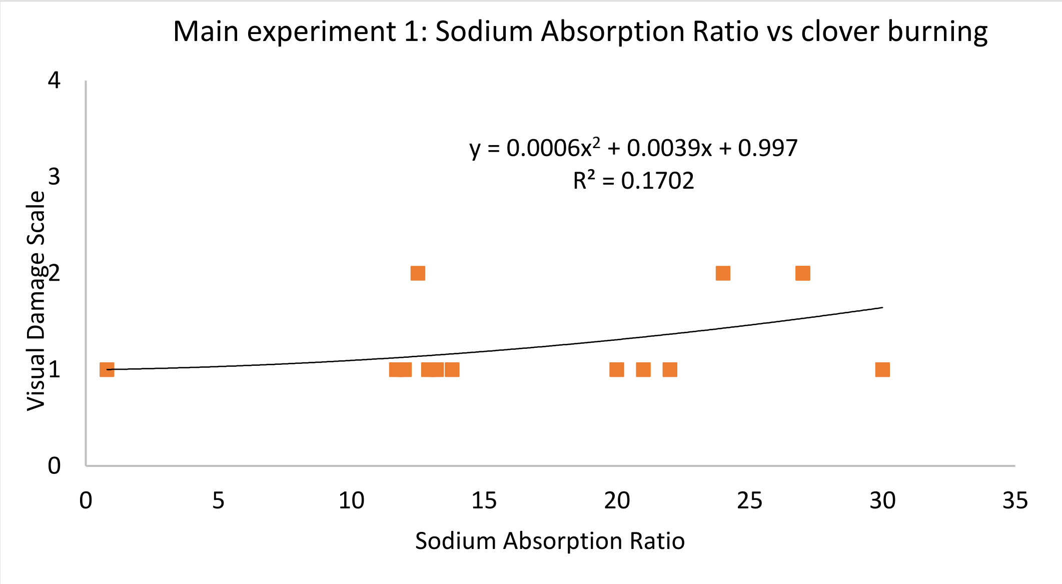
Main experiment; Block 1: Results

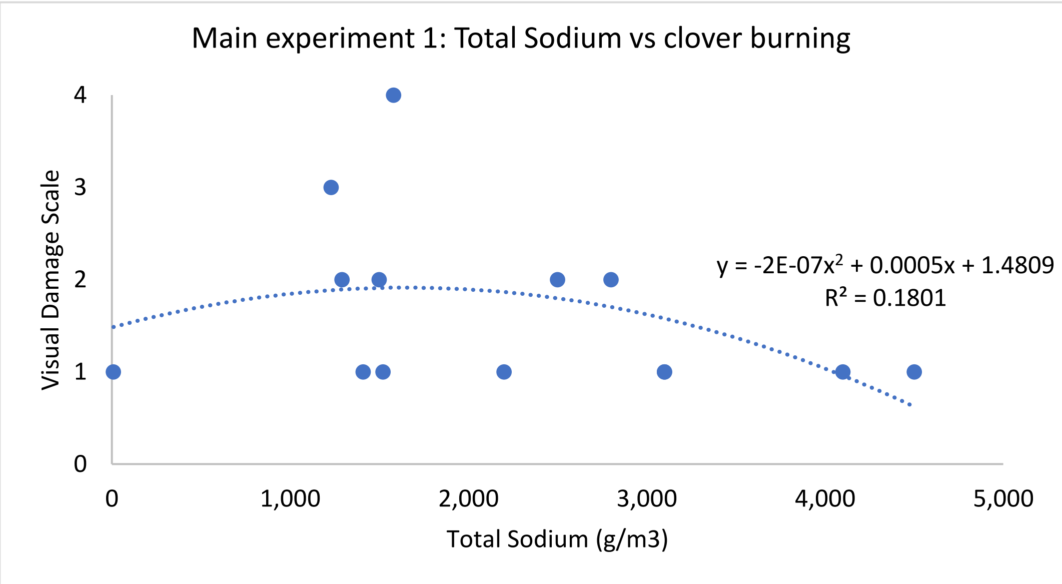


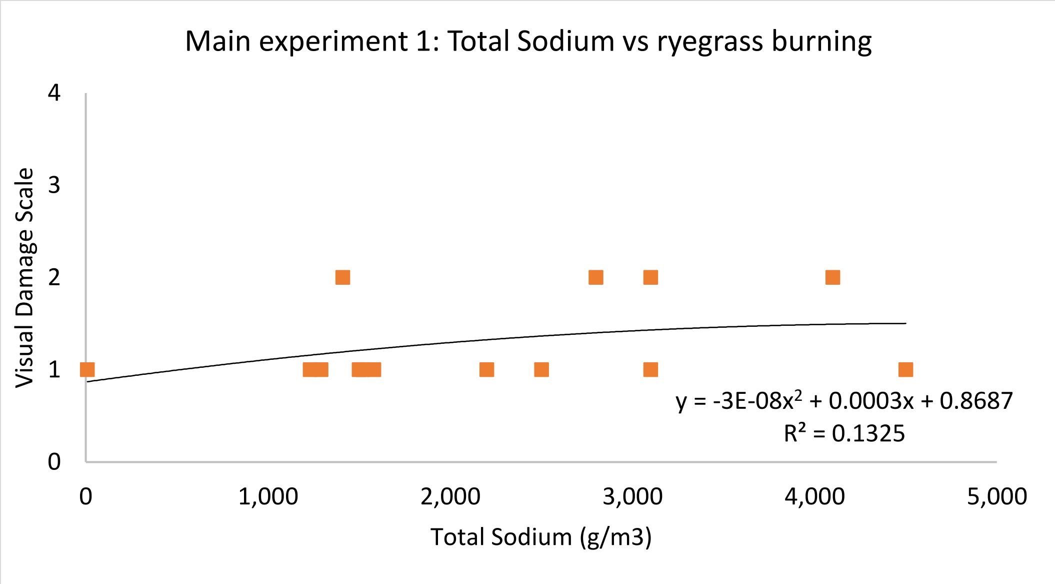




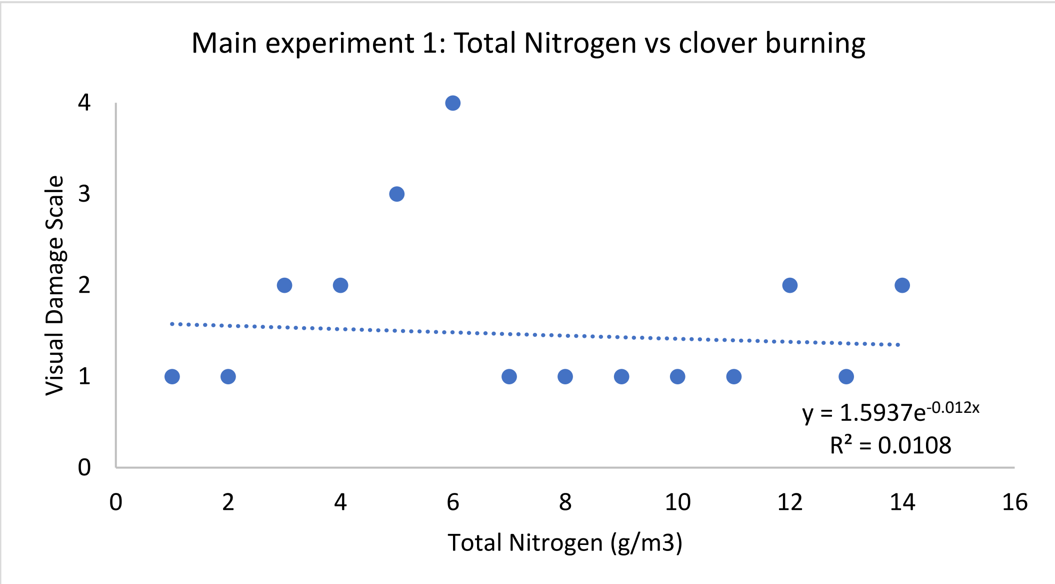

Main experiment 1: Sodium Absorption Ratio vs clover burning
y = -0.0041x² + 0.111x + 1.22
R² = 0.1615
Visual Damage Scale
Sodium Absorption Ratio
0
1
2
3
4
0
5
10
15
20
25
30
35


Main experiment 1: Sodium Absorption Ratio vs clover burning
y = 0.0006x² + 0.0039x + 0.997
R² = 0.1702
Visual Damage Scale
Sodium Absorption Ratio
0
1
2
3
4
0
5
10
15
20
25
30
35

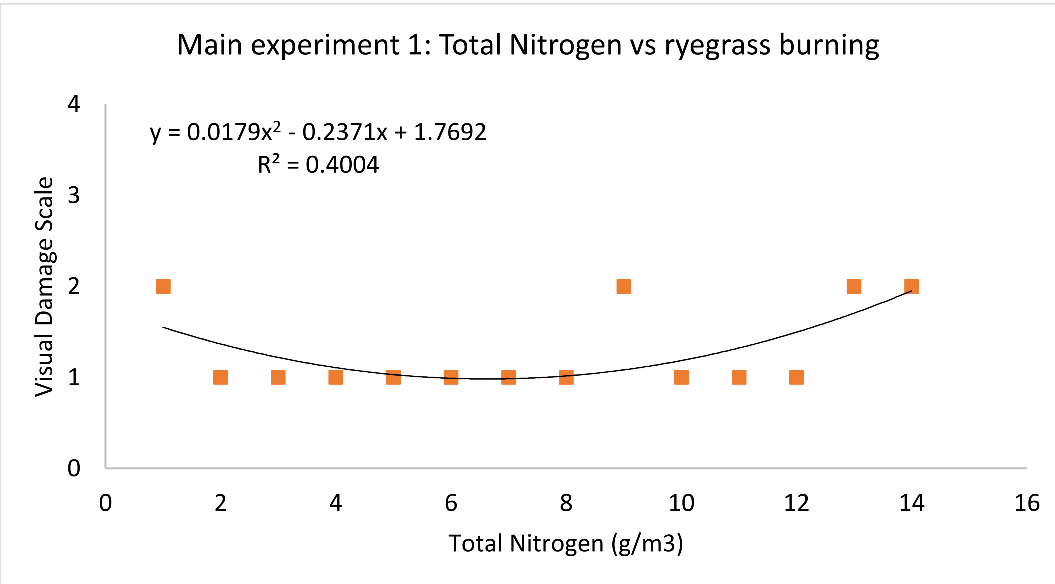

Main experiment 1: Total Sodium vs clover burning
y = -2E-07x² + 0.0005x + 1.4809
R² = 0.1801
Visual Damage Scale
Total Sodium (g/m3)
0
1
2
3
4
0
1,000
2,000
3,000
4,000
5,000



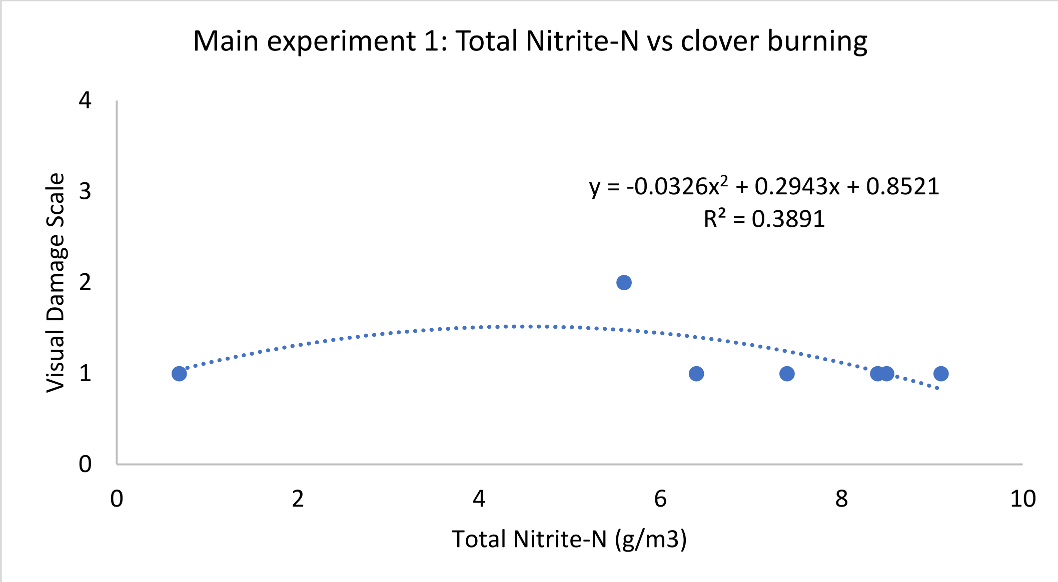
Main experiment 1: Total Sodium vs ryegrass burning
Visual Damage Scale
Total Sodium (g/m3)
y = -3E-08x² + 0.0003x + 0.8687
R² = 0.1325
0
1
2
3
4
0
1,000
2,000
3,000
4,000
5,000

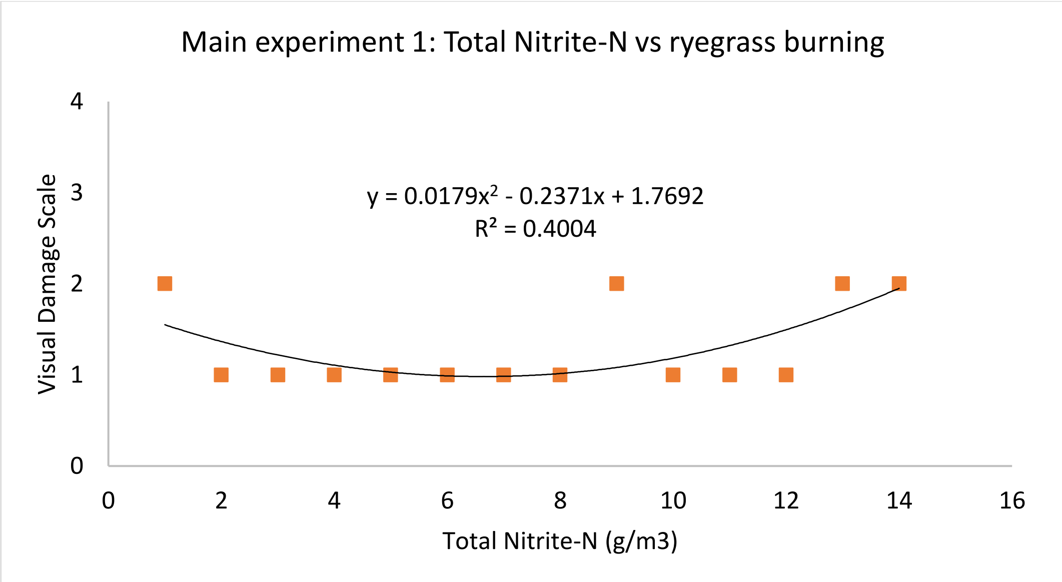


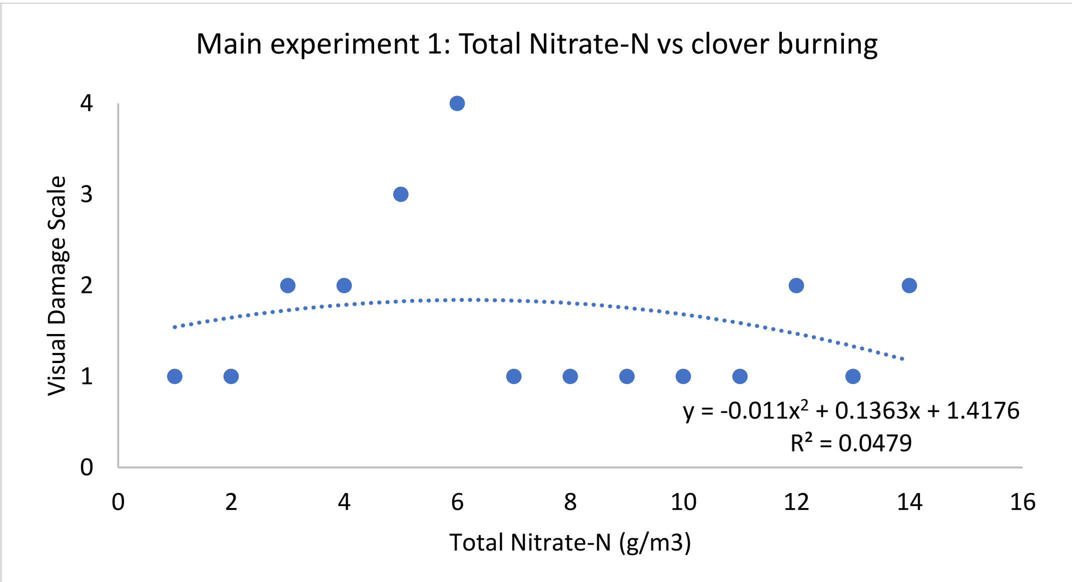
Main experiment 1: Total Nitrogen vs clover burning
Visual Damage Scale
Total Nitrogen (g/m3)
y = 1.5937e^-0.012x
R² = 0.0108
0
1
2
3
4
0
2
4
6
8
10
12
14
16

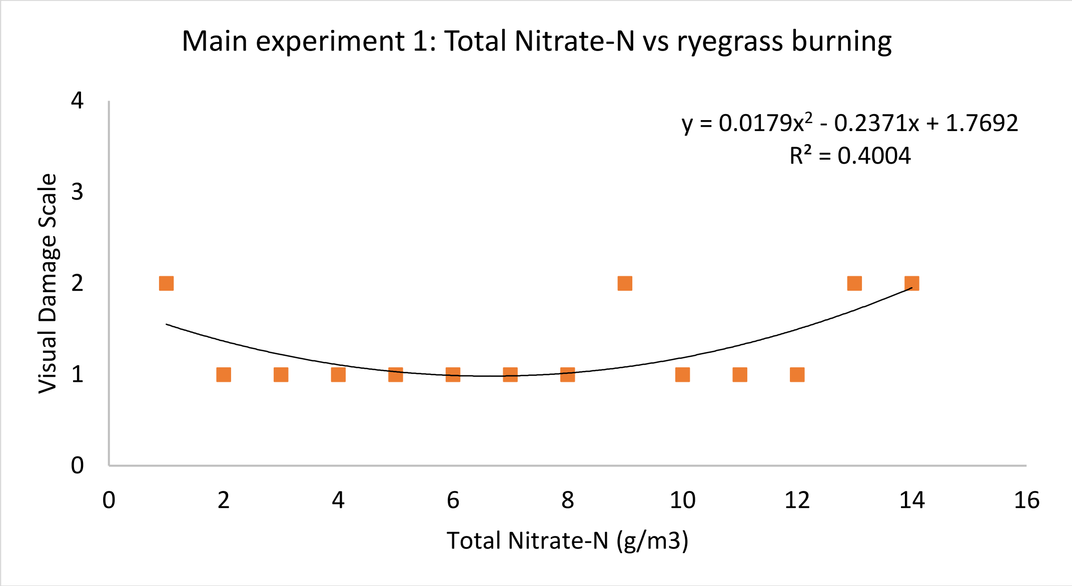


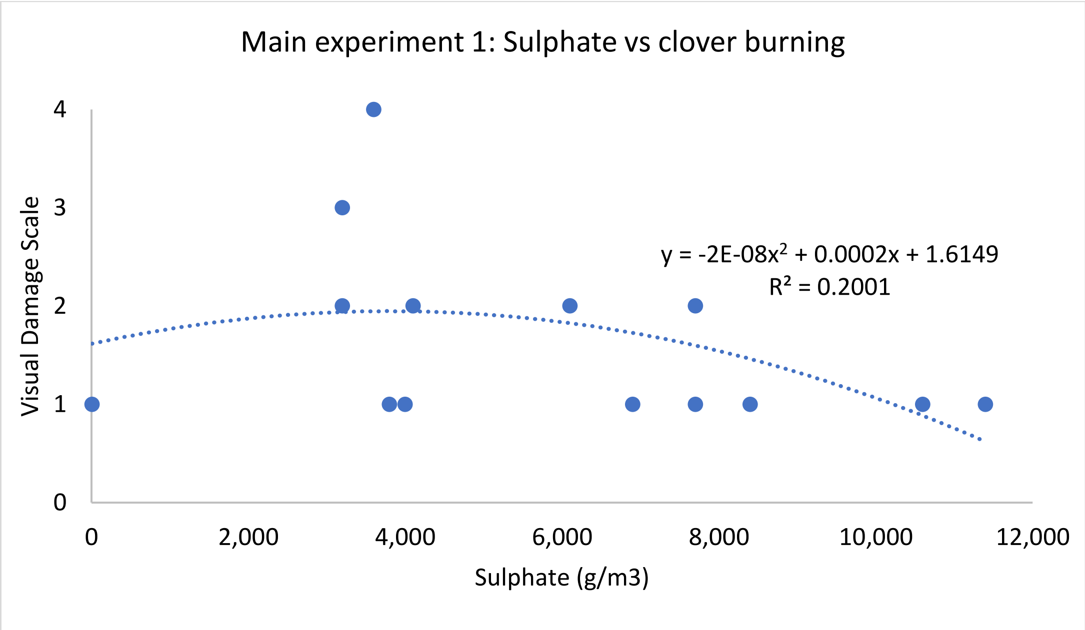
Main experiment 1: Total Nitrogen vs ryegrass burning
Visual Damage Scale
Total Nitrogen (g/m3)
y = 0.0179x² - 0.2371x + 1.7692
R² = 0.4004
0
1
2
3
4
0
2
4
6
8
10
12
14
16

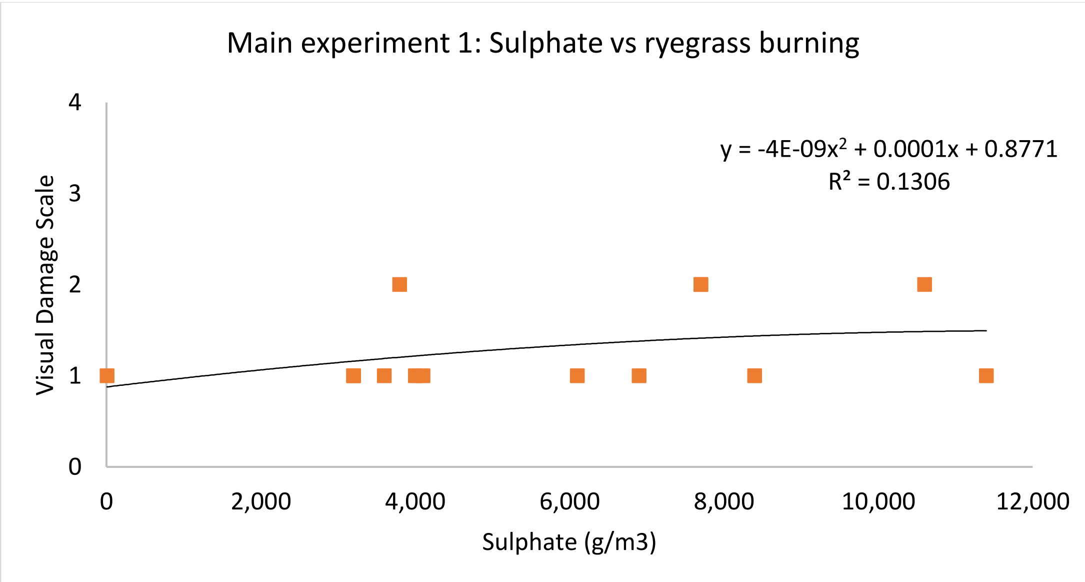

Main experiment 1: Total Nitrite-N vs clover burning
y = -0.0326x² + 0.2943x + 0.8521
R² = 0.3891
Visual Damage Scale
0
1
2
3
4
0
2
4
6
8
10
Total Nitrite-N (g/m3)

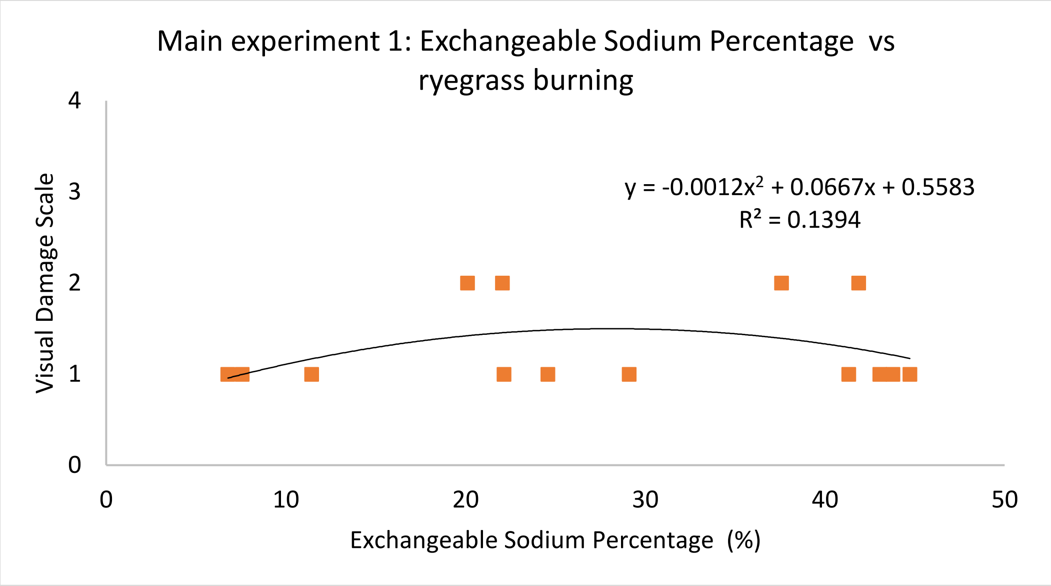

Main experiment 1: Total Nitrite-N vs ryegrass burning
y = 0.0179x² - 0.2371x + 1.7692
R² = 0.4004
Visual Damage Scale
0
1
2
3
4
0
2
4
6
8
10
12
14
16
Total Nitrite-N (g/m3)

