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Manure management to reduce greenhouse emissions from cattle feedlots

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Abstract

The project assessed the feasibility of application of urease inhibitor (UI) to cattle pens and manure stockpiles, as a strategy for reducing ammonia (NH_3) and nitrous oxide (N_2O) emissions. The study included a combination of atmospheric dispersion modelling, mineral nitrogen analysis and laboratory incubations. UI-application to cattle pens was found to have a significant effect on urea content in manure but, even after treatment, retained urea was rapidly depleted within the first days after pen clearing and manure stockpiling, and UI-treatment could not be reliably linked to reduced NH_3 emissions from manure stockpiles. Sustained retention of urea in the manure as it is removed, stockpiled and ultimately incorporated into agricultural soils remains an operational challenge, because of the transient effect of the UI, and pen-access difficulties in wetter months. Moreover, even if practicable, the additional cost of implementing UI-application, at the label rate, was estimated at $38 per turned-out-steer, or $459 per tonne of mitigated CO_2-e. In conclusion, cost-effectiveness of UI-application for mitigation of ammonia and greenhouse gas emissions seems doubtful, however recommendations to progress this work include more resilient additives, cheaper and more reliable application methods, and improved emissions measurement within the pens.

Executive Summary

The objective of the project was to examine manure management strategies for reducing greenhouse gas emissions from a beef cattle feedlot. The focus of the work was on the effectiveness of operational application of urease inhibitor (UI) to cattle pens and manure stockpiles, in reducing ammonia (NH_3) and nitrous oxide (N_2O) emissions.

The study employed atmospheric dispersion modelling, field sample extractions and laboratory incubations to characterise the effect of UI-application (NBPT-Agrotain) on ammonia emissions, and mineral nitrogen and urea concentrations, as manure was removed from cattle pens and stockpiled in the field.

Application of UI to cattle pens was found to have a significant effect on urea content in manure, but retained urea was rapidly depleted within the first days after pen-clearing and manure stockpiling. Moreover, despite some increased retention of urea in UI-treated manure, ammonia emissions from manure stockpiles were not significantly and consistently reduced by UI treatment. Rather, given the large existing pool of ammonium (NH_4^+) already in the manure, emissions were more strongly affected by temperature, wind-speed and moisture status of the manure. Average NH_3 emissions from manure stockpiles ranged from 61 to 88 mg NH_3-N / $kg_{\text{dry manure}}$ /day, in the first and second summer experiments respectively. This was equivalent to a loss of 3.0 and 4.3 % of initial total nitrogen, from manure, within the first 7 days following removal from the pens.

Given the increased urea retention in UI-treated pens, UI-application might (technically) be a potential management strategy for reducing NH_3 emissions from manure. However some considerable challenges remain. First, direct measurement of ammonia emissions within treated and untreated cattle pens was not achieved in this study, and further work on emissions measurement within the cattle pens would be recommended, to confirm a link between UI-application and NH_3 emissions within the pens. Second, access of application machinery to cattle pens remains problematic in wet weather, and further work to improve application methods would be recommended. Third, the transient effectiveness of UIs (Agrotain for example) would necessitate a sustained schedule of UI-application that, at the label rate, could increase operational costs by $38 per turned-out-steer. More resilient additives, with more cost-effective methods of application would be recommended. Furthermore, mitigation of greenhouse gas emissions (direct and indirect) by this method would cost an estimated $459 per tonne of mitigated CO_2-e, an order of magnitude greater than the nominal price of carbon. Thus UI-application is unlikely to be a viable methodology under the Carbon Farming Initiative. The study concluded that Agrotain was unlikely to be a cost-effective manure management strategy for reducing ammonia and greenhouse gas emissions, within the existing operational framework of the feedlot.

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1 Background

In Australian beef cattle feedlots, manure management accounts for about 35% of total greenhouse gas emissions (GHGE), including 2% attributed to CH_4, and 33% attributed to nitrous oxide (N_2O), (DCCEE, 2011). While there is growing evidence that the contribution of N_2O to total GHGE may be overestimated in the Australian context (Chen et. al., 2009), these levels nevertheless underscore the relative importance of N_2O (and NH_3) in feedlot manure management compared with CH_4, which, by contrast, dominates enteric GHGE from feedlots.

Ammonia (NH_3) can contribute significantly to indirect feedlot GHGE via a process of volatilisation, downwind deposition and, under suitable soil conditions, nitrification and denitrification to N_2O (Denmead et. al. 2008). Moreover, NH_3 volatilisation from Australian feedlots can be substantial, as much as 5 tonnes NH_3 – N per day from a feedlot of 20 000 head capacity (Loh et. al. 2008). Thus, if as little as 1% of emitted NH_3 is eventually deposited downwind and nitrified-denitrified to N_2O (Mosier 1998; NGGIC 2007), then this results in indirect N_2O emissions equivalent to 75% of the direct N_2O emissions, or a total N_2O greenhouse impact equivalent to 60% of the enteric feedlot emissions (Chen et. al. 2009).

In addition, NH_3 volatilisation may also have other off-site ramifications for the environment such as soil acidification and eutrophication of surface water (Groot Koerkamp et. al. 1998), and it is a component of aerosol pollutants (MacVean 1986; McCubbin 2002). It also represents a significant loss of N from organic fertilisers which are produced from composted feedlot manure. Thus there are strong grounds for focusing on mitigation of NH_3 volatilisation in management of feedlot manure.

The most effective urease inhibitors for soil applications are analogs of urea that bind to the active site of the urease enzyme, and yet do not form free amines in the process, thus preventing the hydrolysis of urea to its component amine groups (Byrnes and Freney, 1995). As a means of mitigating NH_3 volatilisation from manure, these urease inhibitors (UIs) have been explored extensively in controlled laboratory experiments. Varel et.al. 1997 compared the effectiveness of two UIs, cyclohexylphosphoric triamide (CHPT) and phenyl phosphorodiamidate (PPDA), in cattle and swine manure slurries. In both cases, urea hydrolysis was prevented for between 4 and 11 days, with complete hydrolysis being delayed until day 28. Using the urease inhibitor N−(n−butyl) thiophosphoric triamide (NBPT), Parker et. al. (2005) estimated an optimum re-application frequency of eight days at a rate of 1 – 2 $kg.ha^{-1}$, reducing ammonia volatilisation by 49 to 69%. Shi et. al. (2001) found cumulative reduction in ammonia volatilisation of 34 to 36%, over a 21-day period, from a single NBPT-treatment of manure.

Urease inhibitors have been applied to cattle pens in a limited number of field experiments in the Unites States. Varel et. al. (1999) found that urease inhibitor significantly reduced ammonia volatilisation from feedlot yards for up ten days following application. In contrast, Parker et. al. (2005b) were unable to detect significant reductions in ammonia volatilisation from urease-inhibitor-treated feedlot pens, due to high variability, however they did demonstrate an increased retention of total nitrogen in the manure pack of treated feedlot pens.

The objective of this project was to use field and lab experiments to explore the operational effectiveness of UI in mitigation of NH_3 volatilisation from an Australian beef cattle feedlot.

2 Project Objectives

The formal project objectives were;

- to evaluate the effects of innovation in manure management, including stockpile aeration, urease inhibitors and livestock management practices on reducing methane and ammonia emissions from beef cattle feedlots;
- to provide and communicate recommendations for effective, measurable strategies to reduce greenhouse gas emissions from beef cattle feedlots; and
- to validate modelling of treatments effects on greenhouse emissions from cattle feedlots.

3 Methodology

The project employed a combination of laboratory and field experiments to examine the effectiveness of the urease inhibitor N−(n−butyl) thiophosphoric triamide (NBPT), as “Agrotain”, applied to solid manure from a beef cattle feedlot. The feedlot, located at Charlton, Victoria (36°21’41” S, 143°24’5” E), consisted of open, dry-lot pens, accommodating between 16 000 and 20 000 head of mostly Angus and Angus-Hereford-cross, beef cattle. Field experiments consisted of atmospheric dispersion modelling to determine NH_3 emissions and mineral N and urea analyses.

Four field experiments were carried out, two in the winter of 2010 and two in the summer of 2011. Prior to each experiment, approximately sixty tonnes of fresh manure was removed from each of two (25 x 50 m) cattle pens, following approximately eight weeks of animal retention, of approximately 100 cattle in each. The manure was formed up into two rings, each 2 metres thick, by 0.8 metres high, by 20 metres in diameter (Figure 1). One ring was immediately treated with urease inhibitor (UI), while the other ring remained untreated. UI-treatment, at the manufacturer label rate (0.08 mL NBPT [“Agrotain”] / kg fresh manure), was repeated every two weeks for the duration of the experiment.

The two winter (2010) experiments were carried out adjacent to the main feedlot, and were therefore subject to large, variable background concentrations of ammonia (NH_3) from cattle pens and other sources. In contrast, the two summer (2011) experiments were carried out at a field site one kilometre from the main feedlot, and therefore not subject to as-large fluctuations in background concentrations of NH_3. Also, the summer experiments received a UI pre-treatment, consisting of two applications, a week apart, while the manure was still in the pen, prior to pen-clearing and manure ring construction. In addition, in the summer experiments, both manure rings were turned over at two weeks, to simulate feedlot operations, immediately after which the treated ring was re-treated with UI.