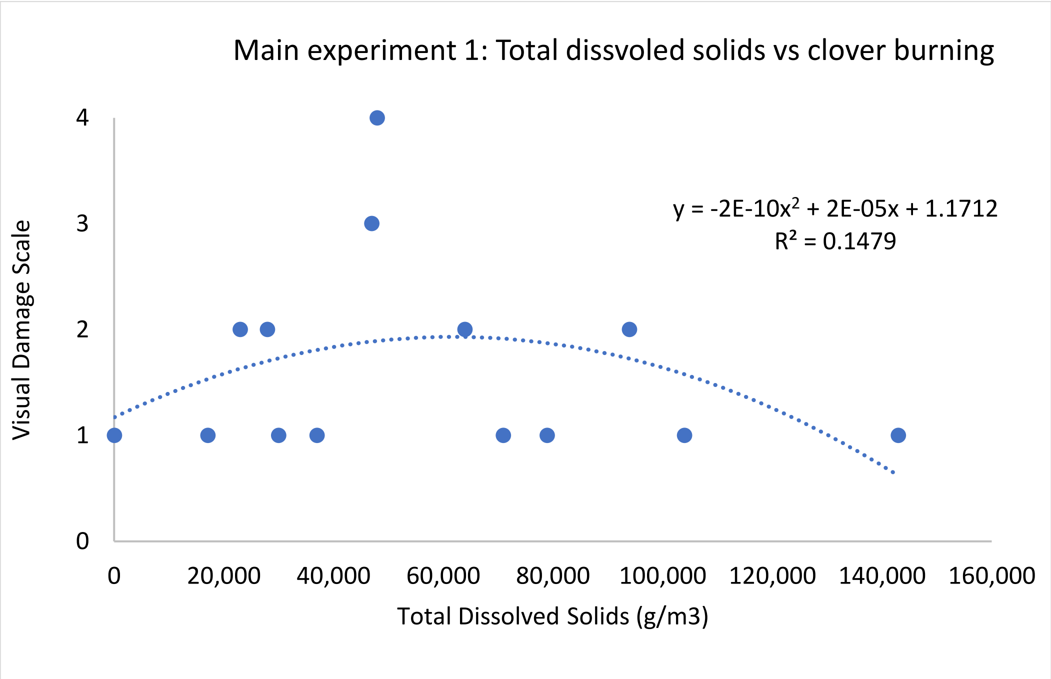

Main experiment 1: Total Nitrate-N vs clover burning
y = -0.011x² + 0.1363x + 1.4176
R² = 0.0479
Visual Damage Scale
0
1
2
3
4
0
2
4
6
8
10
12
14
16
Total Nitrate-N (g/m3)

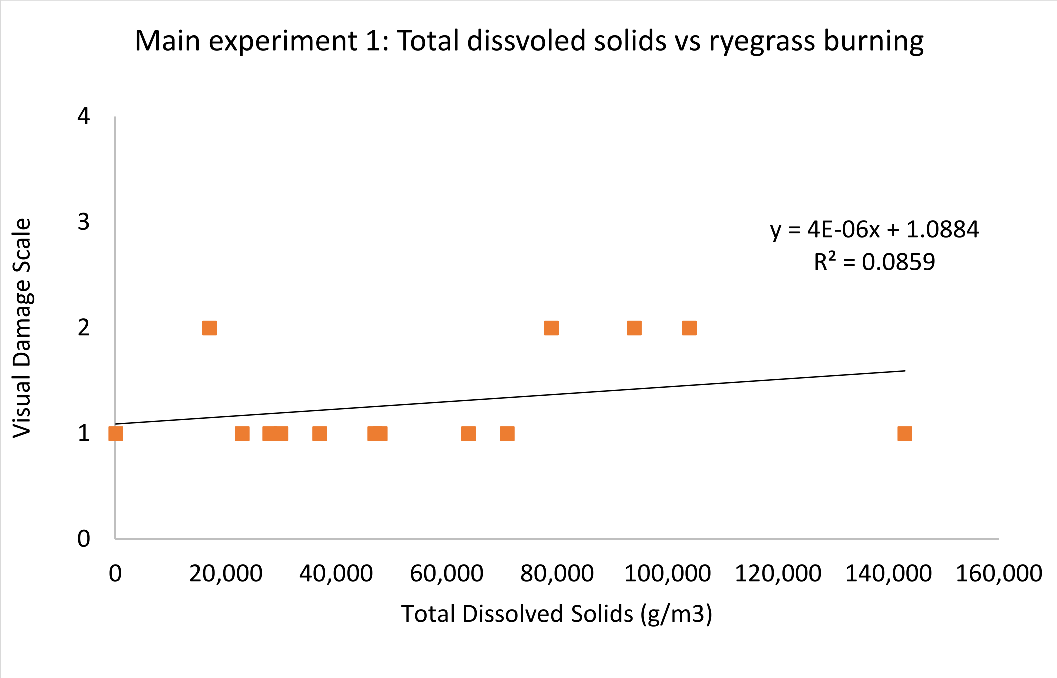

Main experiment 1: Total Nitrate-N vs ryegrass burning
y = 0.0179x² - 0.2371x + 1.7692
R² = 0.4004
Visual Damage Scale
0
1
2
3
4
0
2
4
6
8
10
12
14
16
Total Nitrate-N (g/m3)

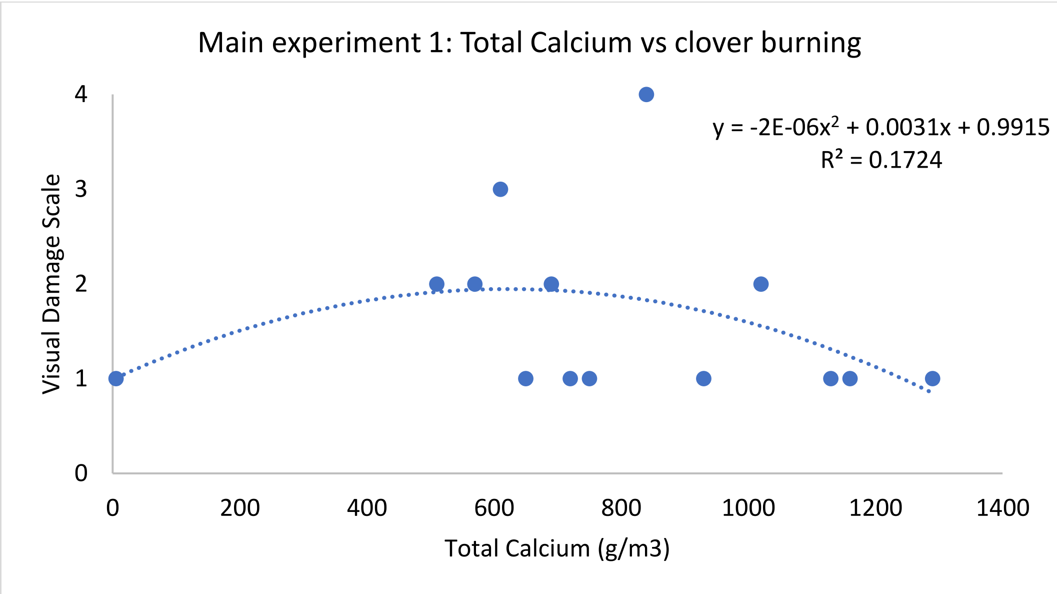

Main experiment 1: Sulphate vs clover burning
y = -2E-08x² + 0.0002x + 1.6149
R² = 0.2001
Visual Damage Scale
0
1
2
3
4
0
2,000
4,000
6,000
8,000
10,000
12,000
Sulphate (g/m3)

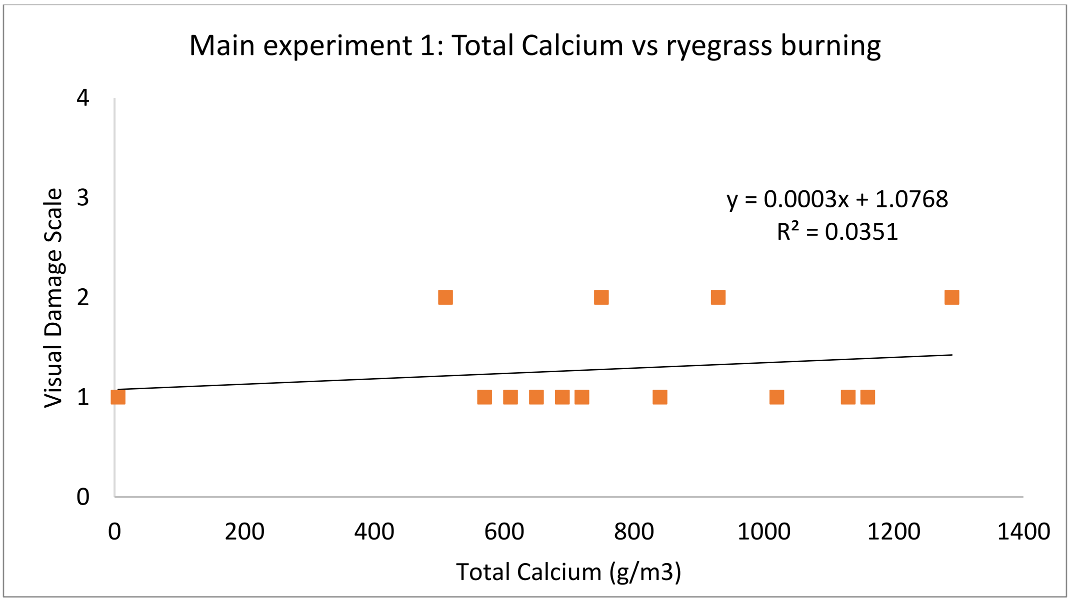

Main experiment 1: Sulphate vs ryegrass burning
y = -4E-09x² + 0.0001x + 0.8771
R² = 0.1306
Visual Damage Scale
0
1
2
3
4
0
2,000
4,000
6,000
8,000
10,000
12,000
Sulphate (g/m3)

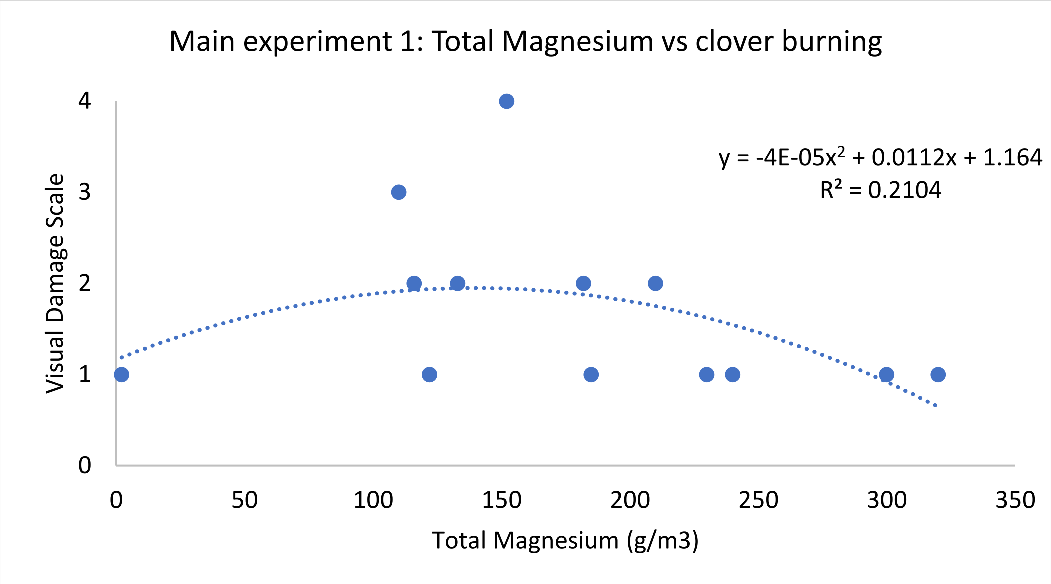

Main experiment 1: Exchangeable Sodium Percentage vs ryegrass burning
Visual Damage Scale
0
1
2
3
4
y = -0.0012x² + 0.0667x + 0.5583
R² = 0.1394
0
10
20
30
40
50
Exchangeable Sodium Percentage (%)

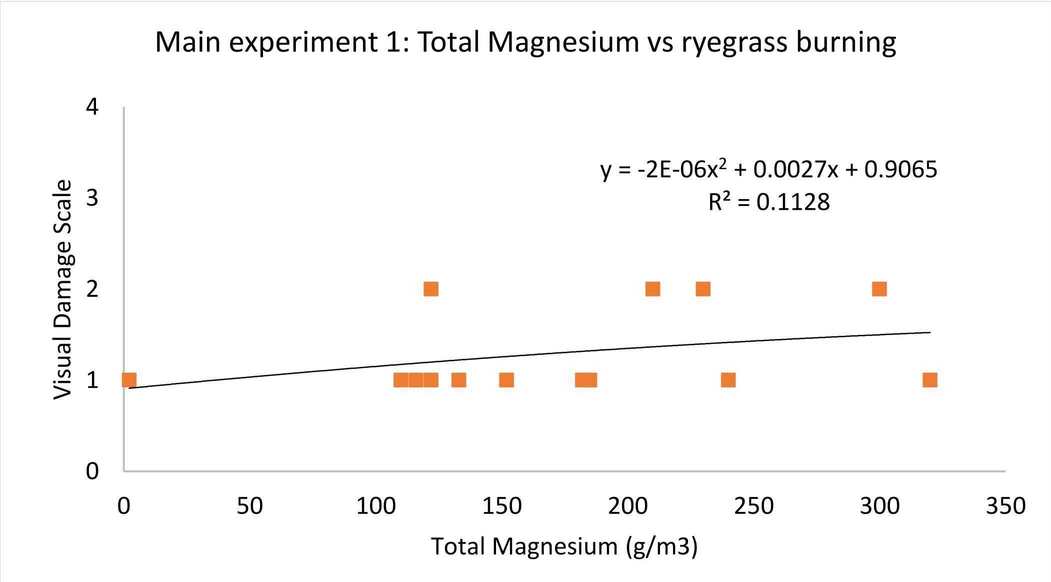

Main experiment 1: Total dissvoled solids vs clover burning
Visual Damage Scale
0
1
2
3
4
y = -2E-10x² + 2E-05x + 1.1712
R² = 0.1479
0
20,000
40,000
60,000
80,000
100,000
120,000
140,000
160,000
Total Dissolved Solids (g/m3)

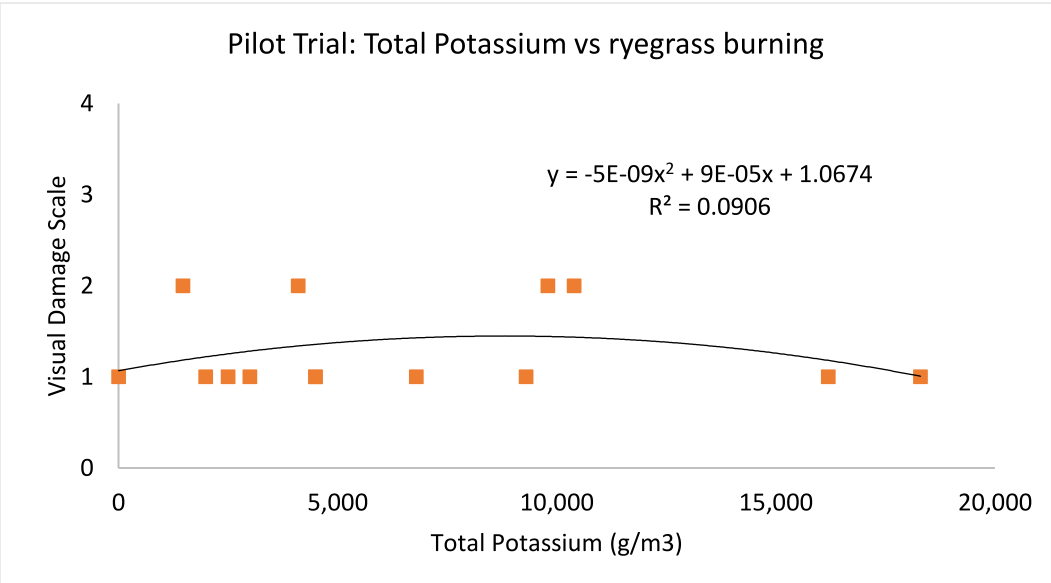

Main experiment 1: Total dissvoled solids vs ryegrass burning
y = 4E-06x + 1.0884
R² = 0.0859
Visual Damage Scale
0
1
2
3
4
0
20,000
40,000
60,000
80,000
100,000
120,000
140,000
160,000
Total Dissolved Solids (g/m3)

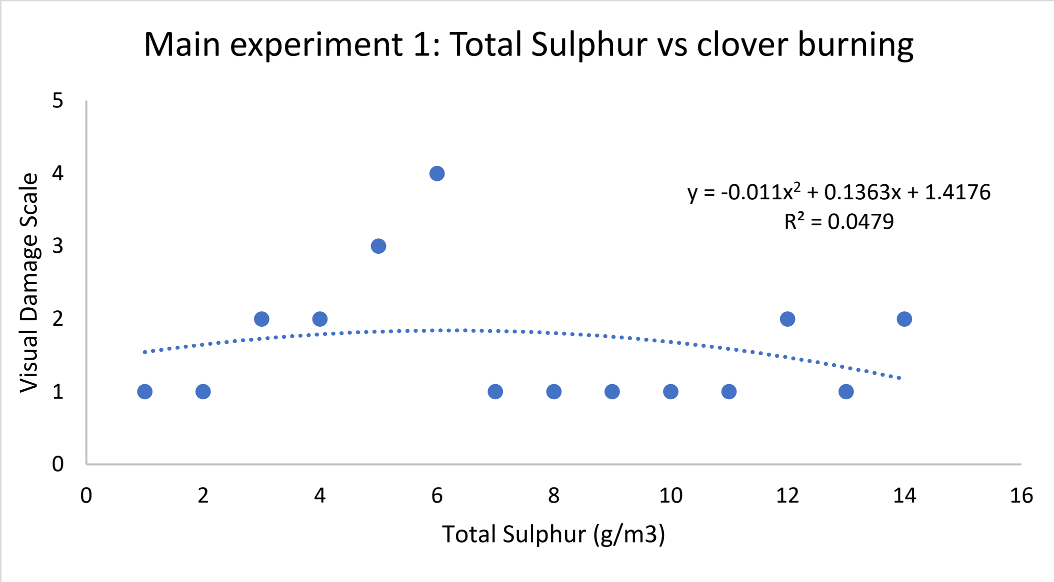

Main experiment 1: Total Calcium vs clover burning
y = -2E-06x² + 0.0031x + 0.9915
R² = 0.1724
Visual Damage Scale
0
1
2
3
4
0
200
400
600
800
1000
1200
1400
Total Calcium (g/m3)

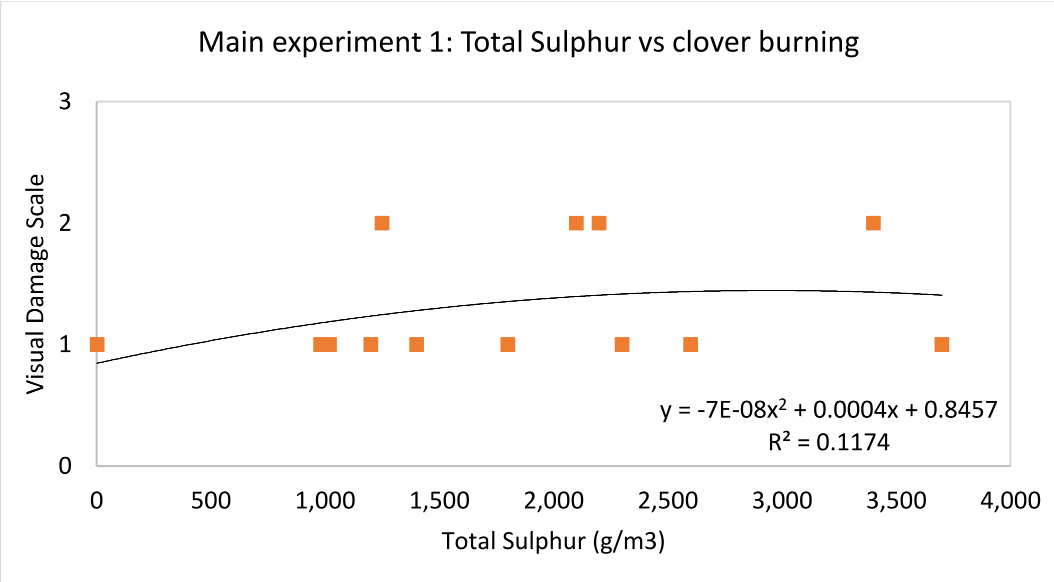

Main experiment 1: Total Calcium vs ryegrass burning
y = 0.0003x + 1.0768
R² = 0.0351
Visual Damage Scale
0
1
2
3
4
0
200
400
600
800
1000
1200
1400
Total Calcium (g/m3)

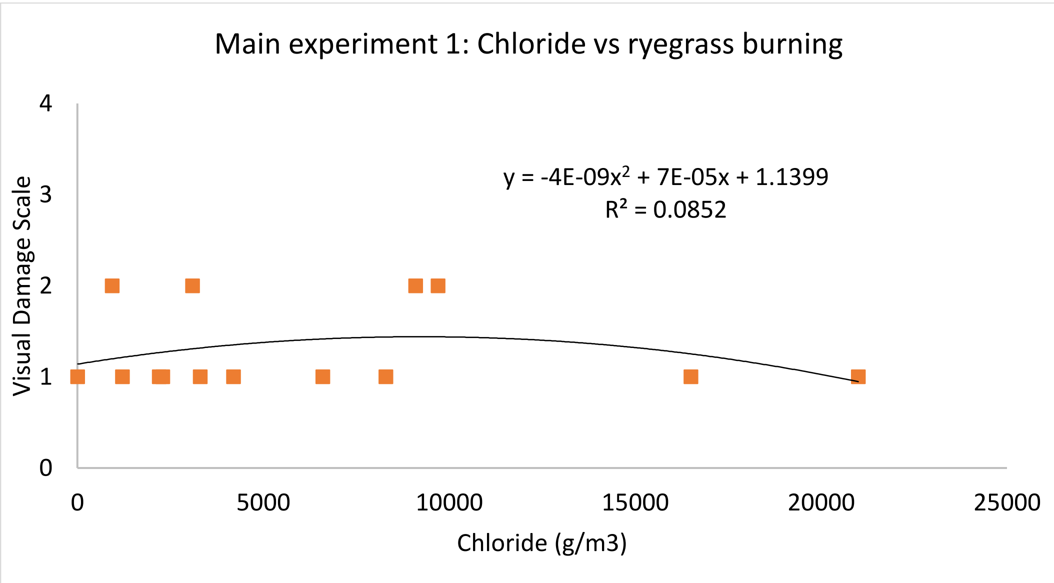

Main experiment 1: Total Magnesium vs clover burning
y = -4E-05x² + 0.0112x + 1.164
R² = 0.2104
Visual Damage Scale
0
1
2
3
4
0
50
100
150
200
250
300
350
Total Magnesium (g/m3)

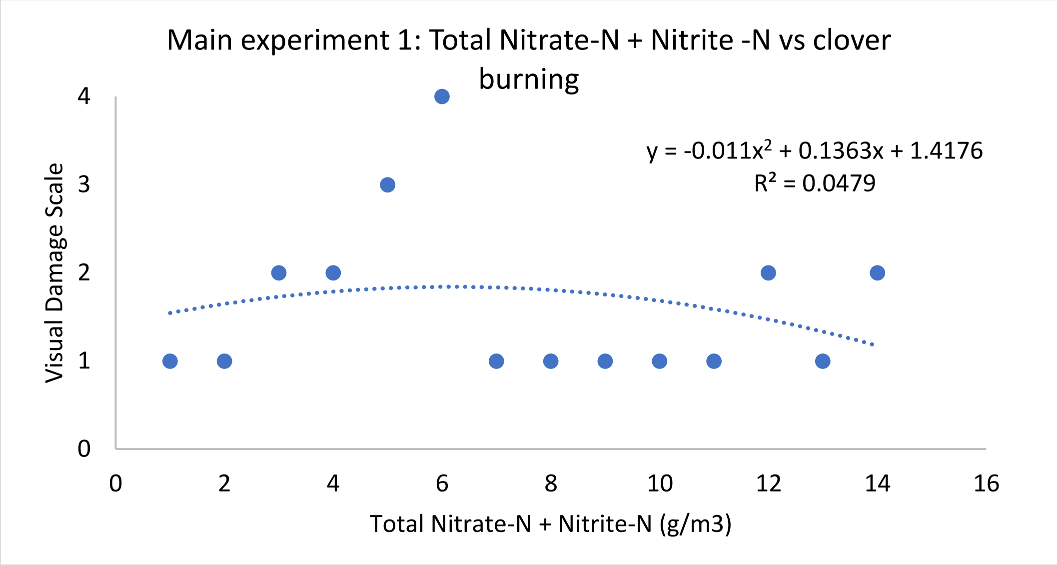

Main experiment 1: Total Magnesium vs ryegrass burning
y = -2E-06x² + 0.0027x + 0.9065
R² = 0.1128
Visual Damage Scale
0
1
2
3
4
0
50
100
150
200
250
300
350
Total Magnesium (g/m3)