3.1 Field – Atmospheric dispersion modelling of NH_3

Ambient (NH_3) concentrations were measured through sample inlets mounted at five heights on masts at the centre of each ring. NH_3 concentrations were measured continuously, over a period of about four weeks, with chemiluminescence gas analysers (9842, EcoTech, Knoxfield, VIC).

Figure 1 L: UI-treated (foreground) manure rings at the summer 2011 field site. R: Sampling mast of untreated ring (at centre) also includes vertical array of five 2D sonic anemometers.

Wind speed and turbulence statistics were measured with a micrometeorological station, including a 3D sonic anemometer (CSAT-3, Campbell Scientific, Logan, QLD). NH_3 emissions were modelled from concentrations and micrometeorological statistics, using a backward Lagrangian Stochastic (bLS) model in WindTrax (WindTrax, Thunder Beach Scientific, Nanaimo, BC, Canada).

3.2 Field – Mineral N and urea analysis in manure

After treatment-application to manure rings, four replicate samples of manure were collected from each ring from two depths, 0-10 cm and 30-40 cm. Three manure cores were bulked at each replication, of each depth, in each treatment. For the winter trials, the manure samples were transported in a cooler with ice blocks and stored at 4^0C overnight and extracted next morning. During the summer trials the manure samples were extracted on site, within two hours. These samples were analysed for ammonium (NH_4^+-N) and nitrate (NO_3^--N) nitrogen, urea and pH. Eight (8) g of each sample was extracted with KCl-PMA solution for NH_4^+ and NO_3^- -N. Seven (7) g was analysed for pH, while the remainder was weighed and oven-dried overnight to determine moisture content. In the winter trials, samples were collected twice in the first week and then once every week for the next five weeks. In the summer trials, samples were collected twice per week for the first four weeks, and then once every week for the remaining two weeks.

Manure samples were oven-dried (overnight at 105°C) and stored for subsequent analysis of total N and total C at different stages of the experiment.

3.3 Field – N_2O measurements in static chambers

Nitrous oxide (N_2O) and methane emission measurements were commenced one day after treatment application. They were measured twice a week for the first three weeks and then once per week for the following three weeks, for both the trials. Manure moisture and temperature were monitored for the 0–10 cm depth. The emission measurements were made by using a static chamber technique. Each chamber was an open-bottomed, plastic box, measuring 40cm (L) x 20cm (W) x 15cm (H). Four chambers were placed directly onto the surface of each manure-ring, and then sealed shut with air-tight lids. Headspace samples were taken, by syringe, through gas switches fitted to each lid.

Gas samples were taken 24 hours after the manure rings were set up and UI treatments applied. On each sampling day, emission measurements were carried out once between 11 a.m. and 1 p.m. Three headspace gas samples were taken, with syringes, over a period of 60 minutes (t_0, t_{30} and t_{60}). Twenty-five (25) mL of the gas sample was transferred into a 12 mL septum-sealed, screw-capped glass vial. The hourly emissions were calculated for each chamber from the increase in head space concentration of N_2O and CH_4 over the sampling time. The hourly N_2O (mg m^{-2} h^{-1}) and CH_4 emissions (mg m^{-2} h^{-1}) were calculated as follows:

$$N_2O/CH_4\ flux \quad = \quad \frac{\delta N_2O/CH_4}{\delta T} * \frac{M}{Vm} * \frac{V}{A} \qquad (1)$$

where δN_2O /CH_4 is the increase in head space N_2O/CH_4 over time (μL/L); δT is the enclosure period (hours); M is the molar weight of N in N_2O and/or C in CH_4; Vm is the molar volume of gas at the sampling temperature (L/mol); V is the headspace volume (m^3); and A is the area covered (m^2). These hourly emissions were integrated over the day, for each enclosure, to estimate the total daily emission.

3.4 Glasshouse – Continuous flow chamber studies

For this study fresh manure samples were collected from the cattle pens a day before the commencement of the experiment. Manure was stored at 4 °C overnight and 9 kg of fresh manure was weighed into chambers the next morning and placed in a glasshouse. The chambers were plastic boxes of dimensions 49 cm (L) x 33 cm (W) x 33 cm (D). There were two treatments, with four replications (chambers) per treatment. The first treatment was a control with only manure in the chambers and the second treatment was manure treated with UI, at the manufacturer's label rate of 0.8 mL "Agrotain" / kg fresh manure.

NH_3 and N_2O emissions were measured as per a method adapted from McGinn et. al. (2002). Manure samples were incubated in eight modified plastic chambers. For NH_3 measurement, a lid fitted with an inlet-port, an outlet port and two exhaust fans, facilitated continuous flow of ambient air across the top of the incubated manure sample. A vacuum pump, drew a sub-sample of the total flow into an acid trap (50 mL of 0.05 M H_2SO_4), and volatilised NH_3 was determined analytically from soluble NH_4^+-N in the trap.

For N_2O measurement, an air-tight lid, fitted with a gas switch, was used to sample the head space, by syringe, at 0, 30 and 60 minutes followed by analysis on a gas chromatograph. Manure samples were collected from the designated pen (week one of putting animals in the clean pen) and emissions were measured for 16 days. Manure samples were again collected from the same pen and measured for the same period.

NH_3 emissions were measured daily and N_2O emissions every second day. This experiment was repeated twice, each repetition lasting just over two weeks. During each experimental period manure samples were periodically analysed for urea, mineral N and pH.

3.5 Laboratory - Artificial urine "spiking" experiment

The experimental design included the following treatments (3 replications each):

1. Blank (manure without urine spiking)
2. Control (manure spiked with urine every other day)
3. A7 - manure (spiked) + Agrotain (repeated application after 7 days)
4. A14 - manure (spiked) + Agrotain (repeated application after 14 days)
5. L5 - manure (spiked) + Lignite (@5% v/v)
6. L20 - manure (spiked) + Lignite (@20% v/v)

The apparatus consisted of open-topped, plastic bins of dimensions 17cm (L) x 15cm (W) x 15cm (D). The manure was collected from within the cattle pens and stored in a cold room at 4^0C overnight. Next morning, the 5 kg of manure was added to each of the 18 plastic boxes. To simulate cattle pen conditions, 41mL of synthetic urine was added to each box every two days (based on 6 L of daily excretion over an area of $12m^2$). Water was added to all the boxes to keep the moisture content near constant over the period of experiment. Synthetic urine was prepared fresh before each application. The synthetic urine preparation was prepared as described in Parker et al. (2005). The chambers were kept in a glasshouse and temperature inside was monitored throughout. Agrotain was applied at the recommended rate of 0.08 mL / kg manure. Agrotain was dissolved in a small amount of water (20 mL) and sprayed on the manure surface at the rates and frequencies described above. Lignite was spread over the top of the manure and then mixed later to simulate mixing with cattle hooves. The synthetic urine/Agrotain solution and water were all applied evenly across the manure surface as a mist-spray. The boxes were left open throughout the experiment.

The 7-day-application-frequency treatment was terminated on day 15 after two full application periods. The 14-day-application-frequency treatment was terminated on day 28, which also allowed for two full application periods. Lignite treatments were also terminated by day 28. Manure samples for mineral N (NH_4^+ and NO_3^-), urea and pH were taken every second day, until termination of the respective treatments (Table 1).

Table 1: Sampling frequency for mineral N, urea and pH measurements in spiking experiment.

Sampling	Blank	Control	A7	A14	L5	L20
Day 0	✓	✓	✓	✓	✓	✓
Day 1	✓	✓	✓	✓	✓	✓
Day 3	✓	✓	✓	✓	✓	✓
Day 5	✓	✓	✓	✓	✓	✓
Day 7	✓	✓	✓	✓	✓	✓
Day 8	✓	✓	✓			
Day 10	✓	✓	✓	✓	✓	✓
Day 12	✓	✓	✓	✓	✓	✓
Day 14	✓	✓	✓	✓	✓	✓
Day 15	✓	✓		✓		
Day 17	✓	✓		✓	✓	✓
Day19	✓	✓		✓	✓	✓
Day21	✓	✓		✓	✓	✓
Day 25	✓	✓		✓	✓	✓
Day 28	✓	✓		✓	✓	✓

3.6 Statistical analyses

Analysis of variance (ANOVA) of emissions due to campaign (year, season and site) and diurnal variation (hour within campaign) were tested using general linear models in SAS (v9.1.3, SAS Institute Inc., NC, USA) by the ordinary least-squares method. Prior to ANOVA, data were transformed by natural log, to meet the assumption of homoscedasticity. Transformed data with a residual (actual-predicted) value, more than 3 standard deviations greater than, or less than, the mean were removed as outliers, to meet the assumption of standard normal distribution.

4 Results / Discussion

4.1 Field – Atmospheric dispersion modelling of NH_3

Winter 1, 2010

In the first winter experiment, there was no clear difference between emissions from UI-treated and untreated manure piles (Figure 2). The UI-treated manure was not pre-treated in the pens during the winter experiments because of access and trafficability problems and, therefore, there was unlikely to be sufficient urea left in the manure rings for the UI-treatment to take effect. Rapid hydrolysis of almost all urea in manure that had not been UI-treated while still in the pens was previously observed by Varel et. al. (1999), and was confirmed by our own glasshouse studies (see section 4.4, below). On an operational scale, UI-application in pens remains problematic during prolonged wet weather (e.g. winter months in southern Australia), and a technical solution would need to be developed to overcome this problem.