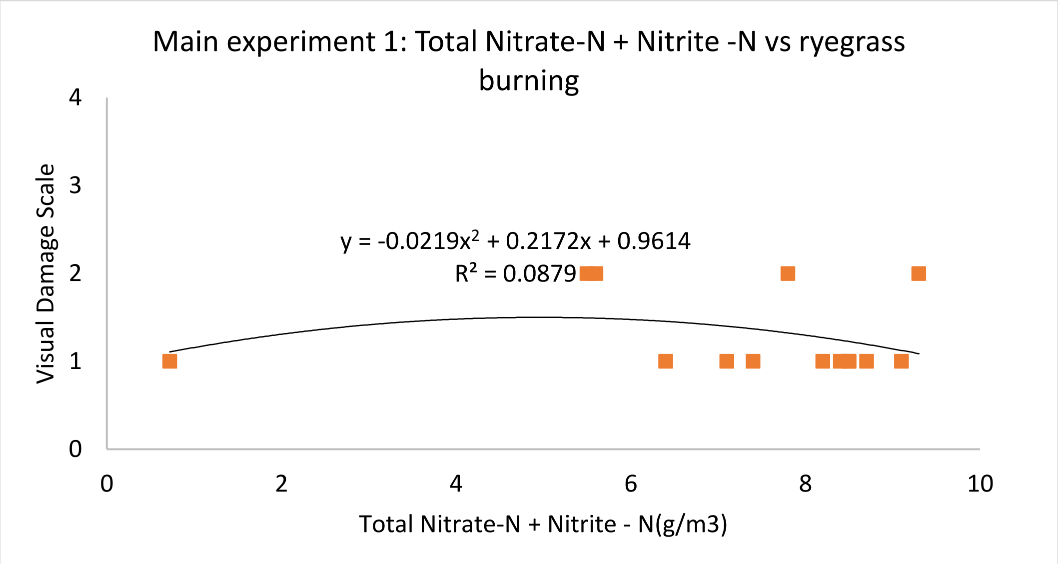

Pilot Trial: Total Potassium vs ryegrass burning
y = -5E-09x² + 9E-05x + 1.0674
R² = 0.0906
Visual Damage Scale
0
1
2
3
4
0
5,000
10,000
15,000
20,000
Total Potassium (g/m3)

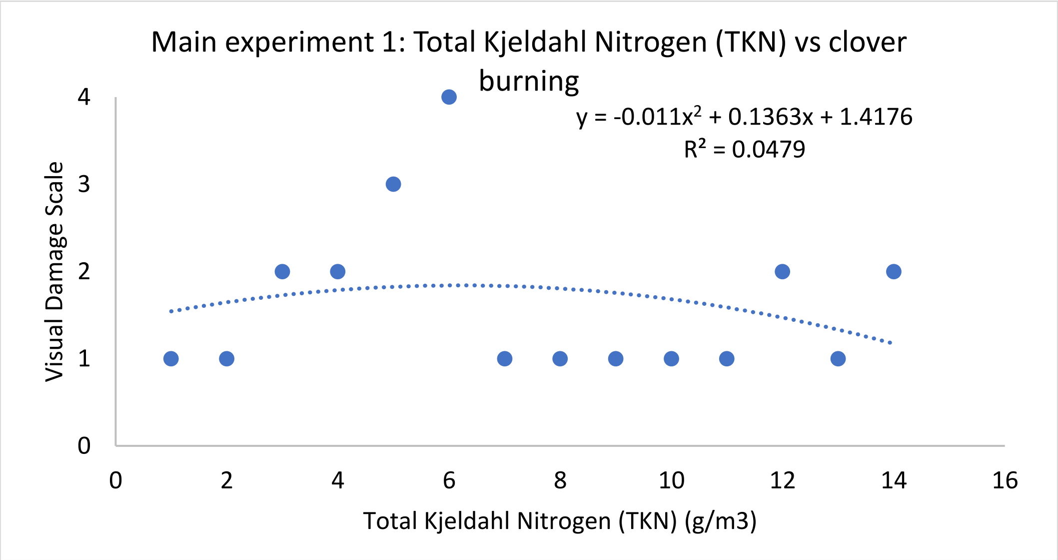

Main experiment 1: Total Sulphur vs clover burning
Visual Damage Scale
Total Sulphur (g/m3)
y = -0.011x² + 0.1363x + 1.4176
R² = 0.0479
0
1
2
3
4
5
0
2
4
6
8
10
12
14
16

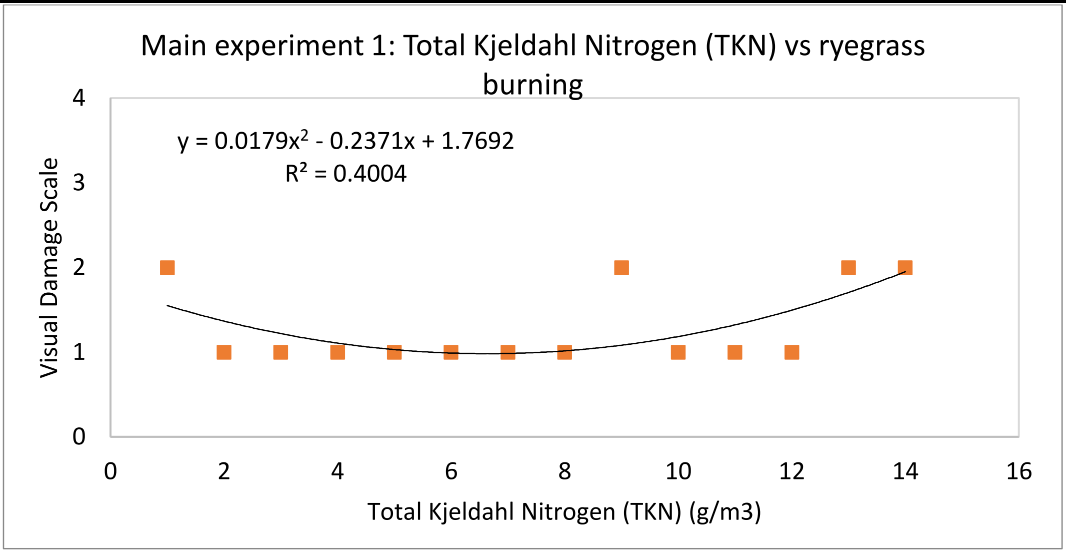

Main experiment 1: Total Sulphur vs clover burning
Visual Damage Scale
Total Sulphur (g/m3)
y = -7E-08x² + 0.0004x + 0.8457
R² = 0.1174
0
1
2
3
0
500
1,000
1,500
2,000
2,500
3,000
3,500
4,000

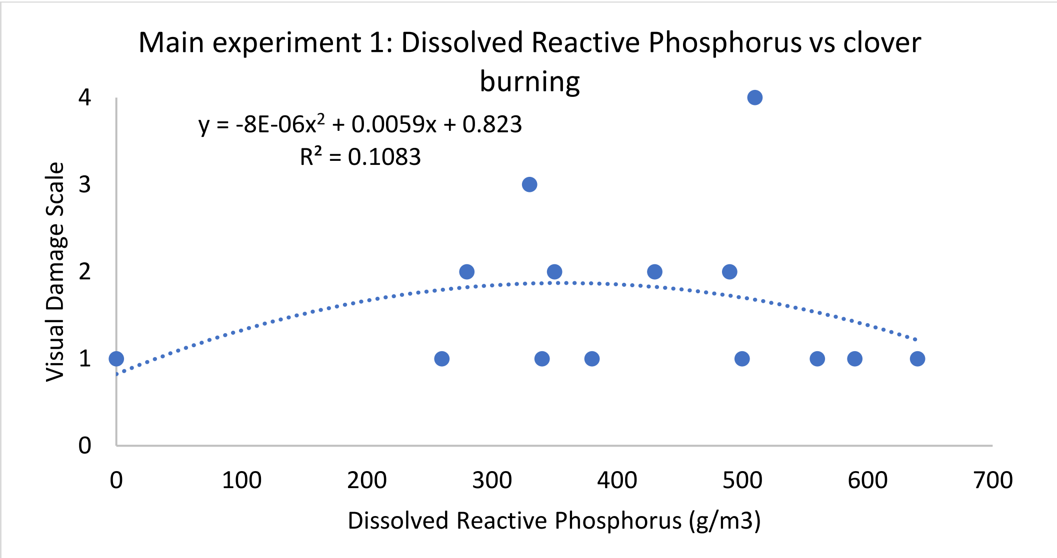

Main experiment 1: Chloride vs ryegrass burning
Visual Damage Scale
Chloride (g/m3)
y = -4E-09x² + 7E-05x + 1.1399
R² = 0.0852
0
1
2
3
4
0
5000
10000
15000
20000
25000

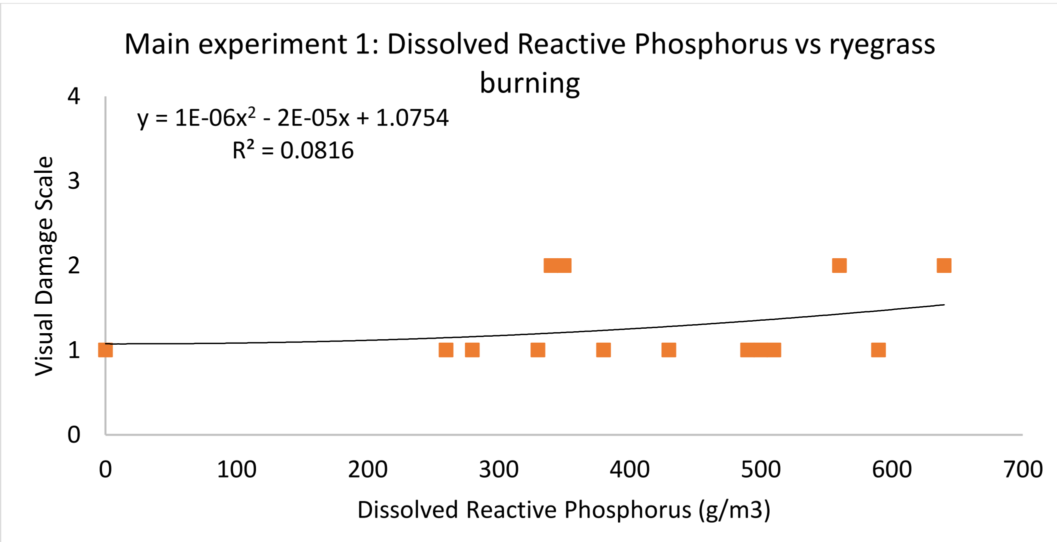

Main experiment 1: Total Nitrate-N + Nitrite -N vs clover burning
y = -0.011x² + 0.1363x + 1.4176
R² = 0.0479
Visual Damage Scale
0
1
2
3
4
0
2
4
6
8
10
12
14
16
Total Nitrate-N + Nitrite-N (g/m3)


Main experiment 1: Total Nitrate-N + Nitrite -N vs ryegrass burning
y = -0.0219x² + 0.2172x + 0.9614
R² = 0.0879
Visual Damage Scale
0
1
2
3
4
0
2
4
6
8
10
Total Nitrate-N + Nitrite - N(g/m3)

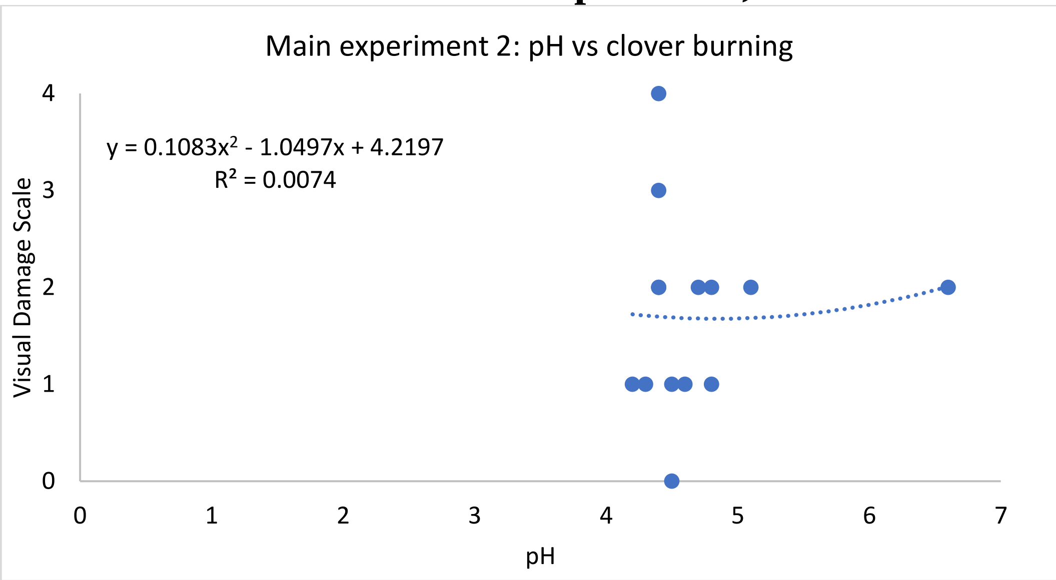

Main experiment 1: Total Kjeldahl Nitrogen (TKN) vs clover burning
y = -0.011x² + 0.1363x + 1.4176
R² = 0.0479
Visual Damage Scale
0
1
2
3
4
0
2
4
6
8
10
12
14
16
Total Kjeldahl Nitrogen (TKN) (g/m3)

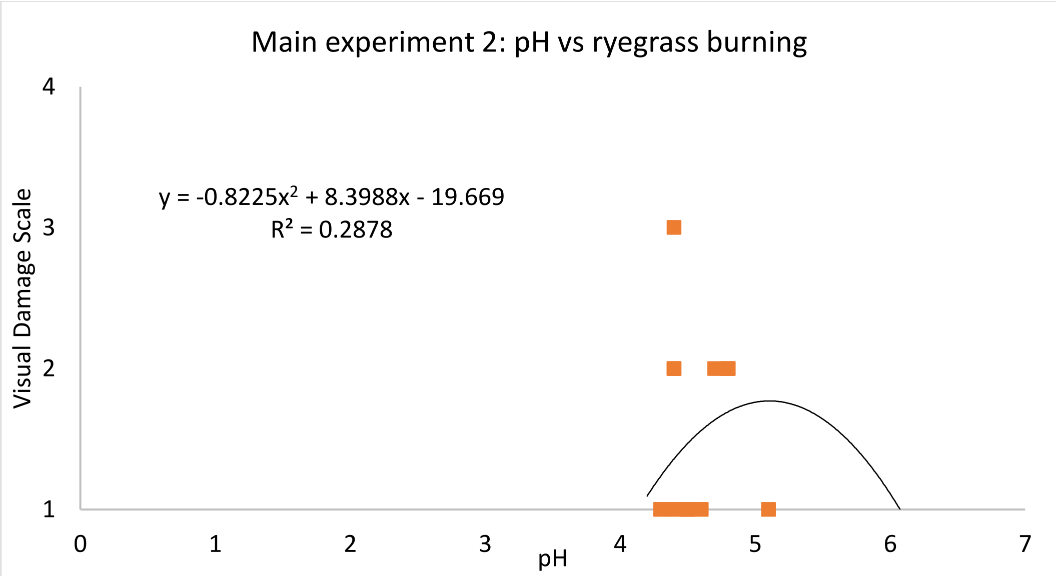

Main experiment 1: Total Kjeldahl Nitrogen (TKN) vs ryegrass burning
y = 0.0179x² - 0.2371x + 1.7692
R² = 0.4004
Visual Damage Scale
0
1
2
3
4
0
2
4
6
8
10
12
14
16
Total Kjeldahl Nitrogen (TKN) (g/m3)

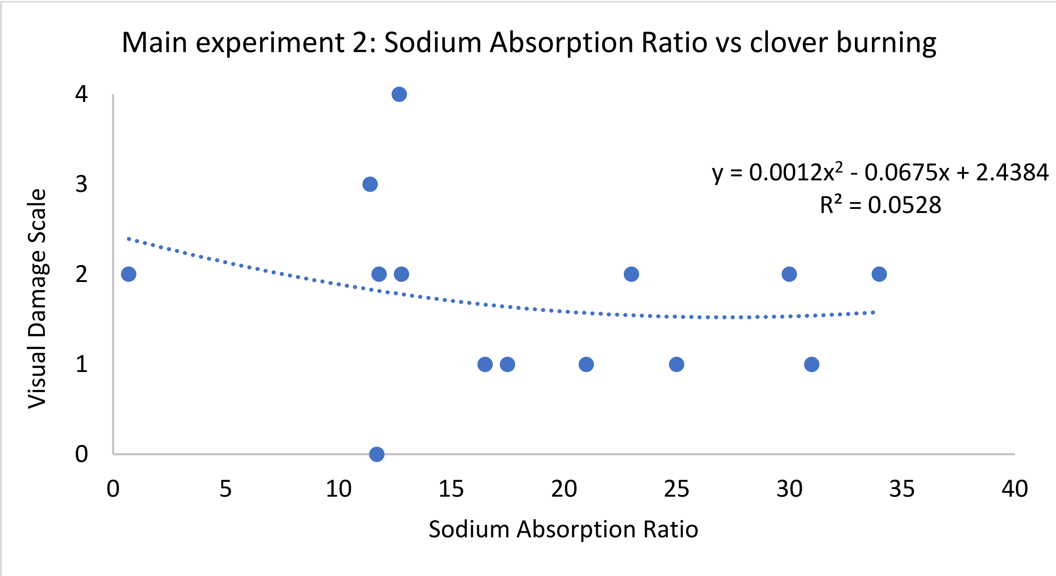

Main experiment 1: Dissolved Reactive Phosphorus vs clover burning
y = -8E-06x² + 0.0059x + 0.823
R² = 0.1083
Visual Damage Scale
0
1
2
3
4
0
100
200
300
400
500
600
700
Dissolved Reactive Phosphorus (g/m3)

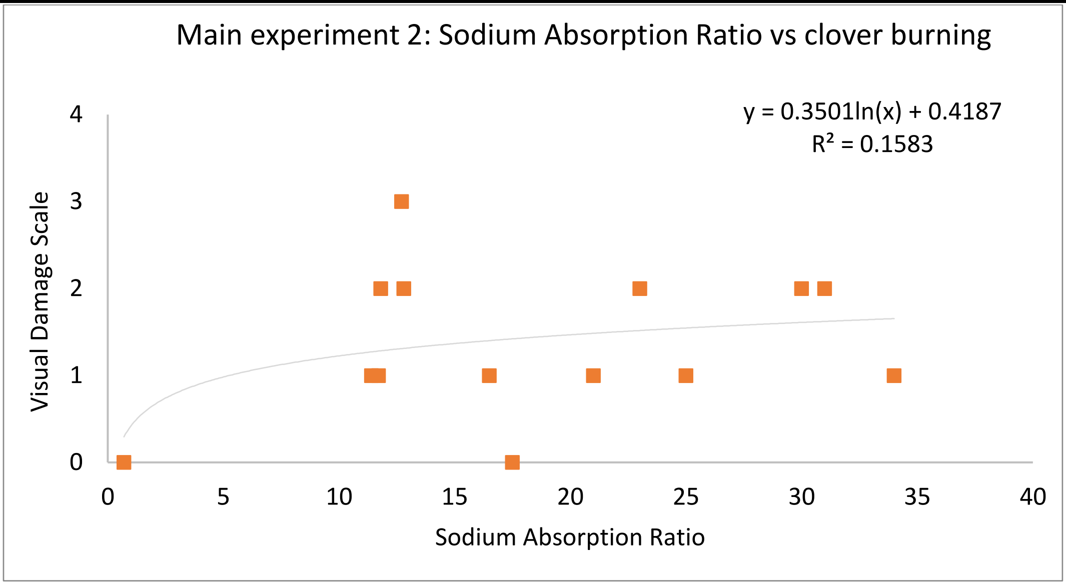

Main experiment 1: Dissolved Reactive Phosphorus vs ryegrass burning
y = 1E-06x² - 2E-05x + 1.0754
R² = 0.0816
Visual Damage Scale
0
1
2
3
4
0
100
200
300
400
500
600
700
Dissolved Reactive Phosphorus (g/m3)