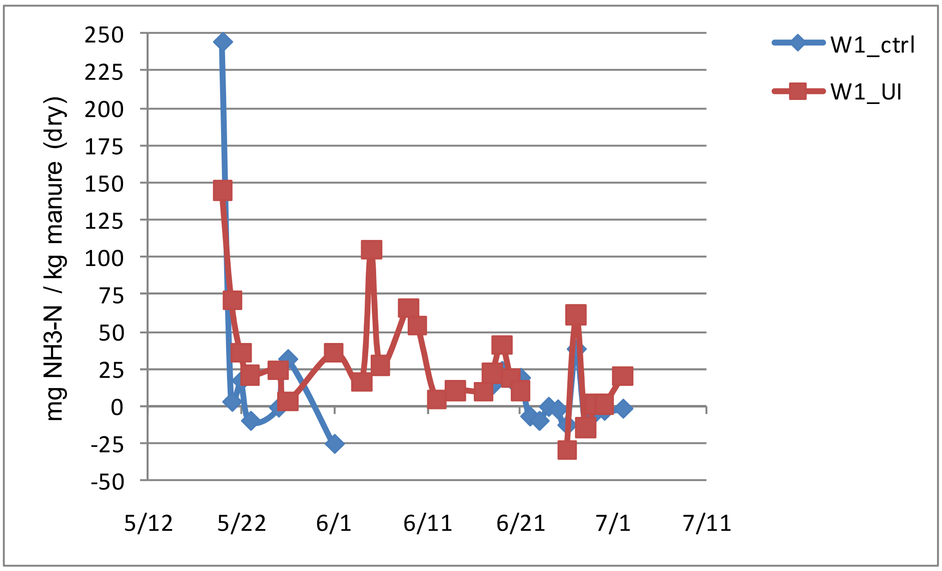

Figure 2: Average daily NH_3 emission (mg NH_3-N / kg dry manure) from UI-treated and untreated manure rings, during 1st winter experiment (2010).

Analysis of variance (Table 2) confirmed that UI treatment was not significant, and that variation in NH_3 emissions was explained principally by a manure dryness index (F=51.1), diurnal temperature (F=49.2), wind speed (F=18.3), and sampling direction (F=13.5), i.e. an artefact of sampling methodology. This predominance of environmental emission factors is consistent with other studies of NH_3 volatilisation from livestock manure. Huijsmans et. al., 2001 found that volatilisation of NH_3 from field-surface-applied livestock slurry was significantly affected by wind speed, temperature, relative humidity, particularly in the first few hours after manure application. Sommer et al (2003) also listed turbulent diffusion and meteorological processes controlling evaporation and surface temperature as among the most important factors controlling NH_3 volatilisation from field-applied livestock slurry.

Table 2: Analysis of variance of NH_3 emissions (mg NH_3-N / kg dry manure) during 1st winter experiment (2010).

Source	df	F	p
UI treatment	1	0.01	0.9253
temperature	1	49.17	<0.0001
wind speed	1	18.25	<0.0001
sampling direction	1	13.46	0.0003
manure dryness index	1	51.14	<0.0001

Winter 2, 2010

Comparison of treatment effect on NH_3 emissions was compromised during the second winter experiment, as ongoing logger faults meant that verifiable, height-linked data for the respective treatments (UI-treated and untreated) did not overlap (Figure 3). The significant treatment difference indicated in the analysis of variance (F=21.7), (Table 3), was likely spurious because, as suggested by the glasshouse chamber studies (see section 4.4, below), there was effectively no urea remaining in the treated manure ring upon which the UI-treatment might have taken effect. It is possible that the increased emissions from the untreated control are, instead, related to a significantly larger pool of NH_4^+-N (see Figure 9b) in the control pen-source.