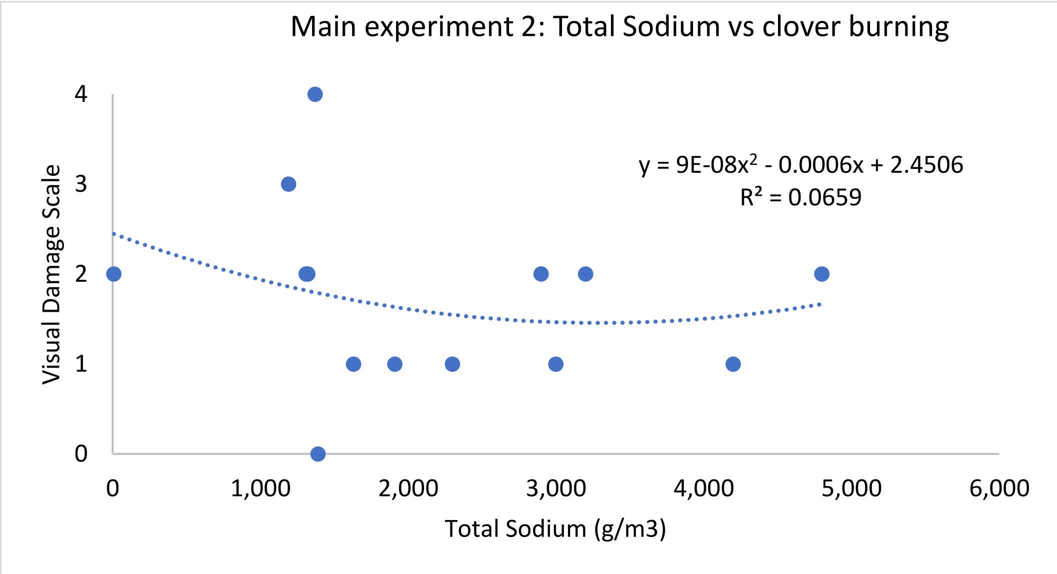
Main experiment; Block 2: Results

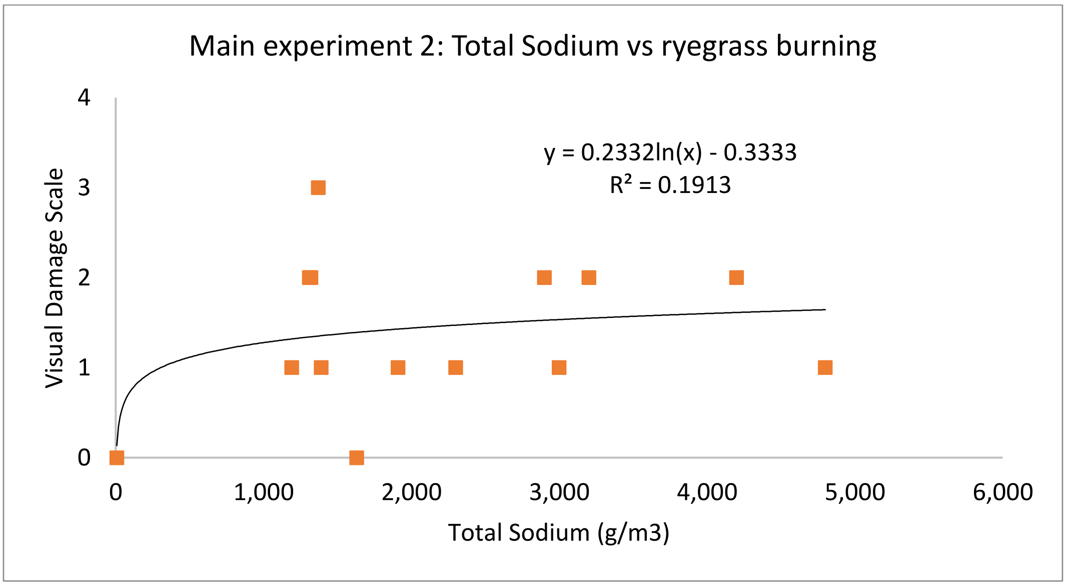


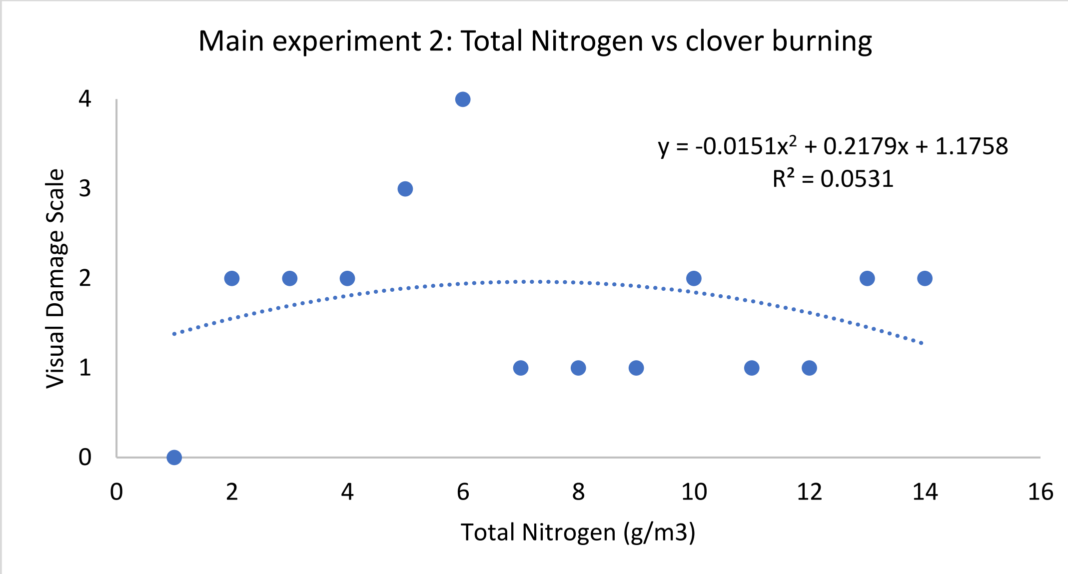


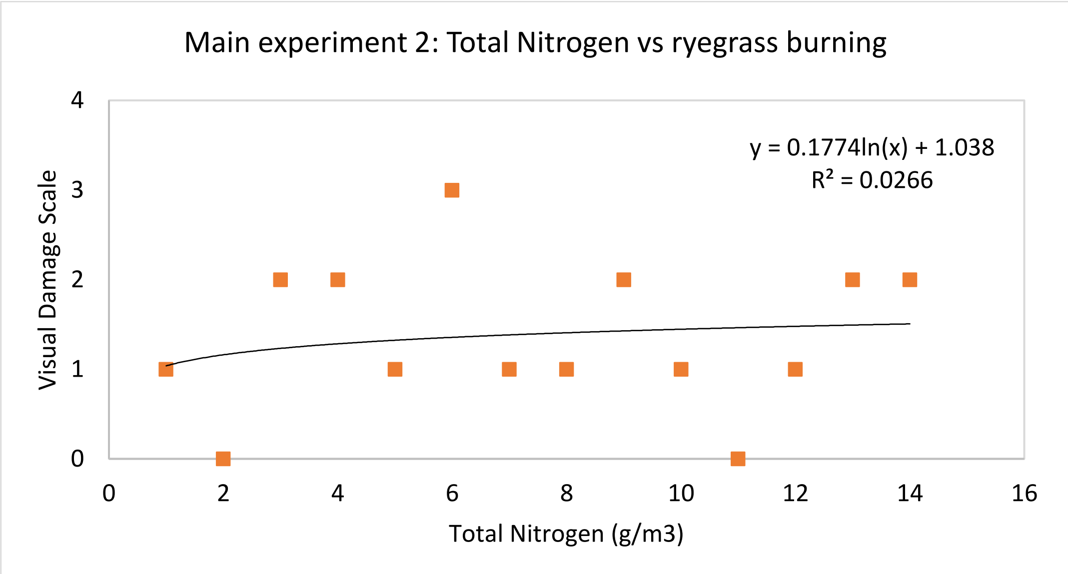


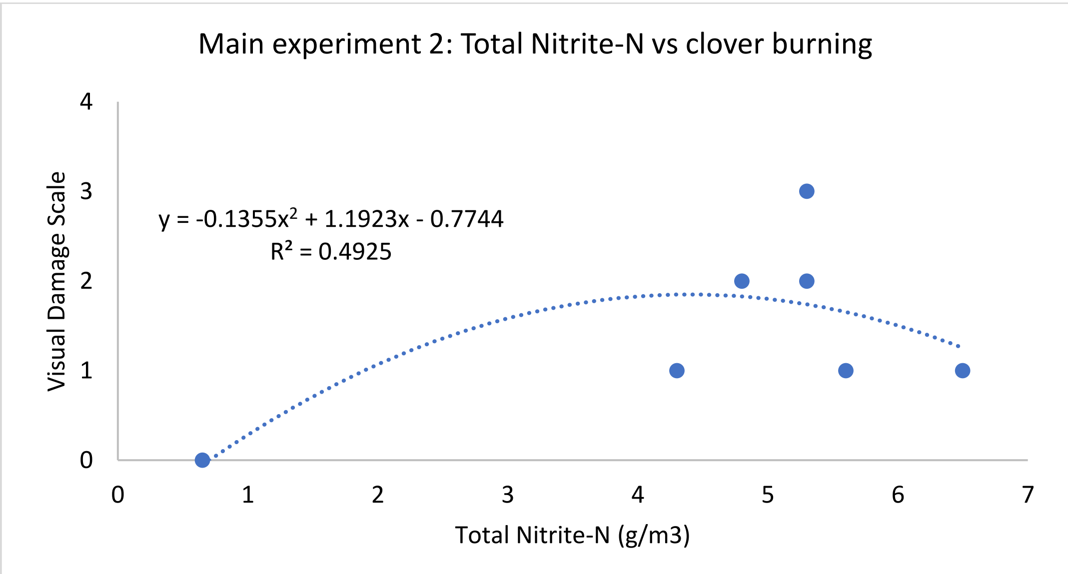

Main experiment 2: Sodium Absorption Ratio vs clover burning
y = 0.3501ln(x) + 0.4187
R² = 0.1583
Visual Damage Scale
0
1
2
3
4
0
5
10
15
20
25
30
35
40
Sodium Absorption Ratio

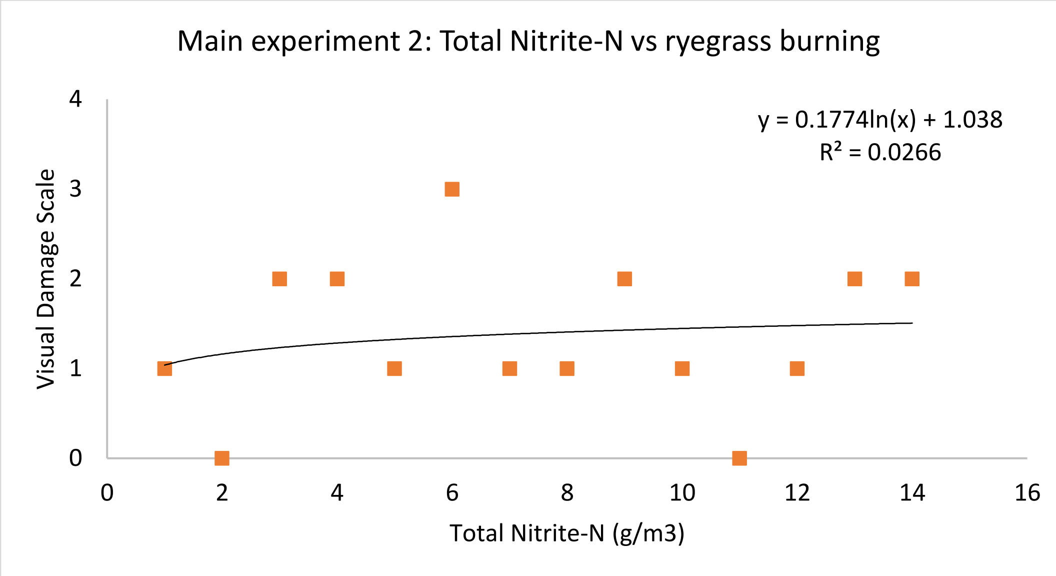

Main experiment 2: Total Sodium vs clover burning
y = 9E-08x² - 0.0006x + 2.4506
R² = 0.0659
Visual Damage Scale
0
1
2
3
4
0
1,000
2,000
3,000
4,000
5,000
6,000
Total Sodium (g/m3)

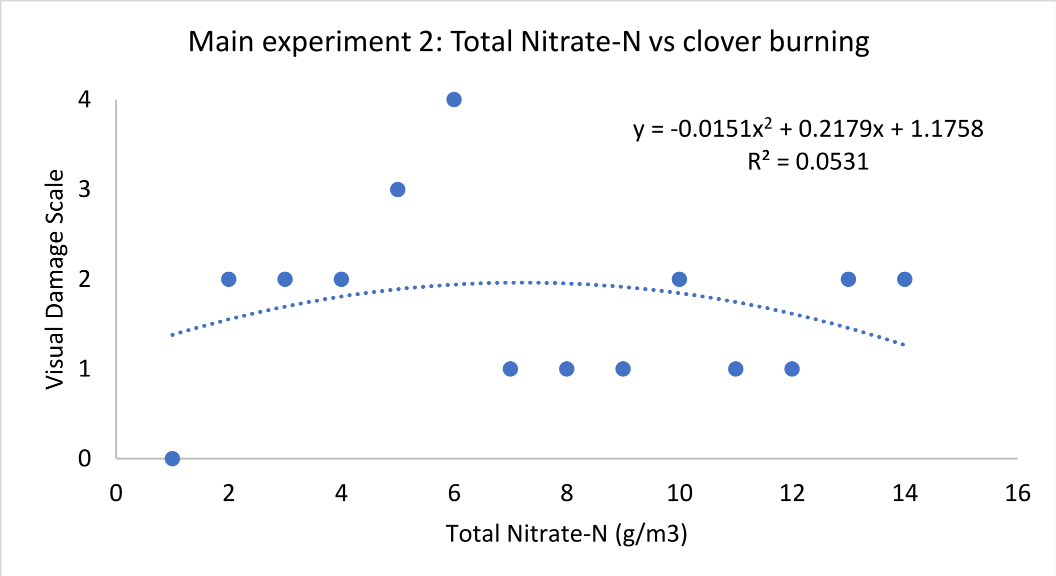

Main experiment 2: Total Sodium vs ryegrass burning
y = 0.2332ln(x) - 0.3333
R² = 0.1913
Visual Damage Scale
0
1
2
3
4
0
1,000
2,000
3,000
4,000
5,000
6,000
Total Sodium (g/m3)

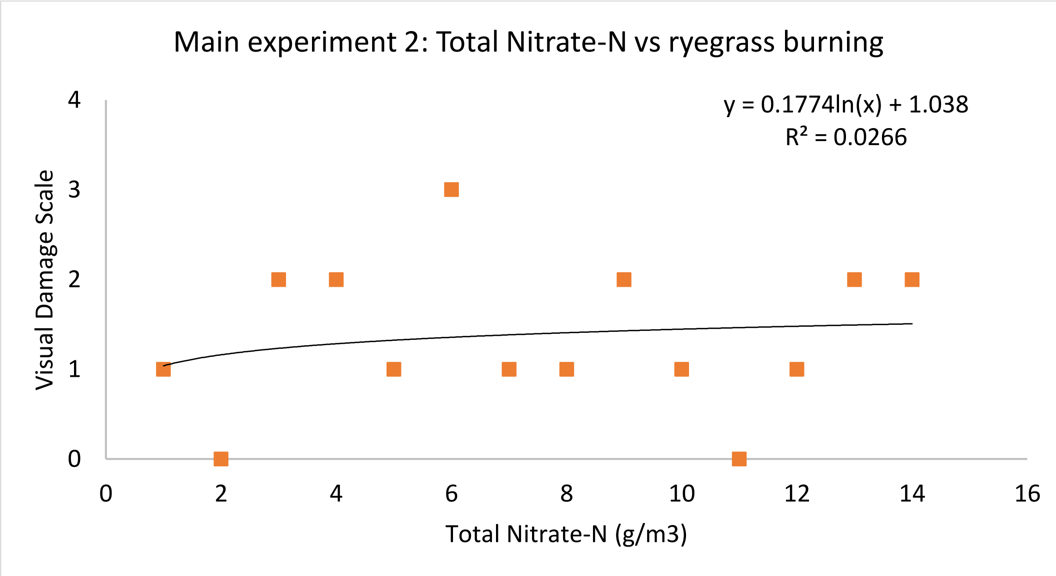

Main experiment 2: Total Nitrogen vs clover burning
y = -0.0151x² + 0.2179x + 1.1758
R² = 0.0531
Visual Damage Scale
Total Nitrogen (g/m3)
0
1
2
3
4
0
2
4
6
8
10
12
14
16

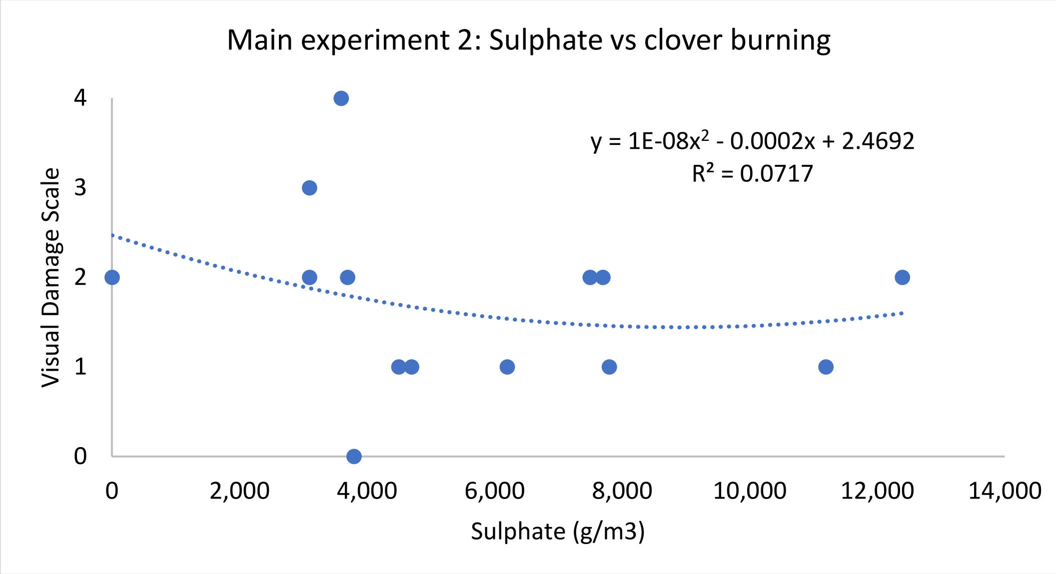

Main experiment 2: Total Nitrogen vs ryegrass burning
y = 0.1774ln(x) + 1.038
R² = 0.0266
Visual Damage Scale
Total Nitrogen (g/m3)
0
1
2
3
4
0
2
4
6
8
10
12
14
16

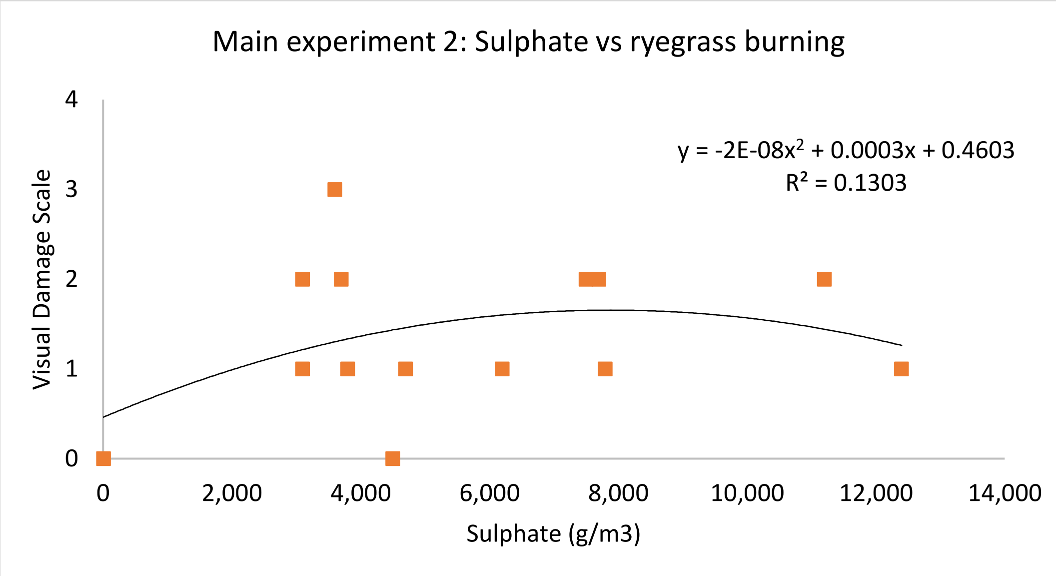

Main experiment 2: Total Nitrite-N vs clover burning
y = -0.1355x² + 1.1923x - 0.7744
R² = 0.4925
Visual Damage Scale
Total Nitrite-N (g/m3)
0
1
2
3
4
0
1
2
3
4
5
6
7

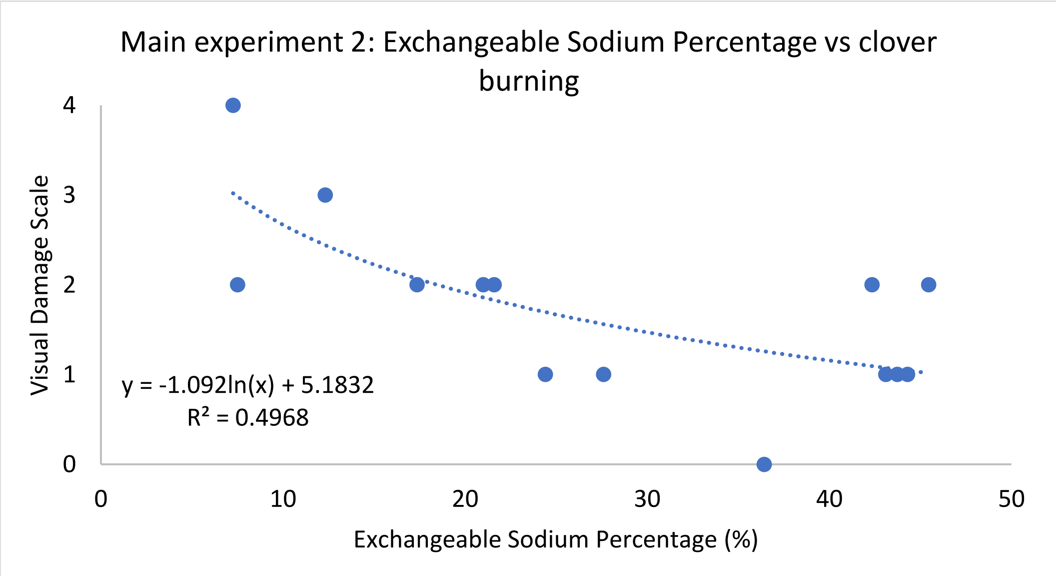

Main experiment 2: Total Nitrite-N vs ryegrass burning
y = 0.1774ln(x) + 1.038
R² = 0.0266
Visual Damage Scale
0
1
2
3
4
0
2
4
6
8
10
12
14
16
Total Nitrite-N (g/m3)

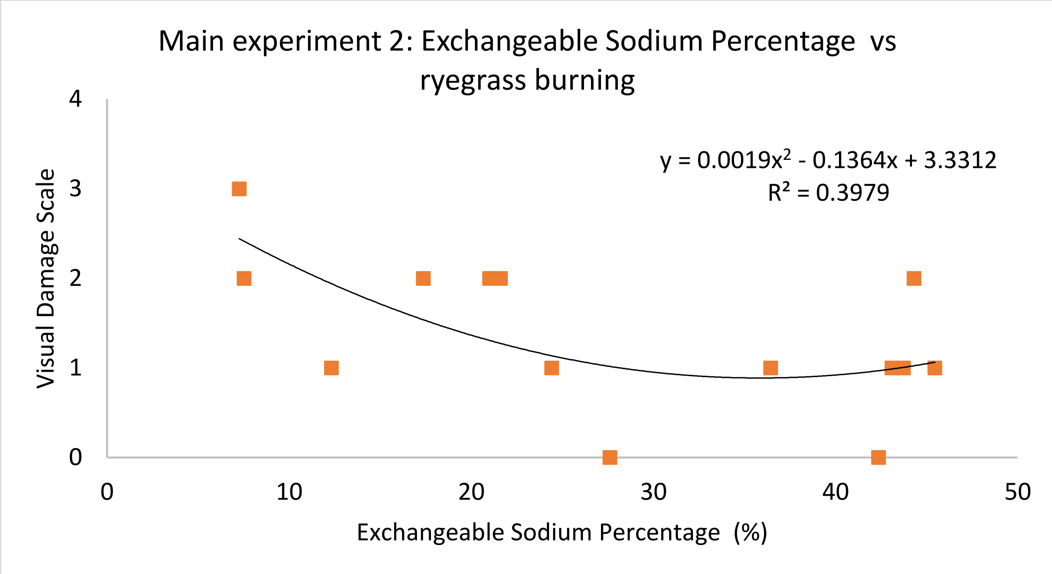

Main experiment 2: Total Nitrate-N vs clover burning
y = -0.0151x² + 0.2179x + 1.1758
R² = 0.0531
Visual Damage Scale
0
1
2
3
4
0
2
4
6
8
10
12
14
16
Total Nitrate-N (g/m3)

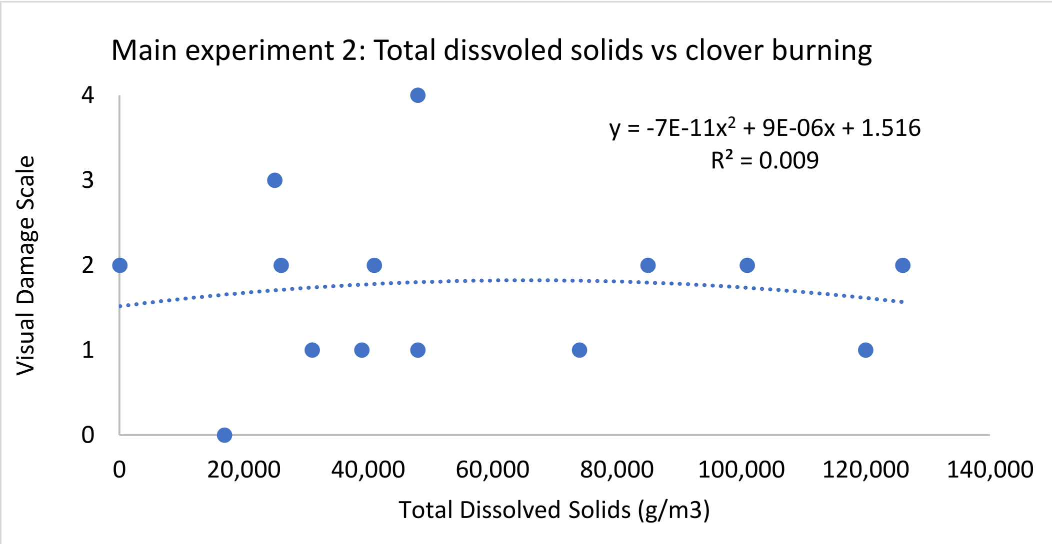

Main experiment 2: Total Nitrate-N vs ryegrass burning
y = 0.1774ln(x) + 1.038
R² = 0.0266
Visual Damage Scale
0
1
2
3
4
0
2
4
6
8
10
12
14
16
Total Nitrate-N (g/m3)

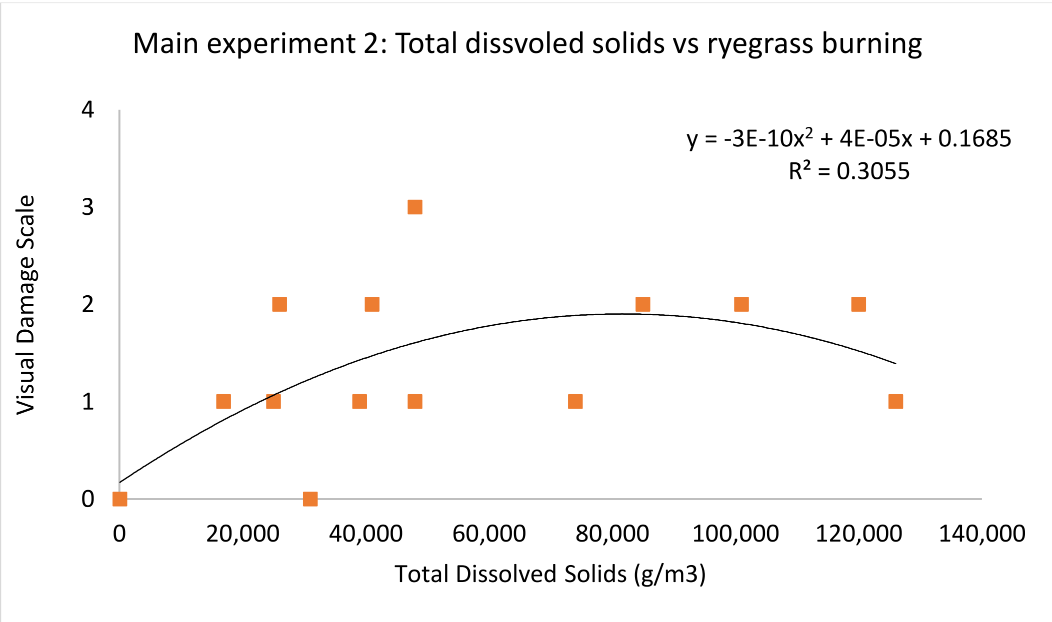

Main experiment 2: Sulphate vs clover burning
Visual Damage Scale
4
3
2
1
0
0
2,000
4,000
6,000
8,000
10,000
12,000
14,000
Sulphate (g/m3)
y = 1E-08x² - 0.0002x + 2.4692
R² = 0.0717

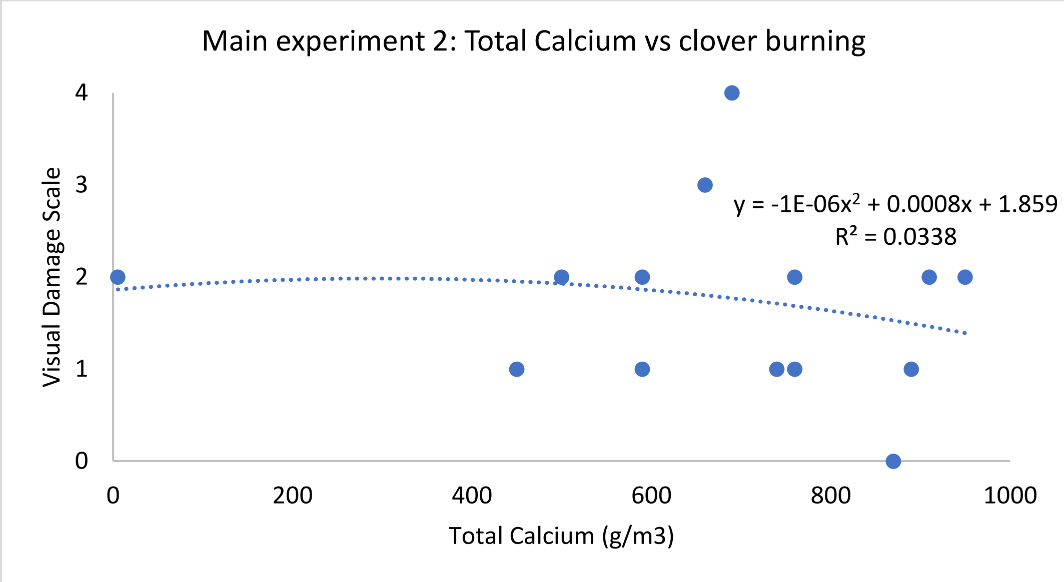

Main experiment 2: Sulphate vs ryegrass burning
Visual Damage Scale
4
3
2
1
0
0
2,000
4,000
6,000
8,000
10,000
12,000
14,000
Sulphate (g/m3)
y = -2E-08x² + 0.0003x + 0.4603
R² = 0.1303

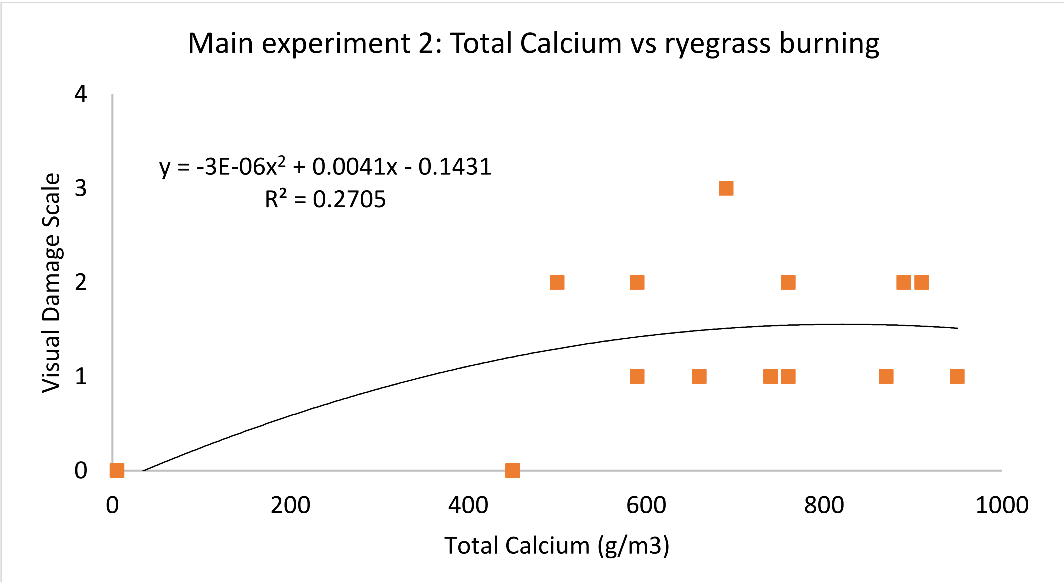

Main experiment 2: Exchangeable Sodium Percentage vs clover burning
Visual Damage Scale
4
3
2
1
0
0
10
20
30
40
50
Exchangeable Sodium Percentage (%)
y = -1.092ln(x) + 5.1832
R² = 0.4968

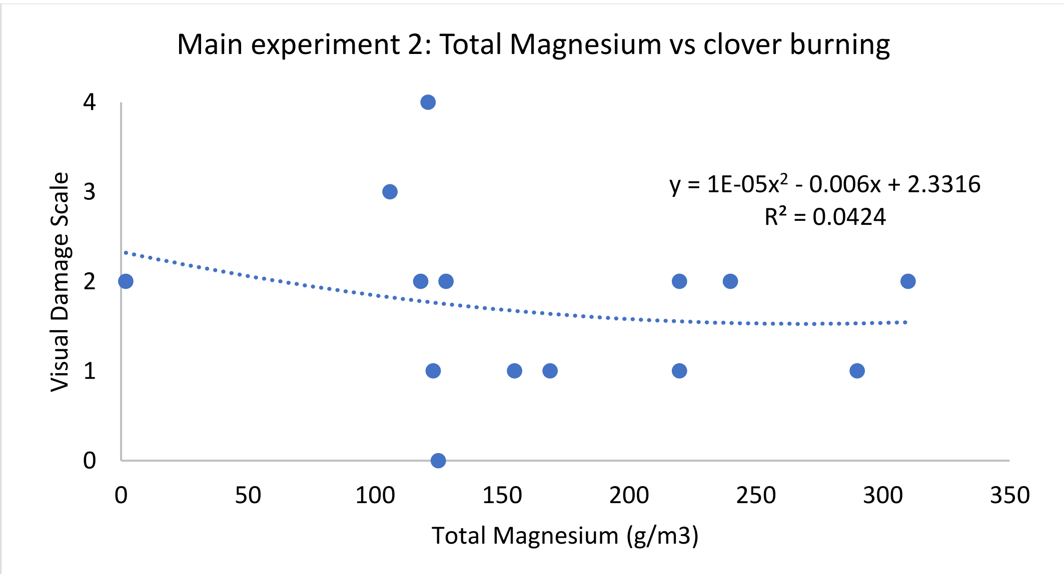

Main experiment 2: Exchangeable Sodium Percentage vs ryegrass burning
y = 0.0019x² - 0.1364x + 3.3312
R² = 0.3979
Visual Damage Scale
0
1
2
3
4
0
10
20
30
40
50
Exchangeable Sodium Percentage (%)

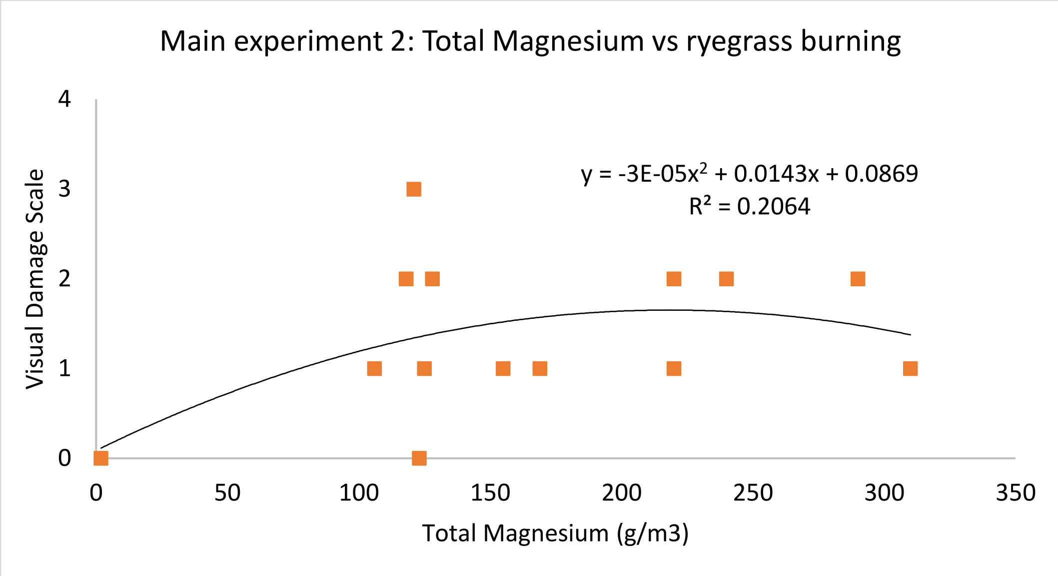

Main experiment 2: Total dissvoled solids vs clover burning
y = -7E-11x² + 9E-06x + 1.516
R² = 0.009
Visual Damage Scale
0
1
2
3
4
0
20,000
40,000
60,000
80,000
100,000
120,000
140,000
Total Dissolved Solids (g/m3)

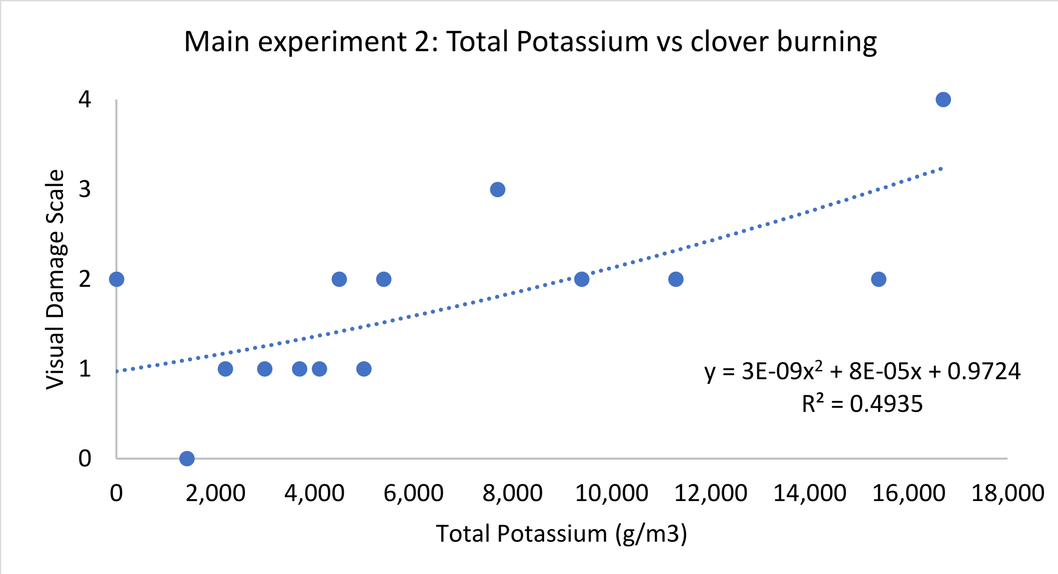

Main experiment 2: Total dissvoled solids vs ryegrass burning
y = -3E-10x² + 4E-05x + 0.1685
R² = 0.3055
Visual Damage Scale
0
1
2
3
4
0
20,000
40,000
60,000
80,000
100,000
120,000
140,000
Total Dissolved Solids (g/m3)

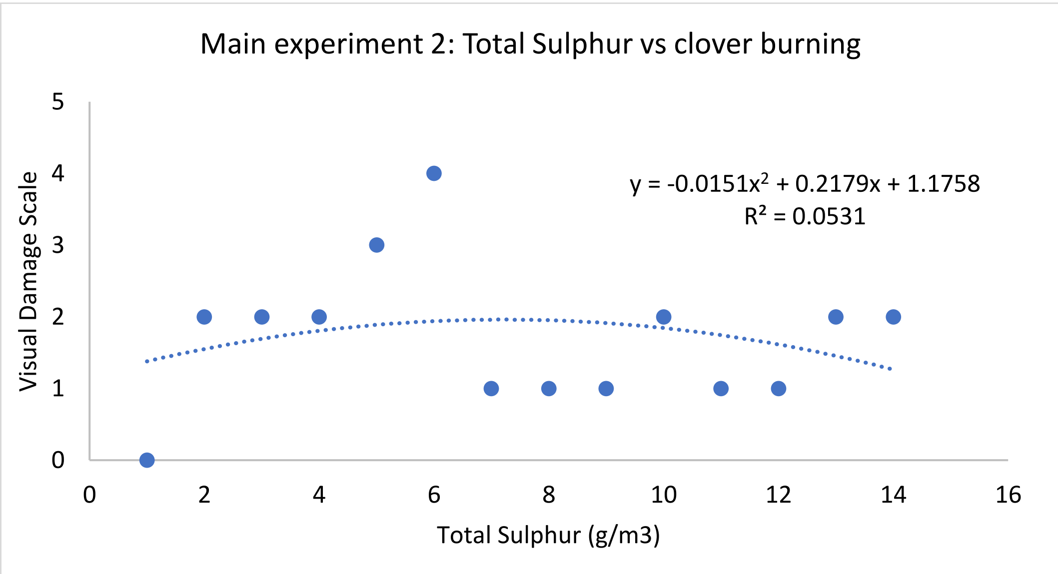

Main experiment 2: Total Calcium vs clover burning
Visual Damage Scale
Total Calcium (g/m3)
y = -1E-06x² + 0.0008x + 1.859
R² = 0.0338
0
1
2
3
4
0
200
400
600
800
1000

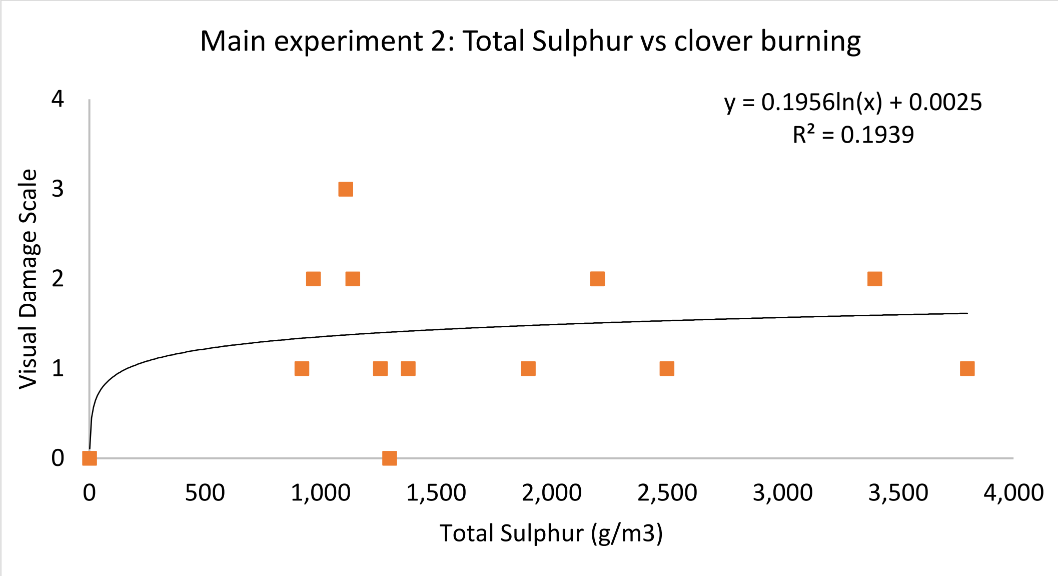

Main experiment 2: Total Calcium vs ryegrass burning
Visual Damage Scale
Total Calcium (g/m3)
y = -3E-06x² + 0.0041x - 0.1431
R² = 0.2705
0
1
2
3
4
0
200
400
600
800
1000

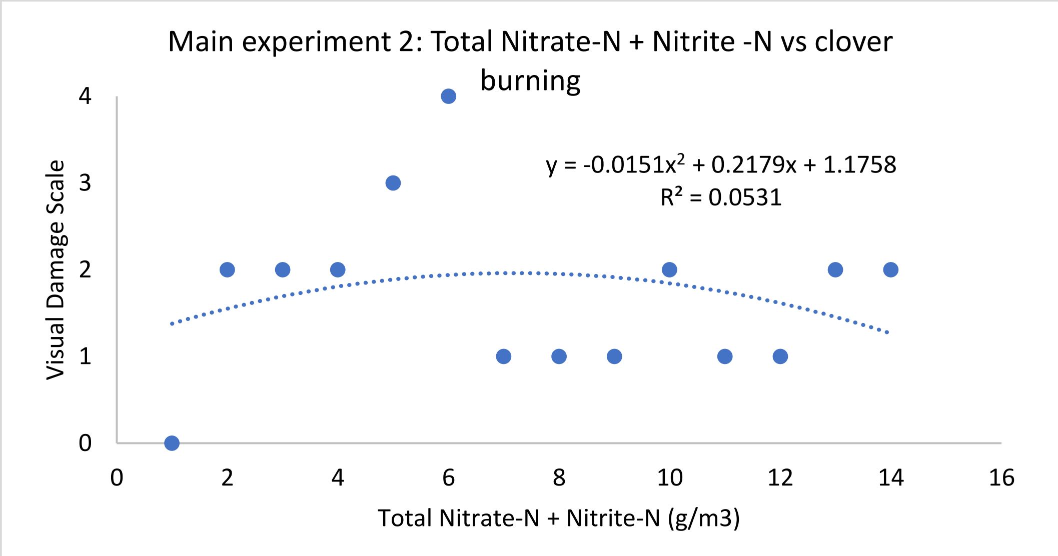

Main experiment 2: Total Magnesium vs clover burning
Visual Damage Scale
Total Magnesium (g/m3)
y = 1E-05x² - 0.006x + 2.3316
R² = 0.0424
0
1
2
3
4
0
50
100
150
200
250
300
350

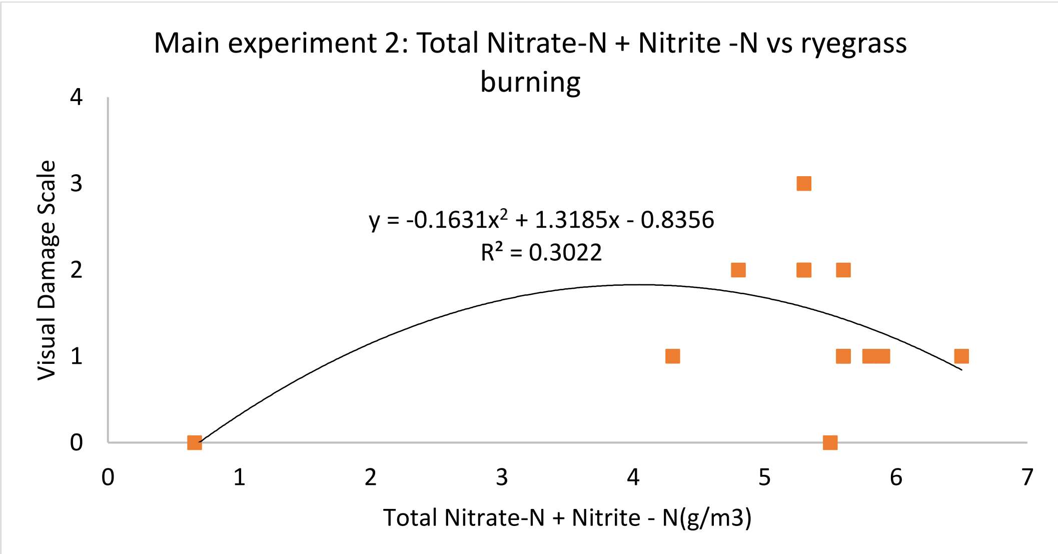

Main experiment 2: Total Magnesium vs ryegrass burning
y = -3E-05x² + 0.0143x + 0.0869
R² = 0.2064
Visual Damage Scale
Total Magnesium (g/m3)
0
1
2
3
4
0
50
100
150
200
250
300
350

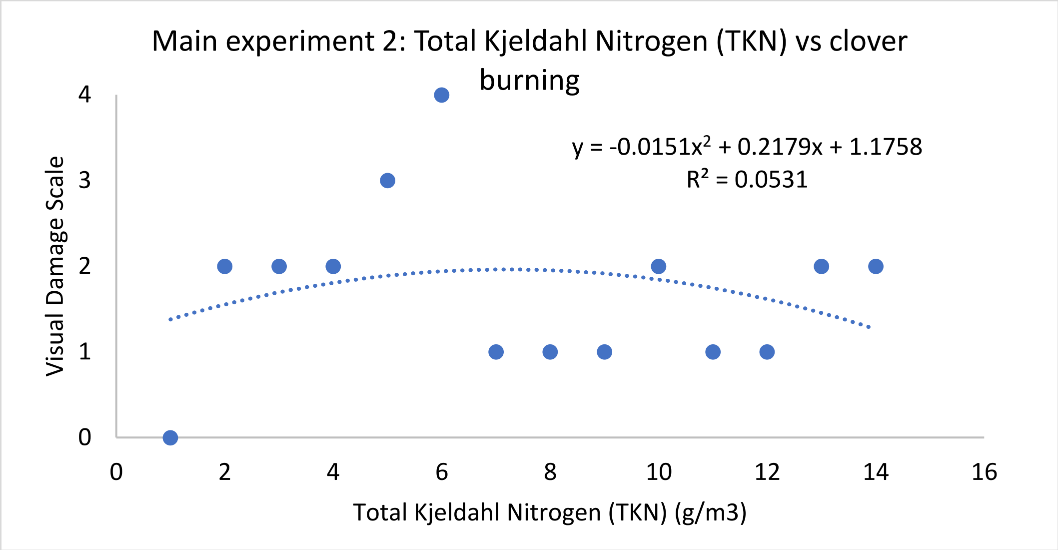

Main experiment 2: Total Potassium vs clover burning
y = 3E-09x² + 8E-05x + 0.9724
R² = 0.4935
Visual Damage Scale
Total Potassium (g/m3)
0
1
2
3
4
0
2,000
4,000
6,000
8,000
10,000
12,000
14,000
16,000
18,000

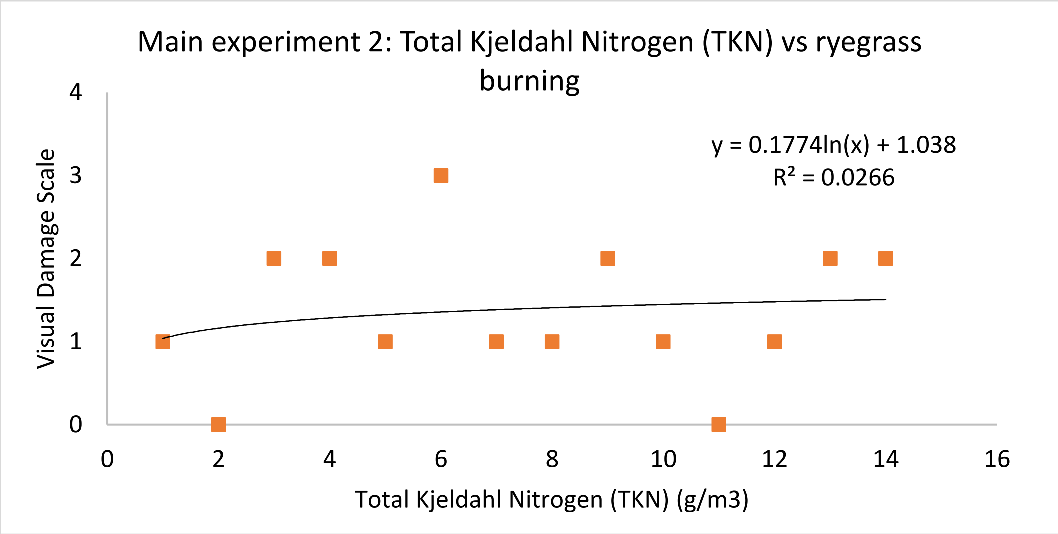

Main experiment 2: Total Sulphur vs clover burning
y = -0.0151x² + 0.2179x + 1.1758
R² = 0.0531
Visual Damage Scale
Total Sulphur (g/m3)
0
1
2
3
4
5
0
2
4
6
8
10
12
14
16

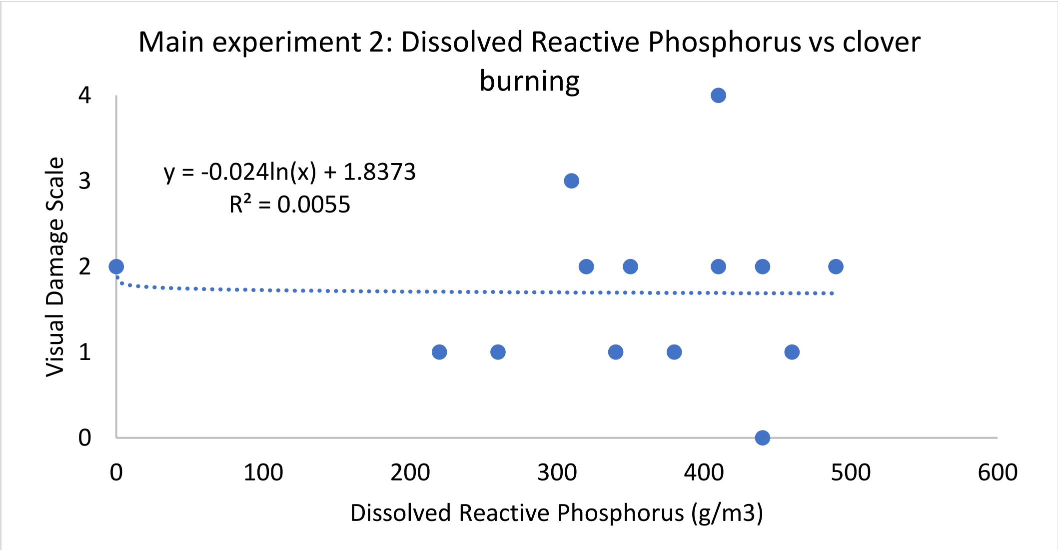

Main experiment 2: Total Sulphur vs clover burning
y = 0.1956ln(x) + 0.0025
R² = 0.1939
Visual Damage Scale
0
1
2
3
4
0
500
1,000
1,500
2,000
2,500
3,000
3,500
4,000
Total Sulphur (g/m3)