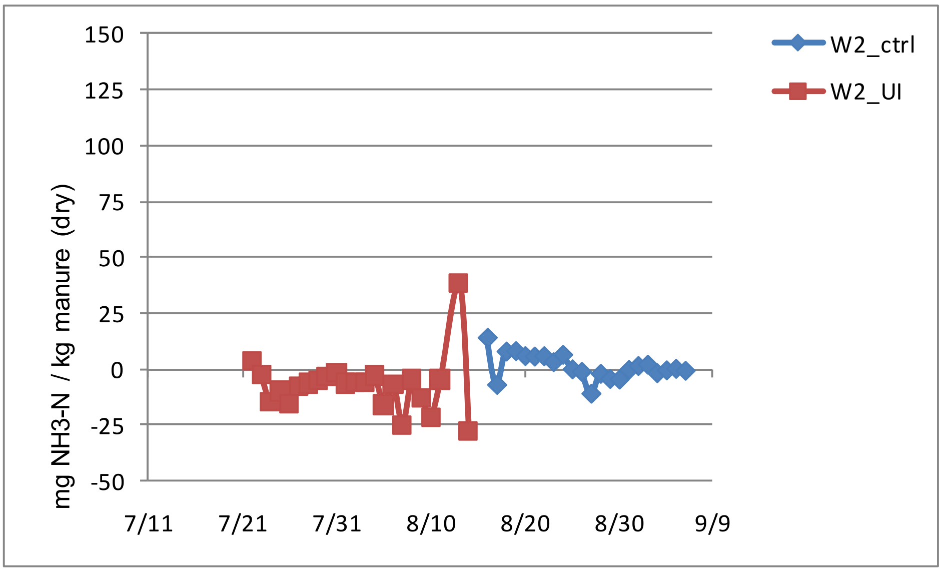

Figure 3: Average daily NH_3 emission (mg NH_3-N / kg dry manure) from UI-treated and untreated manure rings, during 2nd winter experiment (2010).

As for the first winter experiment, variation in NH_3 emissions was largely explained by wind speed (F=76.2), sampling direction (an artefact of sampling methodology), (F=75.0), an index of manure dryness (F=50.7), and temperature (F=7.8), (Table 3).

Table 3: Analysis of variance of NH_3 emissions (mg NH_3-N / kg dry manure) during 2nd winter experiment (2010).

Source	df	F	p
UI treatment	1	21.7	<0.0001
temperature	1	7.8	0.0052
wind speed	1	76.2	<0.0001
sampling direction	1	75.0	<0.0001
manure dryness index	1	50.7	<0.0001

Summer 1, 2011

In the first summer experiment, NH_3 emissions were apparently greater from UI-treated manure than untreated manure (Figure 4), or an average of 68 and 54 mg NH_3-N / $kg_{dry\ manure}$/day, respectively, or 2.7 and 3.4% of initial manure total N emitted in the first 7days. This is consistent with other measured NH_3 emissions from stockpiled solid manure (Sommer et. al. 2004). Unlike the winter experiments, in the summer experiments UI-treatment commenced in the pens prior to removal and ring-building. Field mineral N analyses confirmed that substantial urea was retained in the manure as a result of this pre-treatment (see Figure 8). As most of the increased NH_3 emissions occurred later in the experiment (Figure 4), particularly after the turning of the manure piles on 9/3, increased emissions from the UI-treated manure may indicate delayed hydrolysis and volatilisation of retained urea in the UI-treated manure. This is consistent with marked decrease in urea concentrations following turning (Figure 8a), as well as Varel et. al. (1999), who found that urea concentration in NBPT-treated manure peaked at day-9 following application, before rapidly declining. However, in light of a conflicting treatment-effect in the second summer experiment, a spurious treatment effect due to confounded variables seems more likely (see *Summer 2,* below).

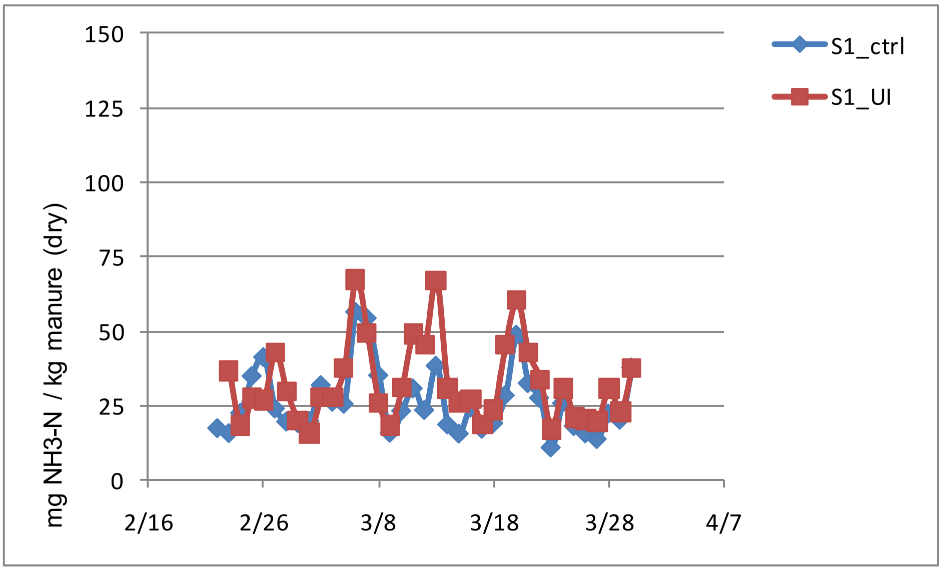

Figure 4: Average daily NH_3 emission (mg NH_3-N / kg dry manure) from UI-treated and untreated manure rings, during 1st summer experiment (2011).