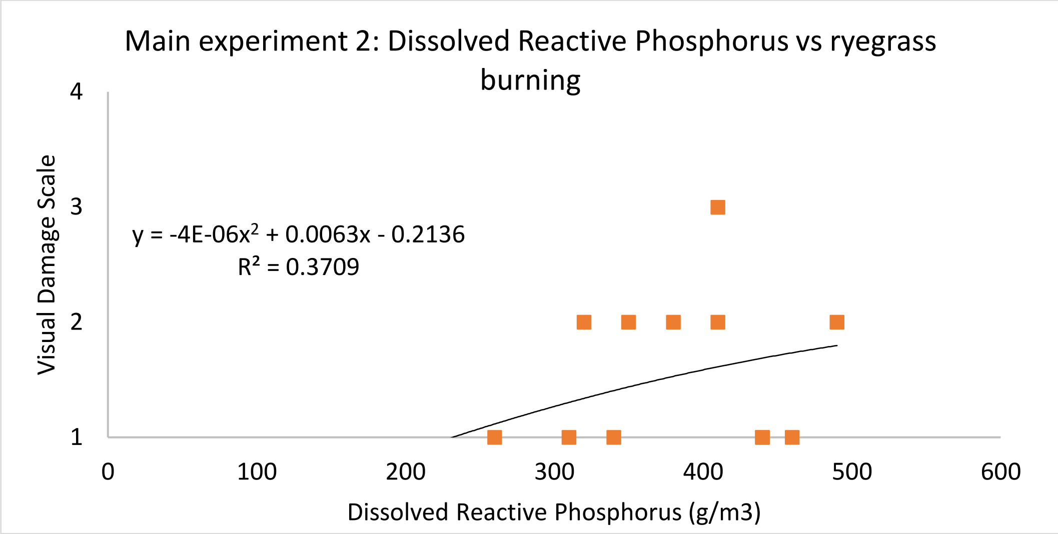

Main experiment 2: Total Nitrate-N + Nitrite -N vs clover burning
y = -0.0151x² + 0.2179x + 1.1758
R² = 0.0531
Visual Damage Scale
0
1
2
3
4
0
2
4
6
8
10
12
14
16
Total Nitrate-N + Nitrite-N (g/m3)


Main experiment 2: Total Nitrate-N + Nitrite -N vs ryegrass burning
y = -0.1631x² + 1.3185x - 0.8356
R² = 0.3022
Visual Damage Scale
0
1
2
3
4
0
1
2
3
4
5
6
7
Total Nitrate-N + Nitrite - N(g/m3)

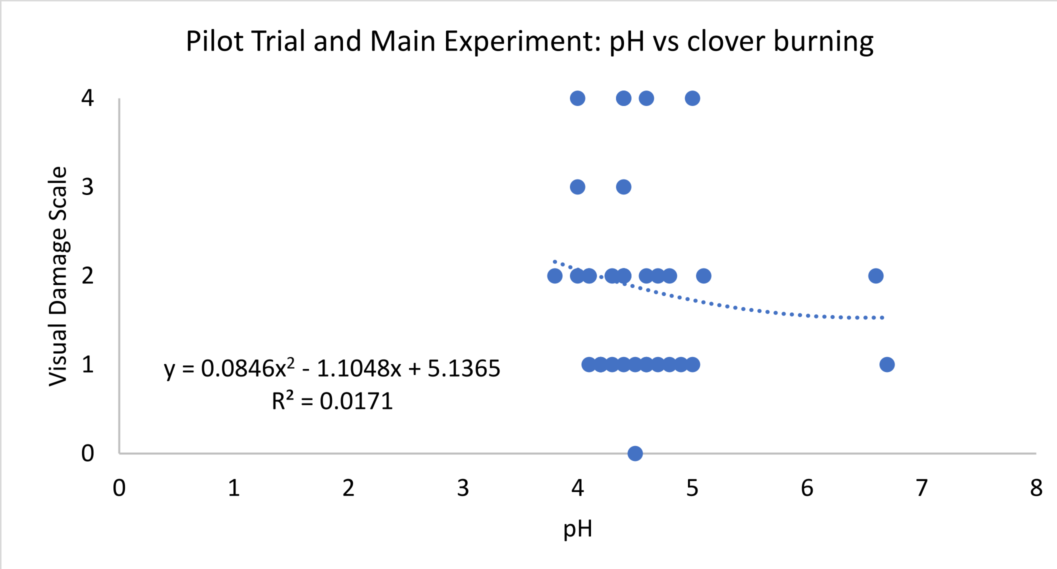

Main experiment 2: Total Kjeldahl Nitrogen (TKN) vs clover burning
y = -0.0151x² + 0.2179x + 1.1758
R² = 0.0531
Visual Damage Scale
0
1
2
3
4
0
2
4
6
8
10
12
14
16
Total Kjeldahl Nitrogen (TKN) (g/m3)

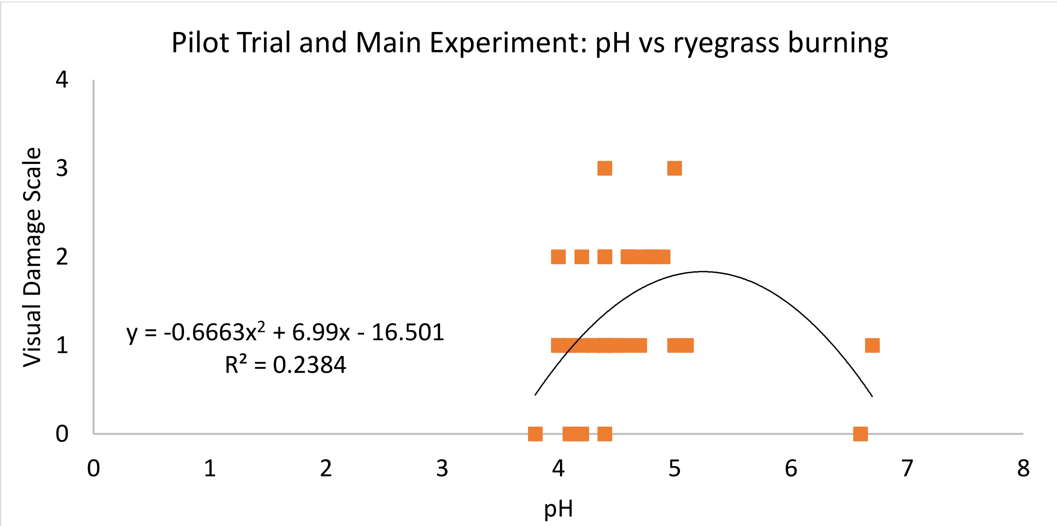

Main experiment 2: Total Kjeldahl Nitrogen (TKN) vs ryegrass burning
y = 0.1774ln(x) + 1.038
R² = 0.0266
Visual Damage Scale
0
1
2
3
4
0
2
4
6
8
10
12
14
16
Total Kjeldahl Nitrogen (TKN) (g/m3)

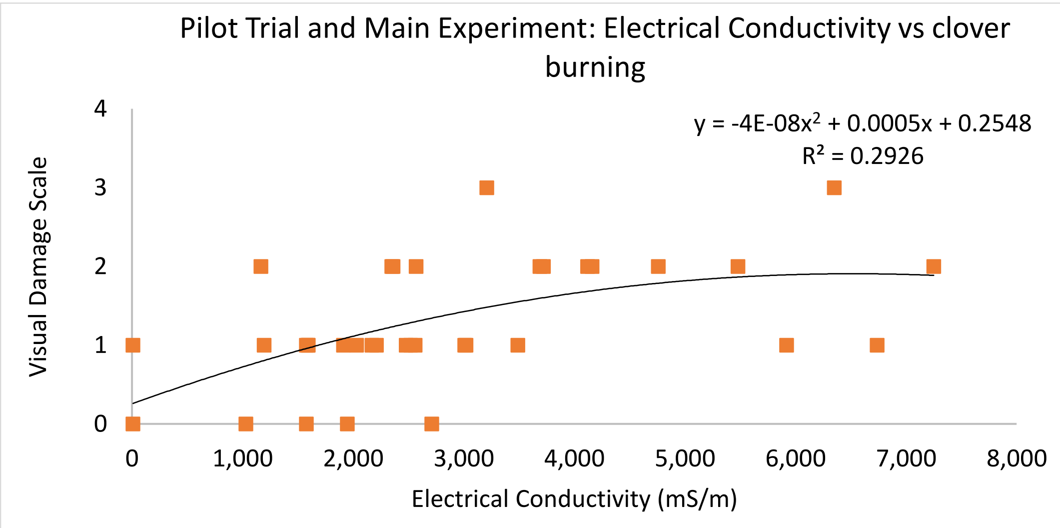

Main experiment 2: Dissolved Reactive Phosphorus vs clover burning
y = -0.024ln(x) + 1.8373
R² = 0.0055
Visual Damage Scale
0
1
2
3
4
0
100
200
300
400
500
600
Dissolved Reactive Phosphorus (g/m3)

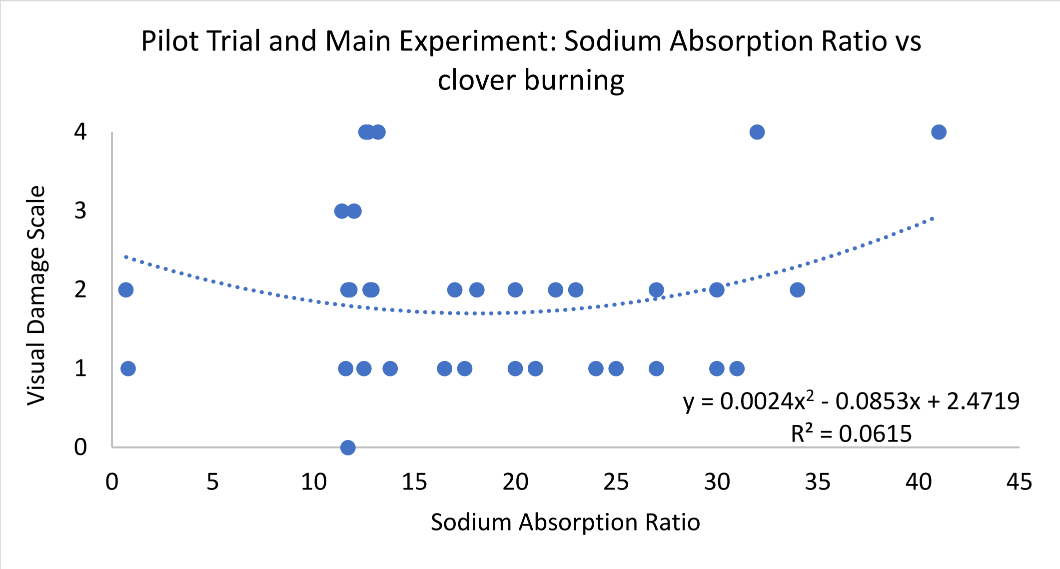

Main experiment 2: Dissolved Reactive Phosphorus vs ryegrass burning
Visual Damage Scale
4
3
2
1
y = -4E-06x² + 0.0063x - 0.2136
R² = 0.3709
0
100
200
300
400
500
600
Dissolved Reactive Phosphorus (g/m3)

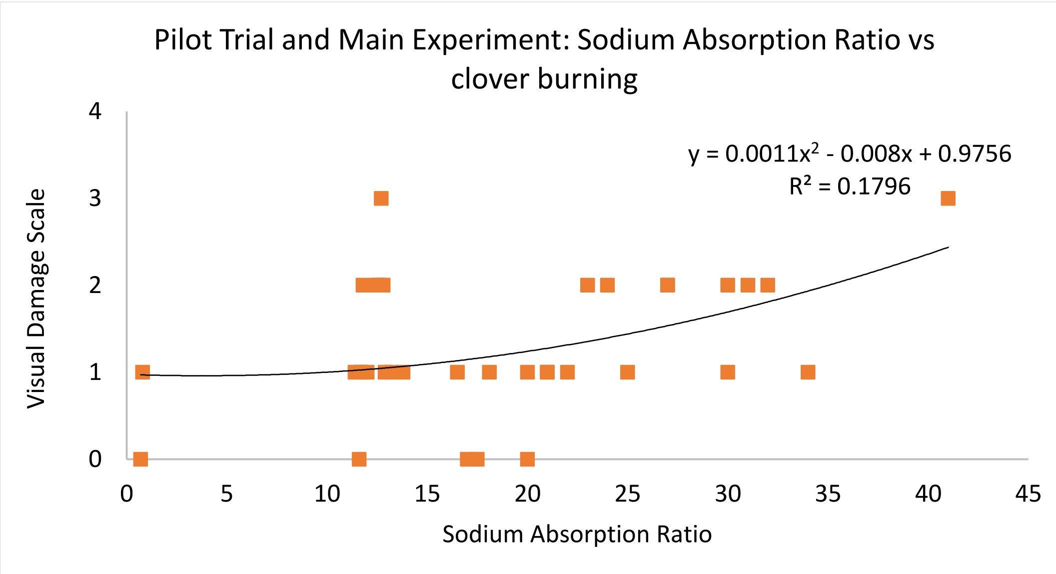
Pilot trial, Main experiment; Block 1 and 2: Results

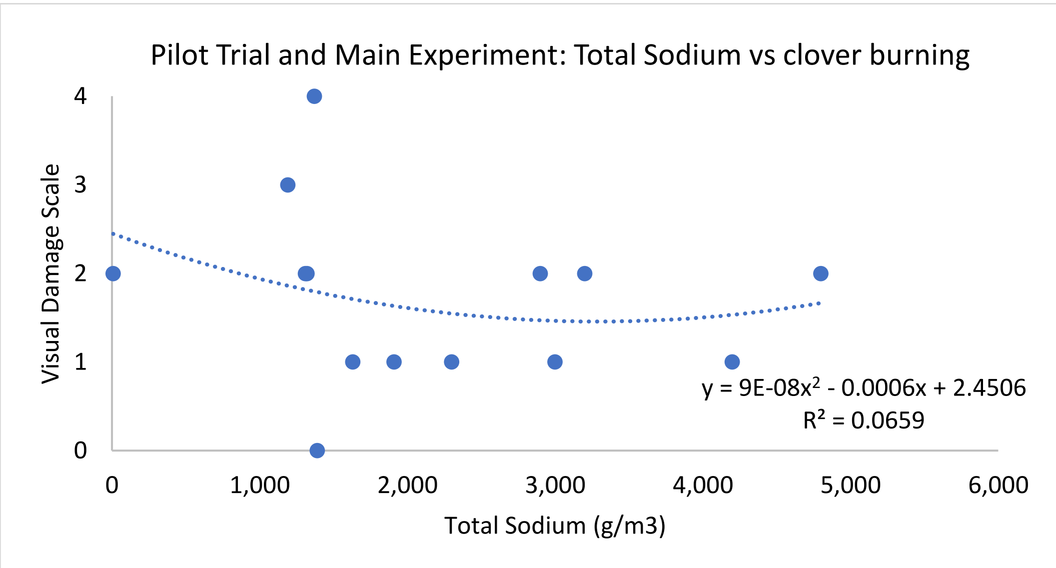


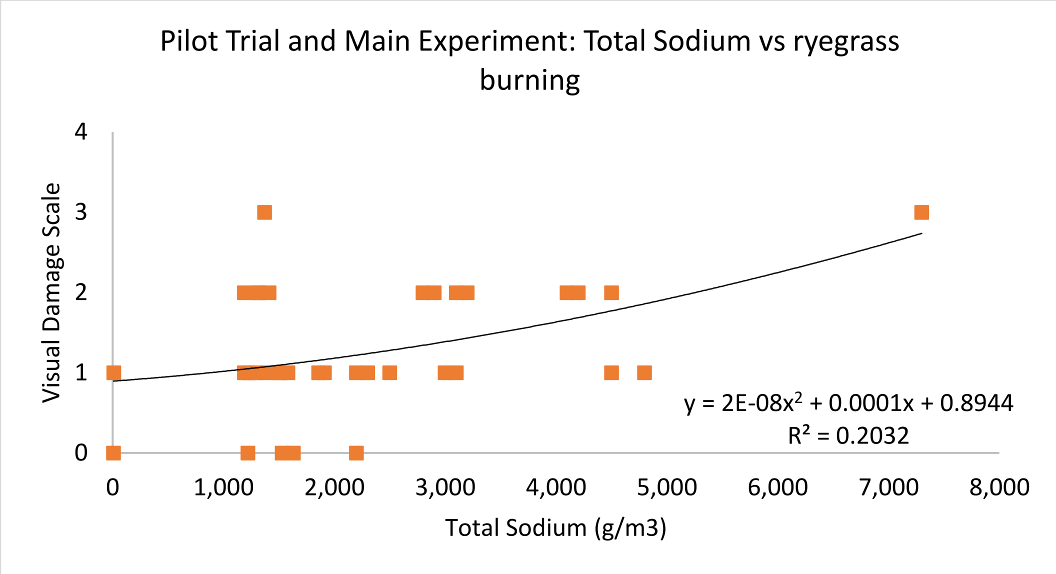


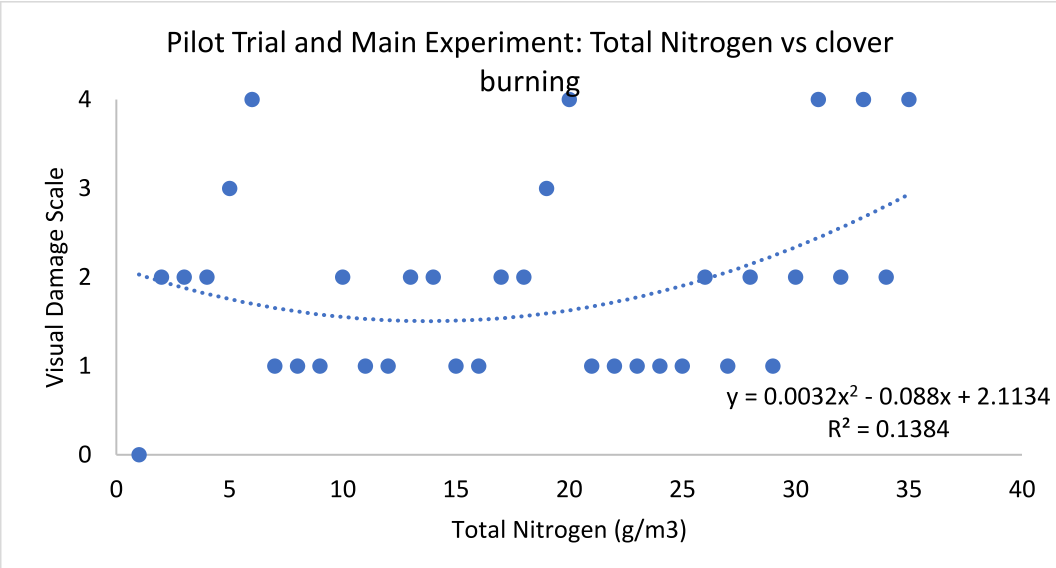


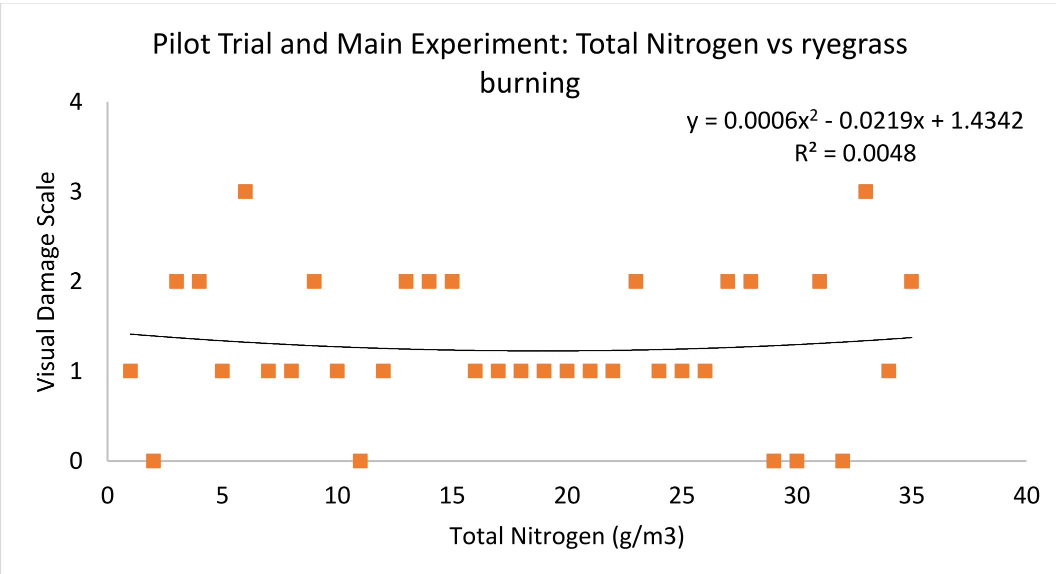

Pilot Trial and Main Experiment: Sodium Absorption Ratio vs clover burning
Visual Damage Scale
4
3
2
1
0
0
5
10
15
20
25
30
35
40
45
Sodium Absorption Ratio
y = 0.0024x² - 0.0853x + 2.4719
R² = 0.0615

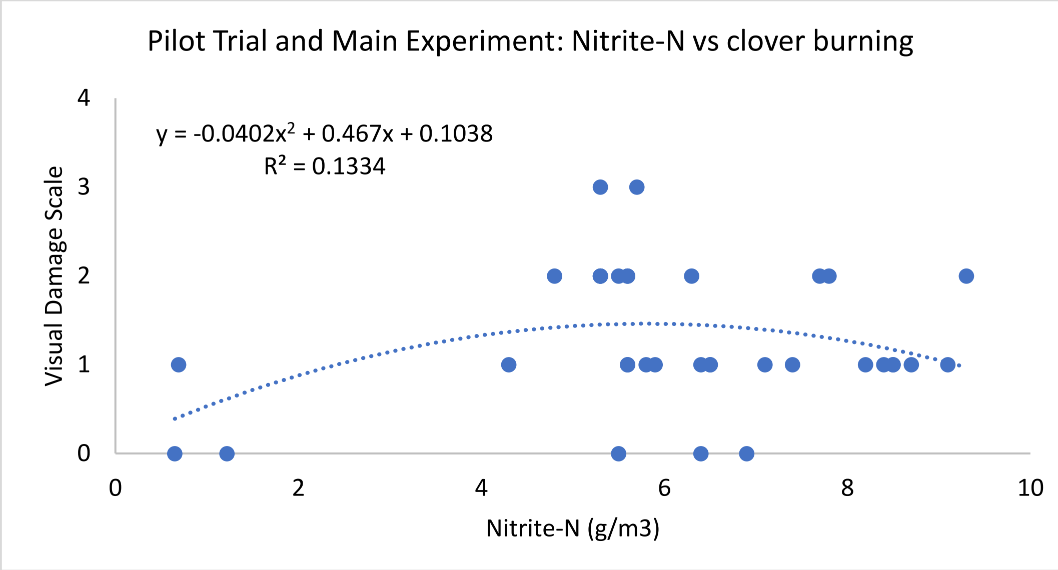

Pilot Trial and Main Experiment: Sodium Absorption Ratio vs clover burning
Visual Damage Scale
4
3
2
1
0
0
5
10
15
20
25
30
35
40
45
Sodium Absorption Ratio
y = 0.0011x² - 0.008x + 0.9756
R² = 0.1796

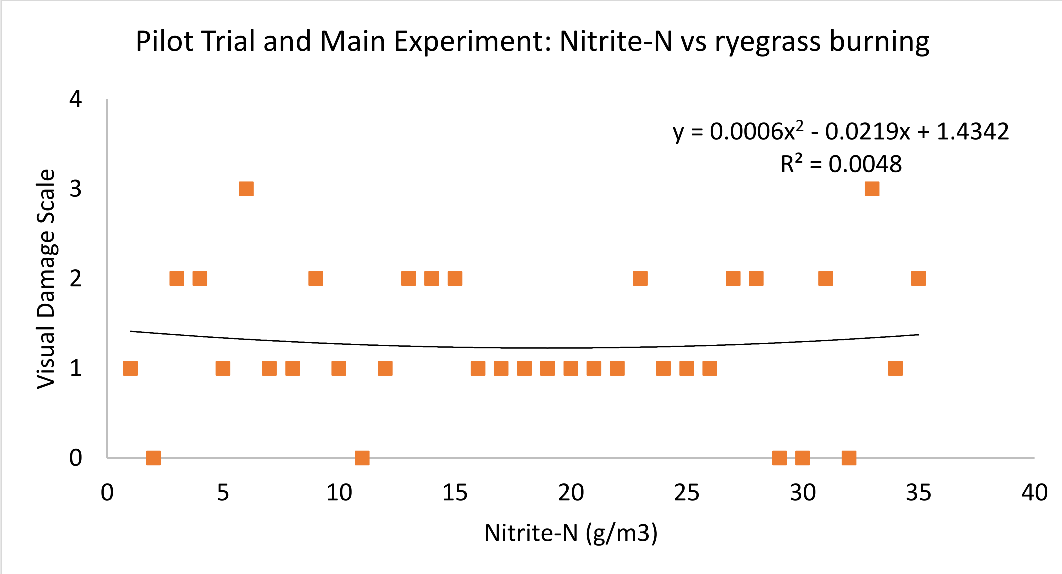

Pilot Trial and Main Experiment: Total Sodium vs clover burning
Visual Damage Scale
4
3
2
1
0
0
1,000
2,000
3,000
4,000
5,000
6,000
Total Sodium (g/m3)
y = 9E-08x² - 0.0006x + 2.4506
R² = 0.0659