Analysis of variance confirmed a significant UI-treatment effect (*F*=298). However, once again, much stronger effects on NH_3 emission variation were attributed to temperature (*F*=11259), wind speed (*F*=3003) and sampling height (*F*=2950). Other significant sources of variation included sampling direction (*F*=89), and an index of manure dryness (*F*=7), (Table 4).

Table 4: Analysis of variance of NH_3 emissions (mg NH_3-N / kg dry manure) during 1st summer experiment (2011).

Source	df	F	p
UI treatment	1	298.1	<0.0001
temperature	1	11258.7	<0.0001
wind speed	1	3003.4	<0.0001
sampling direction	1	88.7	<0.0001
sampling height	1	2950.3	<0.0001
manure dryness index	1	7.4	0.0066

Summer 2, 2011

In the second summer experiment (in contrast with the first summer experiment), NH_3 emissions were apparently greater from untreated manure than from UI-treated manure (Figure 5), or an average of 96 and 79 mg NH_3-N / $kg_{dry\ manure}$/day, respectively, or 4.8 and 3.9 % of initial manure total N emitted in the first 7days. Most of this increase was observed in the first three days after manure removal from the pens (Figure 5). This is consistent with a hypothesis of increased volatilisation in response to increased NH_4^+ pool-size (following rapid hydrolysis of urea in the untreated manure), as observed by Huijsmans ET. al. (2001). However this hypothesis is not supported by the actual measured NH_4^+ pool in the untreated ring, which was in fact smaller (Figure 9b). Rather, in light of conflicting evidence from the first summer experiment, a spurious treatment effect due to confounded variables cannot be ruled out.

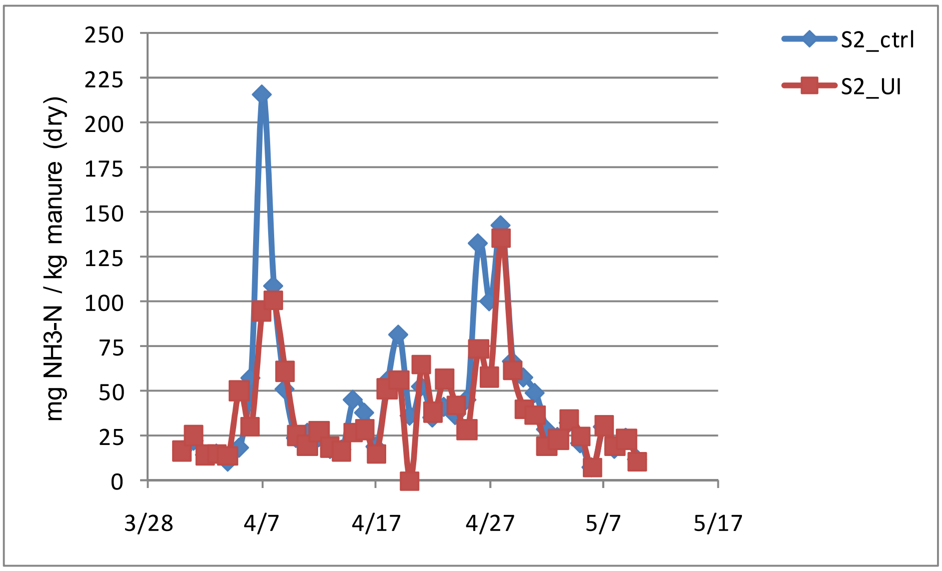

Figure 5: Average daily NH_3 emission (mg NH_3-N / kg dry manure) from UI-treated and untreated manure rings, during 2nd summer experiment (2011).

As for other experiments, daily temperature (*F*=6858), manure dryness (*F*=812) and wind speed (*F*=777) account for a large proportion of the variation in NH_3 emissions (Table 5). Artefacts of sampling, including sampling height (*F*=1332) and sampling direction (*F*=229) are also significant (Table 5).

Table 5: Analysis of variance of NH_3 emissions (mg NH_3-N / kg dry manure) during 2nd summer experiment (2011).