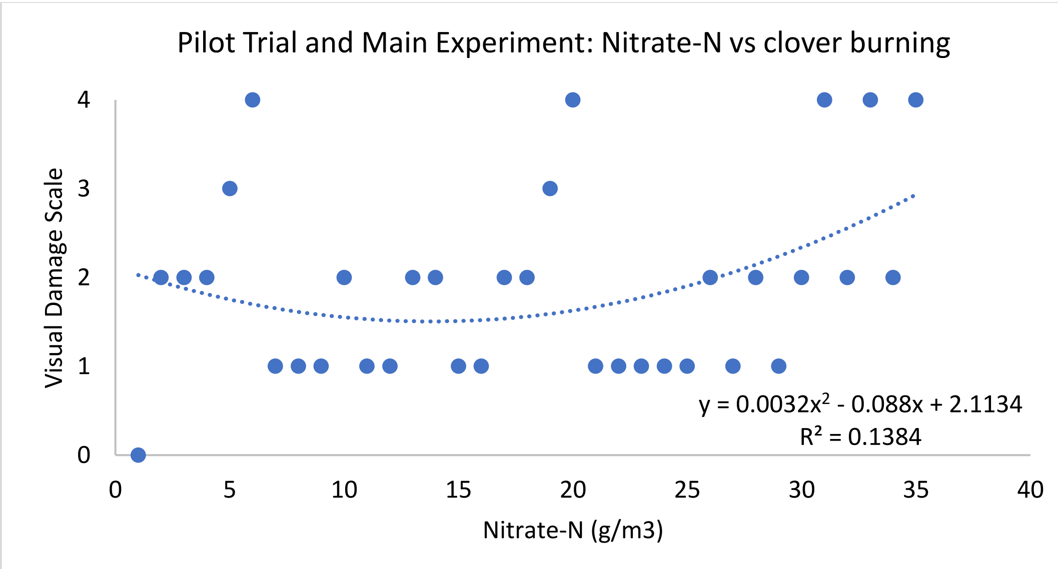

Pilot Trial and Main Experiment: Total Sodium vs ryegrass burning
Visual Damage Scale
Total Sodium (g/m3)
0
1,000
2,000
3,000
4,000
5,000
6,000
7,000
8,000
0
1
2
3
4
y = 2E-08x² + 0.0001x + 0.8944
R² = 0.2032

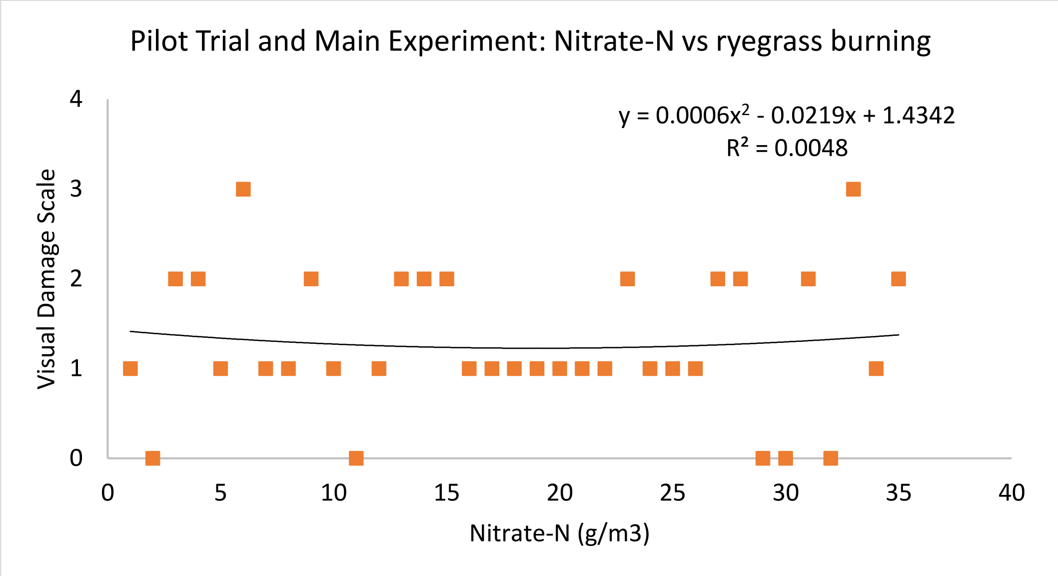

Pilot Trial and Main Experiment: Total Nitrogen vs clover burning
Visual Damage Scale
Total Nitrogen (g/m3)
0
5
10
15
20
25
30
35
40
0
1
2
3
4
y = 0.0032x² - 0.088x + 2.1134
R² = 0.1384

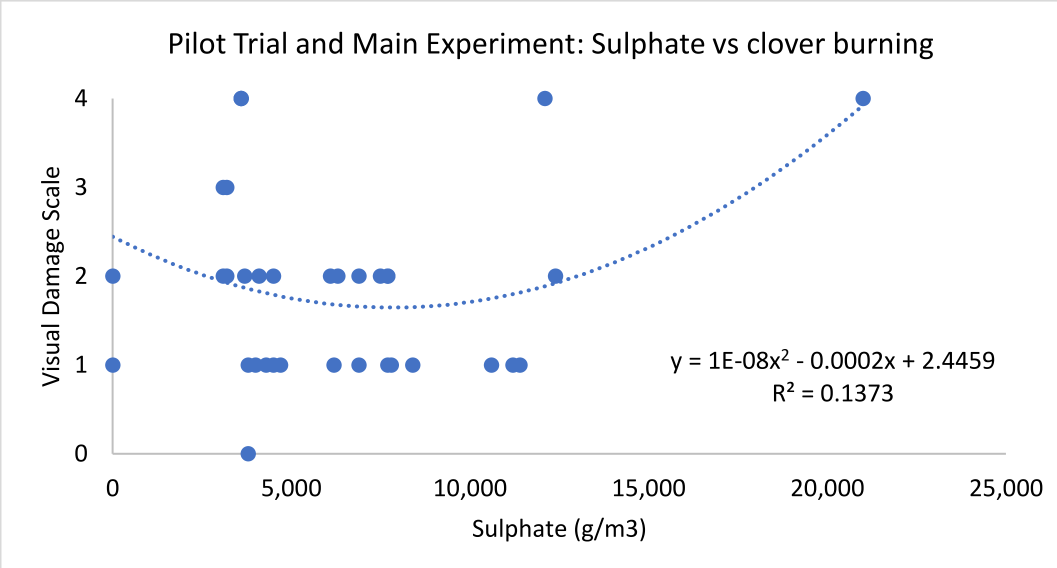

Pilot Trial and Main Experiment: Total Nitrogen vs ryegrass burning
Visual Damage Scale
Total Nitrogen (g/m3)
0
5
10
15
20
25
30
35
40
0
1
2
3
4
y = 0.0006x² - 0.0219x + 1.4342
R² = 0.0048

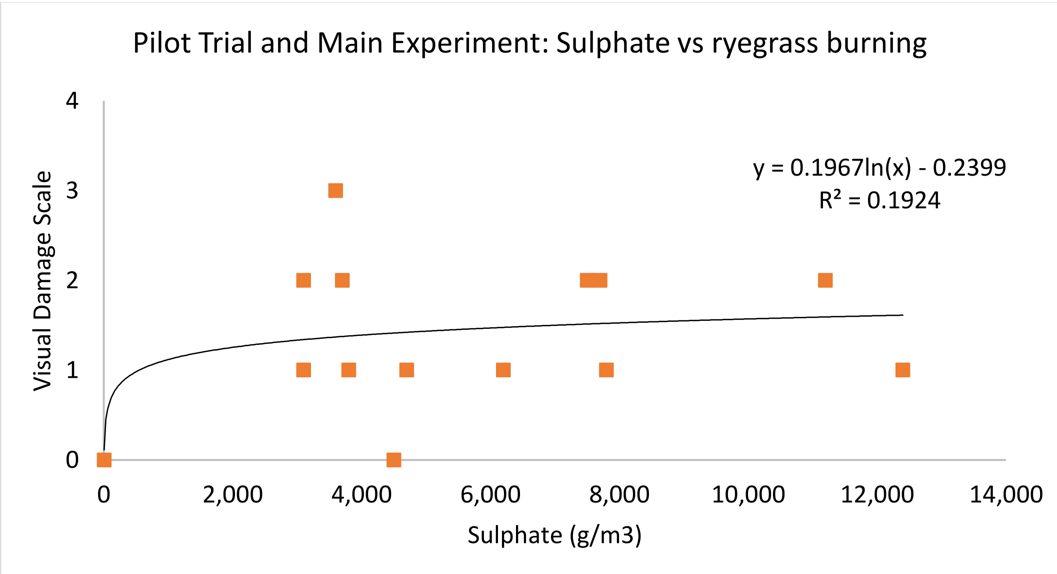

Pilot Trial and Main Experiment: Nitrite-N vs clover burning
y = -0.0402x² + 0.467x + 0.1038
R² = 0.1334
Visual Damage Scale
0
1
2
3
4
0
2
4
6
8
10
Nitrite-N (g/m3)

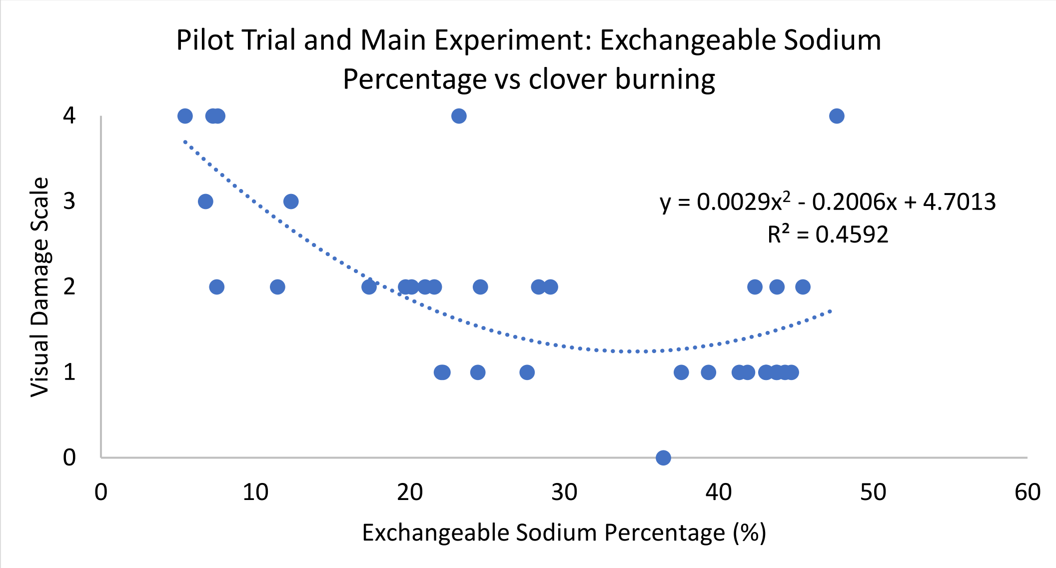

Pilot Trial and Main Experiment: Nitrite-N vs ryegrass burning
y = 0.0006x² - 0.0219x + 1.4342
R² = 0.0048
Visual Damage Scale
0
1
2
3
4
0
5
10
15
20
25
30
35
40
Nitrite-N (g/m3)

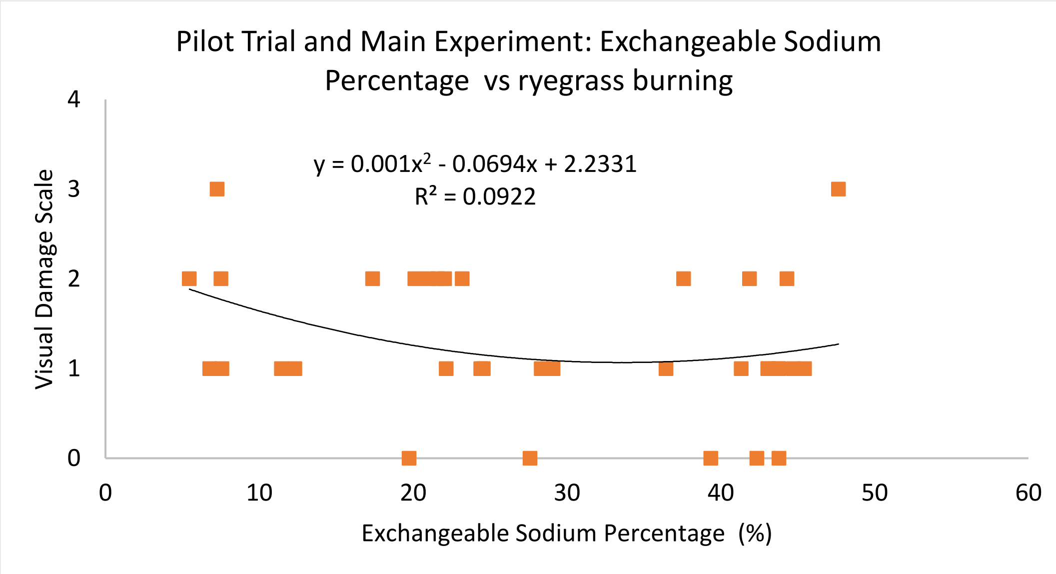

Pilot Trial and Main Experiment: Nitrate-N vs clover burning
y = 0.0032x² - 0.088x + 2.1134
R² = 0.1384
Visual Damage Scale
0
1
2
3
4
0
5
10
15
20
25
30
35
40
Nitrate-N (g/m3)

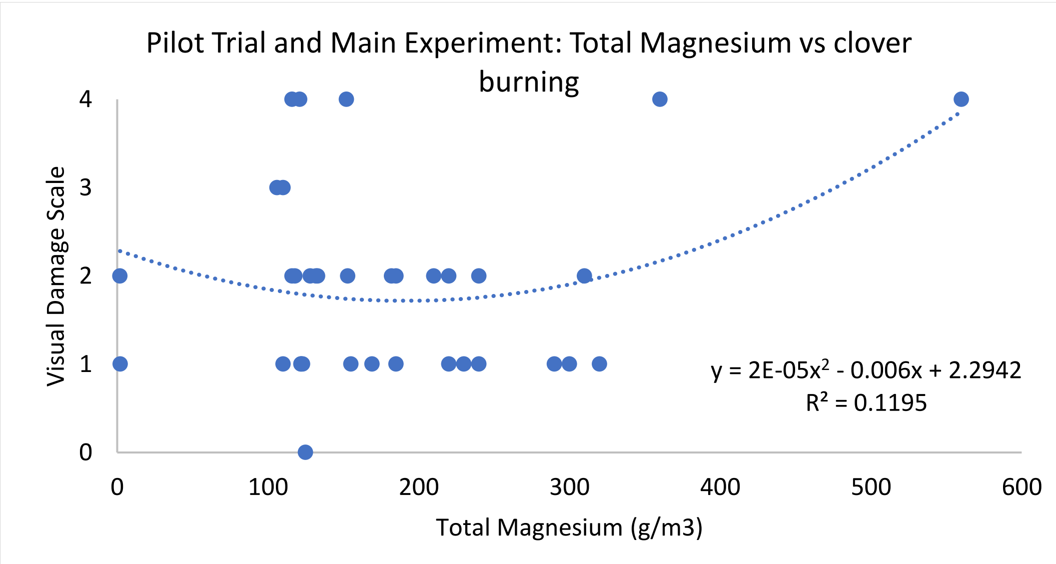

Pilot Trial and Main Experiment: Nitrate-N vs ryegrass burning
y = 0.0006x² - 0.0219x + 1.4342
R² = 0.0048
Visual Damage Scale
Nitrate-N (g/m3)
0
1
2
3
4
0
5
10
15
20
25
30
35
40

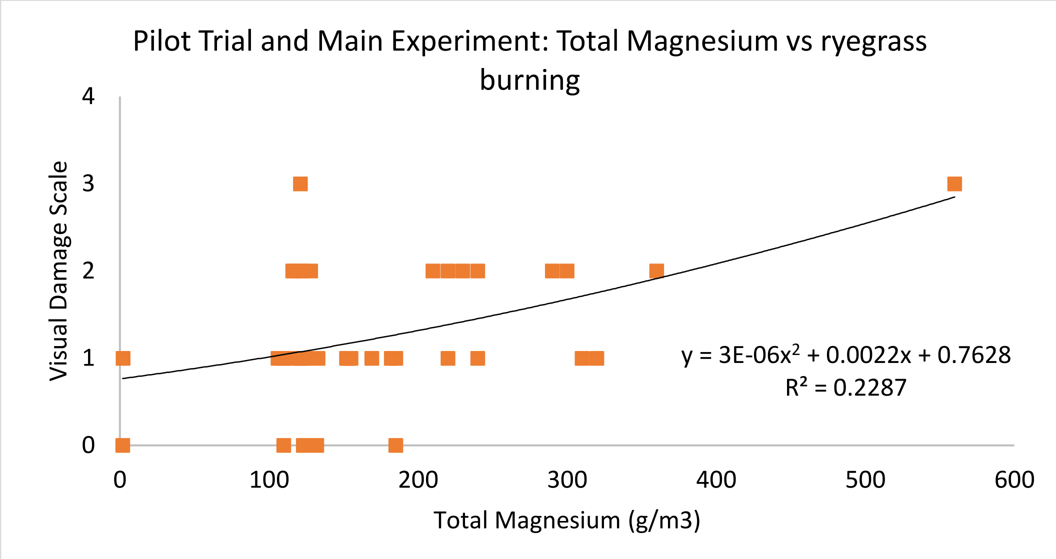

Pilot Trial and Main Experiment: Sulphate vs clover burning
y = 1E-08x² - 0.0002x + 2.4459
R² = 0.1373
Visual Damage Scale
Sulphate (g/m3)
0
1
2
3
4
0
5,000
10,000
15,000
20,000
25,000

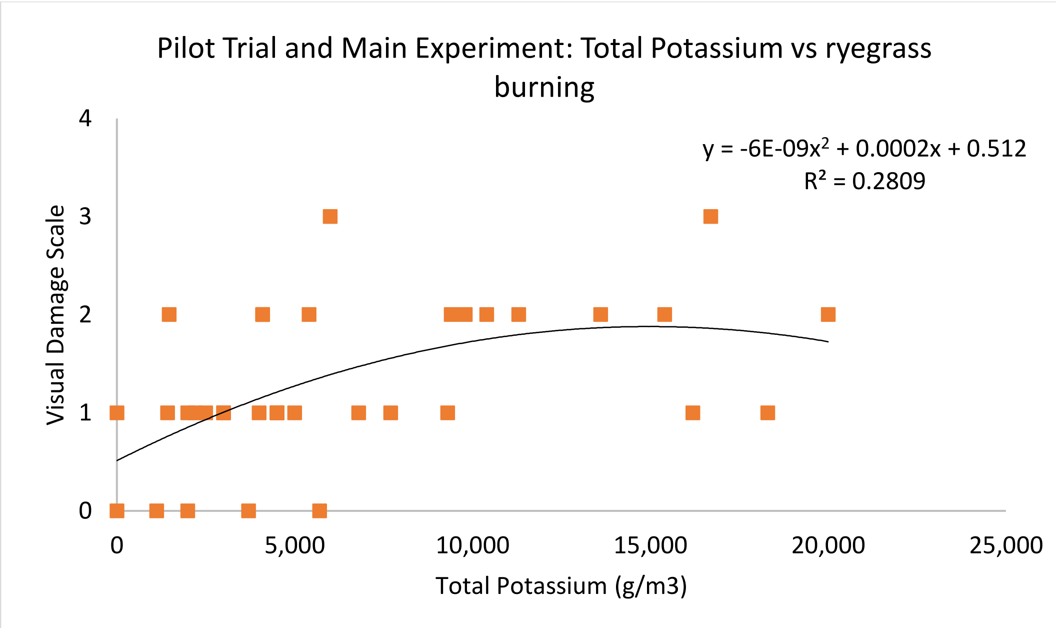

Pilot Trial and Main Experiment: Sulphate vs ryegrass burning
y = 0.1967ln(x) - 0.2399
R² = 0.1924
Visual Damage Scale
Sulphate (g/m3)
0
1
2
3
4
0
2,000
4,000
6,000
8,000
10,000
12,000
14,000

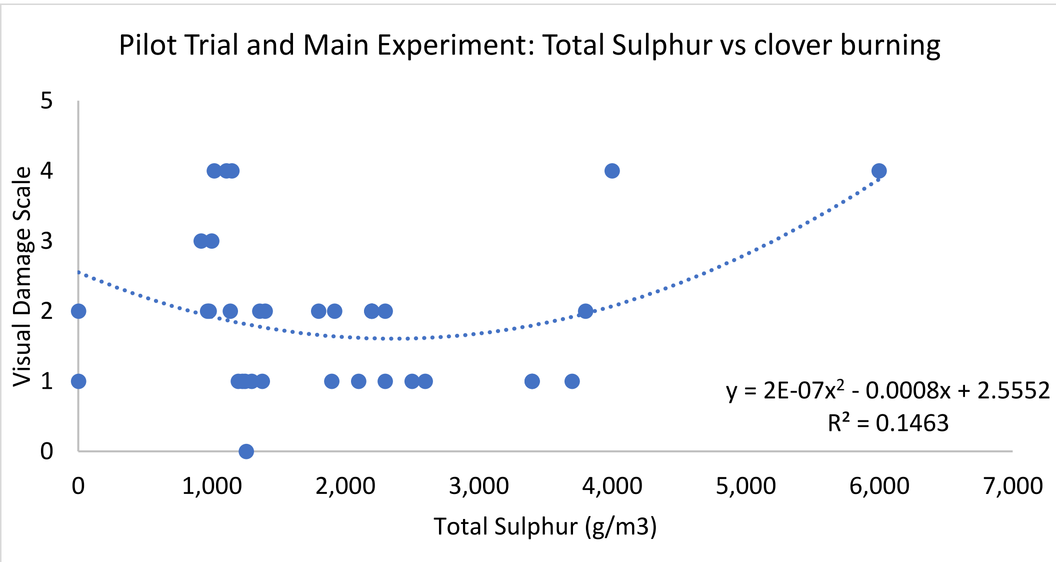

Pilot Trial and Main Experiment: Exchangeable Sodium Percentage vs clover burning
y = 0.0029x² - 0.2006x + 4.7013
R² = 0.4592
Visual Damage Scale
0
1
2
3
4
0
10
20
30
40
50
60
Exchangeable Sodium Percentage (%)

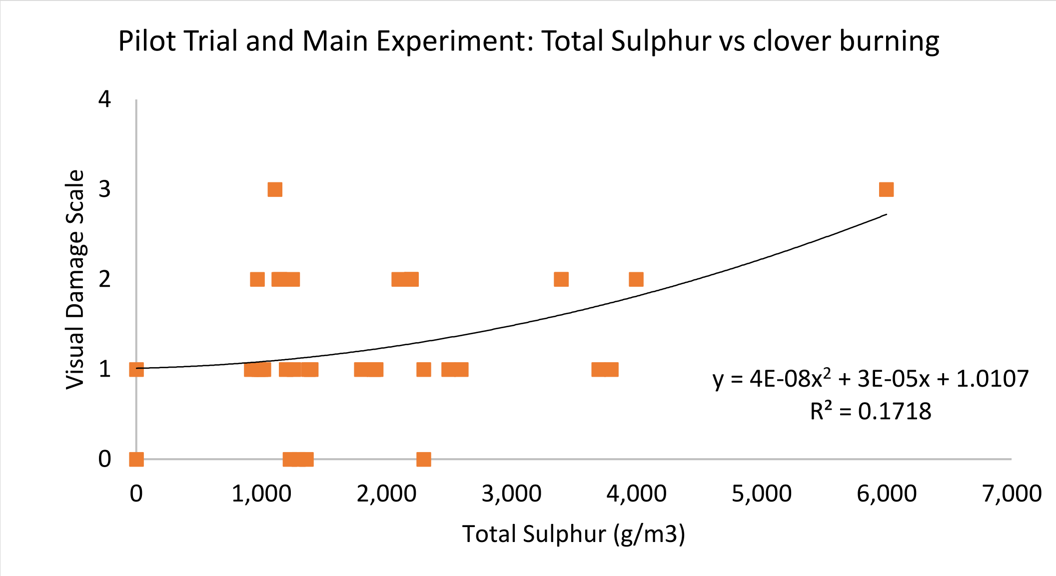

Pilot Trial and Main Experiment: Exchangeable Sodium Percentage vs ryegrass burning
y = 0.001x² - 0.0694x + 2.2331
R² = 0.0922
Visual Damage Scale
0
1
2
3
4
0
10
20
30
40
50
60
Exchangeable Sodium Percentage (%)

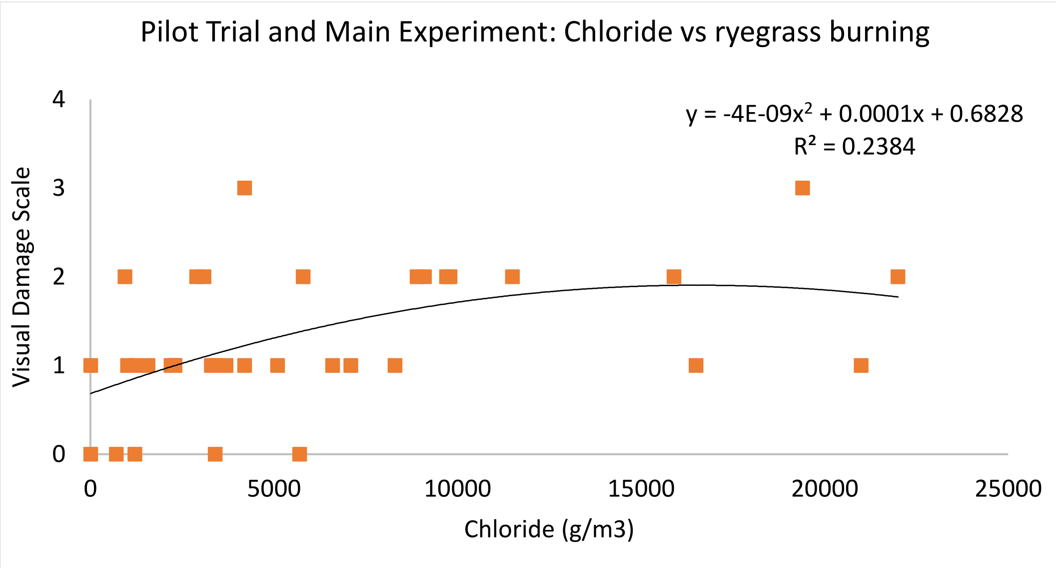

Pilot Trial and Main Experiment: Total Magnesium vs clover burning
y = 2E-05x² - 0.006x + 2.2942
R² = 0.1195
Visual Damage Scale
0
1
2
3
4
0
100
200
300
400
500
600
Total Magnesium (g/m3)

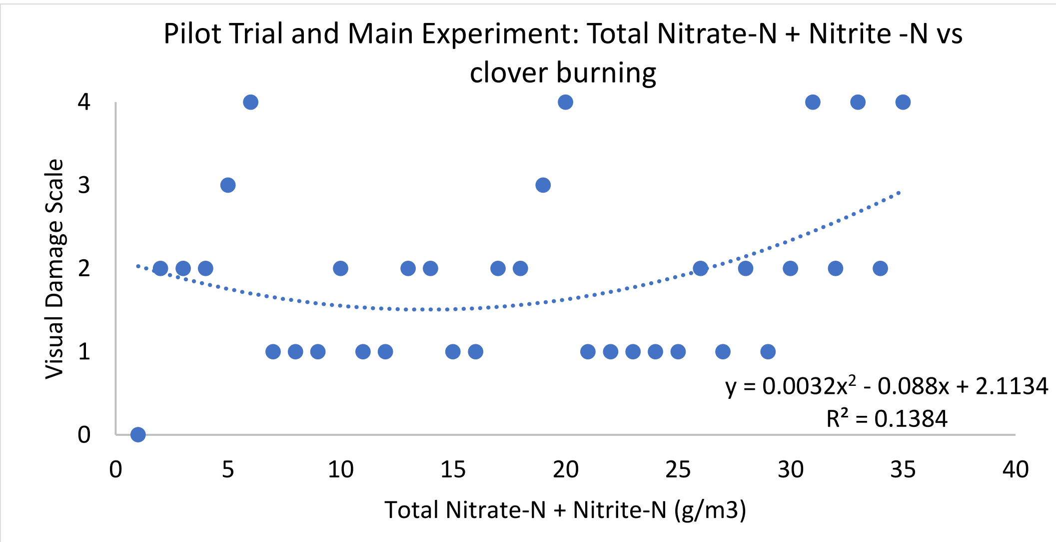

Pilot Trial and Main Experiment: Total Magnesium vs ryegrass burning
Visual Damage Scale
4
3
2
1
0
0
100
200
300
400
500
600
Total Magnesium (g/m3)
y = 3E-06x² + 0.0022x + 0.7628
R² = 0.2287

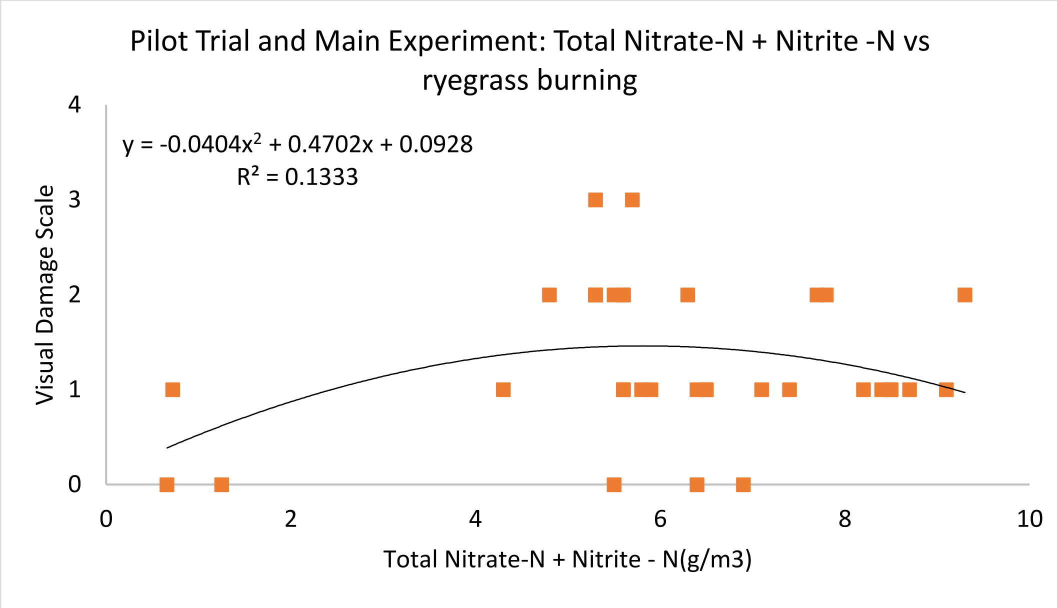

Pilot Trial and Main Experiment: Total Potassium vs ryegrass burning
Visual Damage Scale
4
3
2
1
0
0
5,000
10,000
15,000
20,000
25,000
Total Potassium (g/m3)
y = -6E-09x² + 0.0002x + 0.512
R² = 0.2809

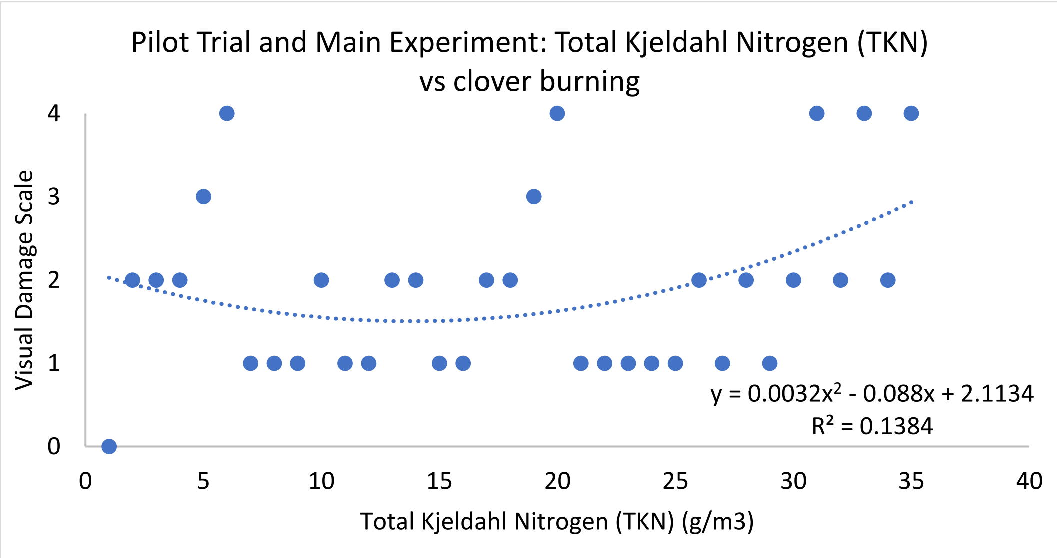

Pilot Trial and Main Experiment: Total Sulphur vs clover burning
Visual Damage Scale
5
4
3
2
1
0
0
1,000
2,000
3,000
4,000
5,000
6,000
7,000
Total Sulphur (g/m3)
y = 2E-07x² - 0.0008x + 2.5552
R² = 0.1463

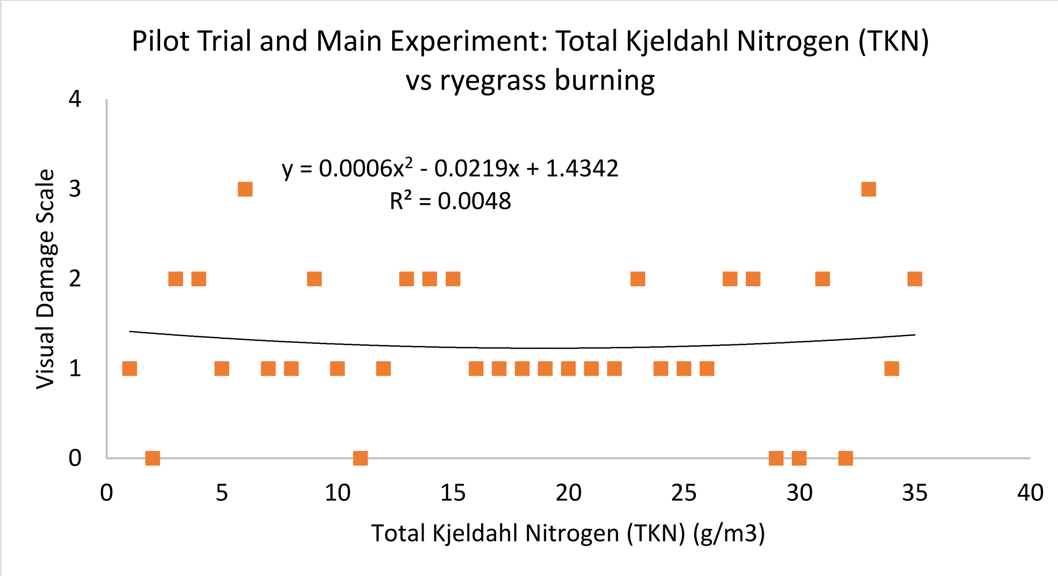

Pilot Trial and Main Experiment: Total Sulphur vs clover burning
Visual Damage Scale
Total Sulphur (g/m3)
y = 4E-08x² + 3E-05x + 1.0107
R² = 0.1718
0
1
2
3
4
0
1,000
2,000
3,000
4,000
5,000
6,000
7,000

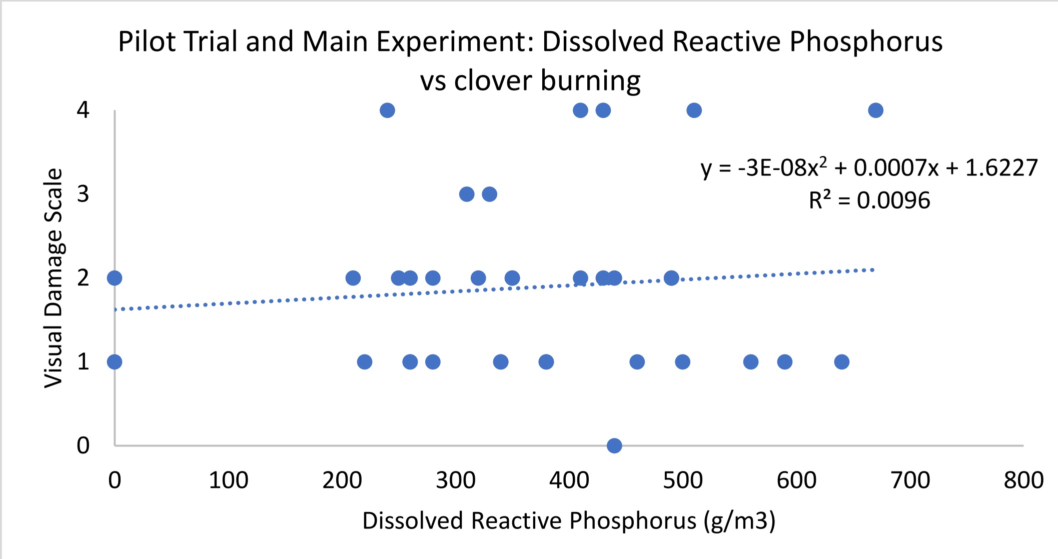

Pilot Trial and Main Experiment: Chloride vs ryegrass burning
Visual Damage Scale
Chloride (g/m3)
y = -4E-09x² + 0.0001x + 0.6828
R² = 0.2384
0
1
2
3
4
0
5000
10000
15000
20000
25000

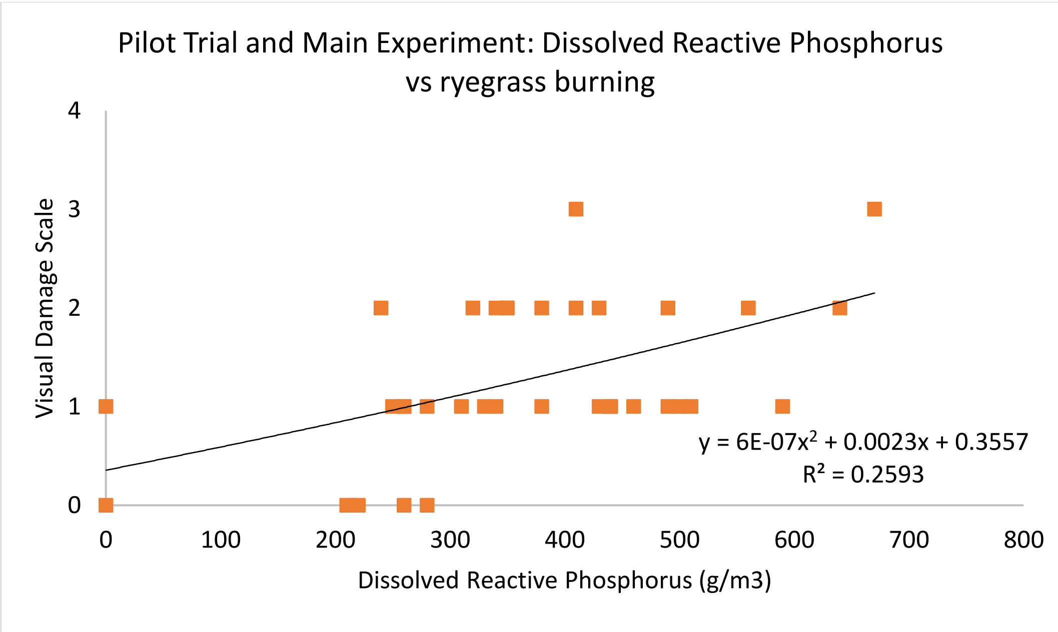

Pilot Trial and Main Experiment: Total Nitrate-N + Nitrite -N vs clover burning
Visual Damage Scale
Total Nitrate-N + Nitrite-N (g/m3)
y = 0.0032x² - 0.088x + 2.1134
R² = 0.1384
0
1
2
3
4
0
5
10
15
20
25
30
35
40

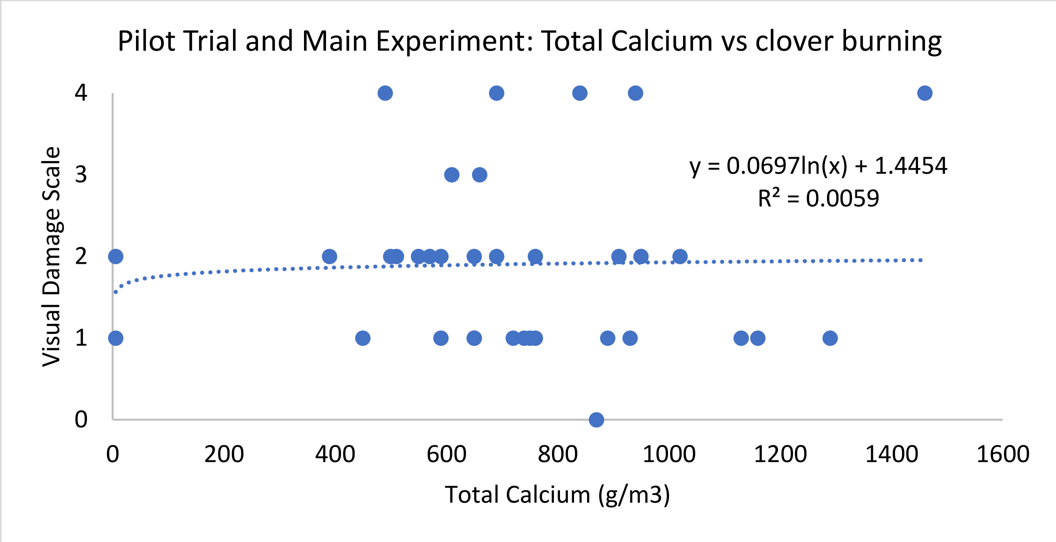

Pilot Trial and Main Experiment: Total Nitrate-N + Nitrite -N vs ryegrass burning
y = -0.0404x² + 0.4702x + 0.0928
R² = 0.1333
Visual Damage Scale
0
1
2
3
4
0
2
4
6
8
10
Total Nitrate-N + Nitrite - N(g/m3)

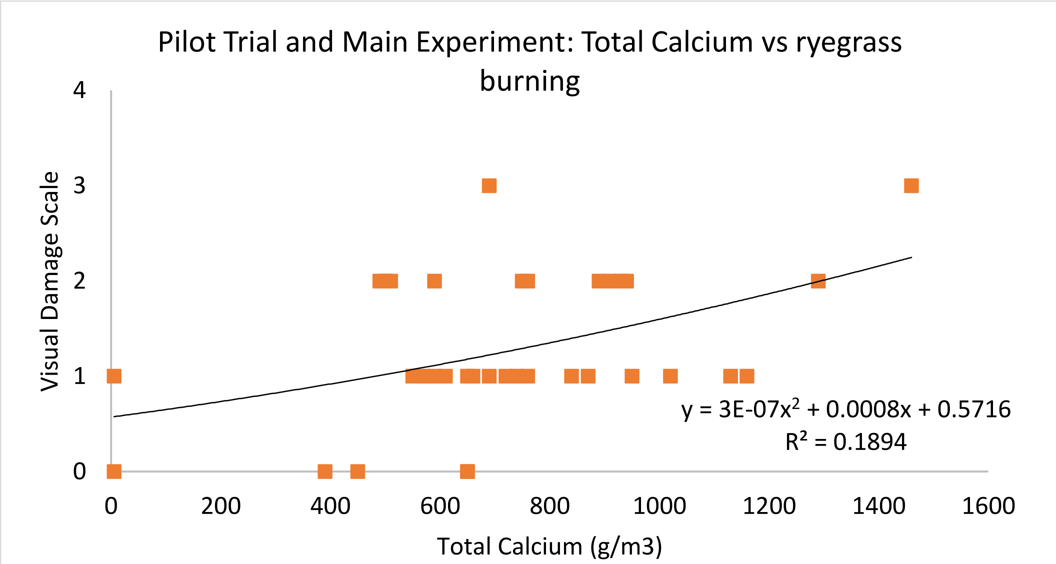

Pilot Trial and Main Experiment: Total Kjeldahl Nitrogen (TKN) vs clover burning
Visual Damage Scale
0
1
2
3
4
0
5
10
15
20
25
30
35
40
y = 0.0032x² - 0.088x + 2.1134
R² = 0.1384
Total Kjeldahl Nitrogen (TKN) (g/m3)

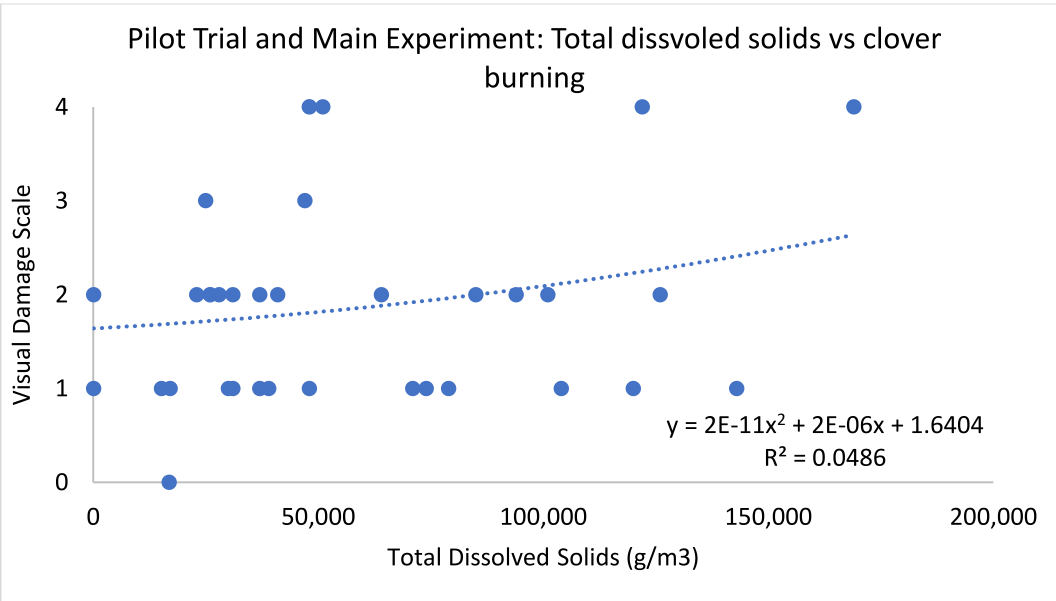

Pilot Trial and Main Experiment: Total Kjeldahl Nitrogen (TKN) vs ryegrass burning
y = 0.0006x² - 0.0219x + 1.4342
R² = 0.0048
Visual Damage Scale
0
1
2
3
4
0
5
10
15
20
25
30
35
40
Total Kjeldahl Nitrogen (TKN) (g/m3)

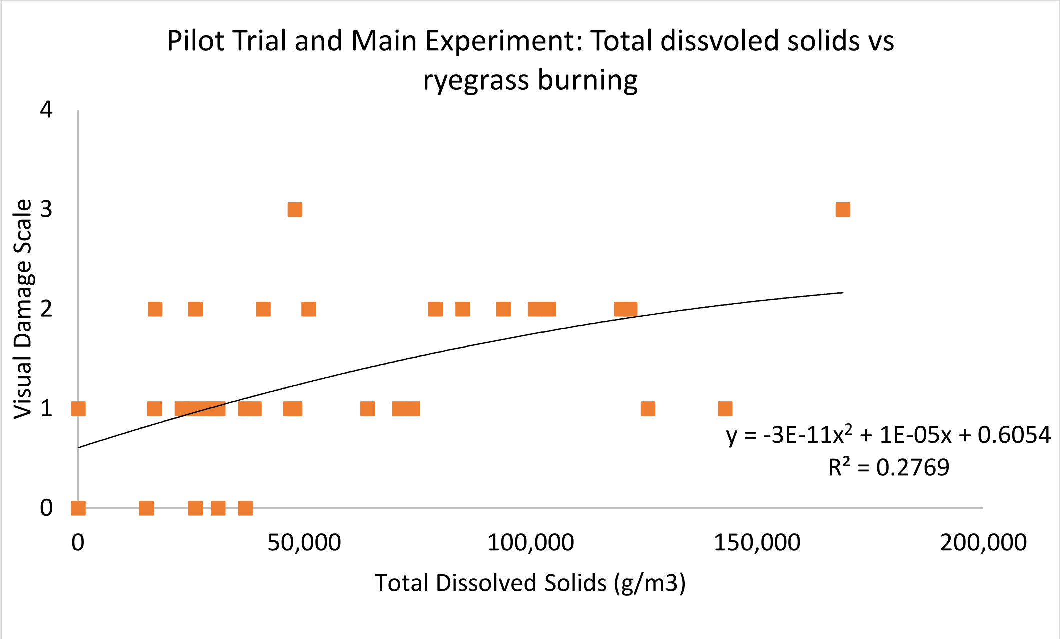

Pilot Trial and Main Experiment: Dissolved Reactive Phosphorus vs clover burning
y = -3E-08x² + 0.0007x + 1.6227
R² = 0.0096
Visual Damage Scale
0
1
2
3
4
0
100
200
300
400
500
600
700
800
Dissolved Reactive Phosphorus (g/m3)


Pilot Trial and Main Experiment: Dissolved Reactive Phosphorus vs ryegrass burning
y = 6E-07x² + 0.0023x + 0.3557
R² = 0.2593
Visual Damage Scale
0
1
2
3
4
0
100
200
300
400
500
600
700
800
Dissolved Reactive Phosphorus (g/m3)


Pilot Trial and Main Experiment: Total Calcium vs clover burning
Visual Damage Scale
Total Calcium (g/m3)
0
200
400
600
800
1000
1200
1400
1600
0
1
2
3
4
y = 0.0697ln(x) + 1.4454
R² = 0.0059


Pilot Trial and Main Experiment: Total Calcium vs ryegrass burning
Visual Damage Scale
Total Calcium (g/m3)
0
200
400
600
800
1000
1200
1400
1600
0
1
2
3
4
y = 3E-07x² + 0.0008x + 0.5716
R² = 0.1894


Pilot Trial and Main Experiment: Total dissvoled solids vs clover burning
Visual Damage Scale
Total Dissolved Solids (g/m3)
0
50,000
100,000
150,000
200,000
0
1
2
3
4
y = 2E-11x² + 2E-06x + 1.6404
R² = 0.0486


Pilot Trial and Main Experiment: Total dissvoled solids vs ryegrass burning
Visual Damage Scale
0
1
2
3
4
0
50,000
100,000
150,000
200,000
Total Dissolved Solids (g/m3)
y = -3E-11x² + 1E-05x + 0.6054
R² = 0.2769