Source	df	F	p
UI treatment	1	17.1	<.0001
temperature	1	6858.0	<.0001
wind speed	1	776.8	<.0001
sampling direction	1	229.2	<.0001
sampling height	1	1332.3	<.0001
manure dryness index	1	812.1	<.0001

In this experiment (as in all four field experiments), treatment was wholly confounded with manure-pen-source and analyser system, and these cannot be ruled out as potential sources of spurious treatment effect. Differences in analyser systems were detected and a corrective calibration was incorporated into the data analysis. However, dry matter content of the manure varied considerably between source-pens, particularly in the summer experiments (Figure 6). Therefore the effect of UI-treatment is inseparable from any effect of manure moisture content. Indeed, from the perspective of manure dry matter content, it appears that drier manure (Figure 6) is correlated with higher NH_3 emissions. This is consistent with studies of NH_3 emission factors in livestock slurries (Meisinger and Jokela 2000; Misselbrook et. al. 2005). Evidence of dry matter content affecting NH_3 emissions from solid manure is more equivocal (Meisinger and Jokela 2000), however Misselbrook et. al. (2005) found that simulated rainfall reduced NH_3 emissions from solid cattle manure. When manure dry matter content is included as a variable in an analysis of variance of both summer experiments combined, not only is it found to be a significant source of variation in NH_3 emissions, but UI-treatment becomes not significant, and the treatment-by-experiment interaction is considerably reduced (*F*=9.4), (Table 6). It therefore seems likely that, in both summer experiments, the UI-treatment effect observed is, to a large degree, an artefact of source-pen differences, including manure dry matter content.

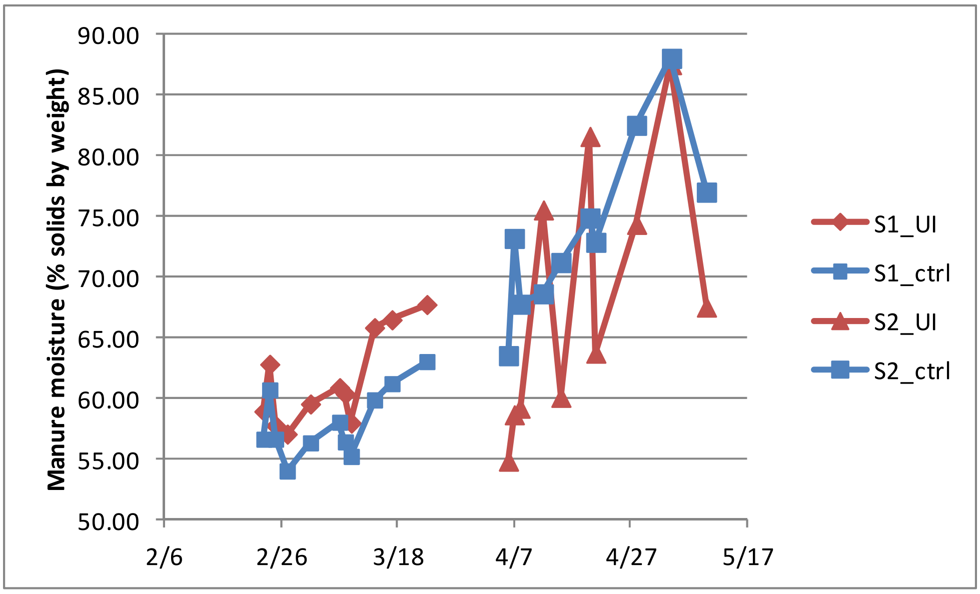

Figure 6: Dry matter content (% by weight) of manure from each pen-source (UI-treated and untreated control) in the two summer experiments.

Table 6: Analysis of variance of NH_3 emissions (mg NH_3-N / kg dry manure) across both summer experiments (2011), including a variable for manure moisture content.

Source	df	F	p
experiment	1	751.1	<0.0001
UI treatment	1	0.1	0.7115
expt*trt	1	9.4	0.0022
temperature	1	2263.3	<0.0001
wind speed	1	477.7	<0.0001
sampling direction	1	44.7	<0.0001
sampling height	1	658.0	<0.0001
manure dryness index	1	41.2	<0.0001

4.2 Field – Mineral N and urea analysis in manure

Winter Experiments (2010)

The surface application of UI resulted in reducing the NH_4^+-N concentrations over the experimental period in both winter experiments. In winter 1, a significantly different NH_4^+-N concentrations was observed between treatments, in the latter half of the experiment (Figure 7a); whereas in the second winter experiment, this difference was obvious from the very beginning of the experiment (Figure 7b). Similar trends were observed in the sub-surface samples.

As no urea could be detected, in either treatment, of either winter experiment, the lower NH_4^+-N concentrations in the UI-treated manure rings are unlikely to be due to a real UI-treatment effect. They may instead be due different NH_4^+-N pool sizes in the original manure pen-source.

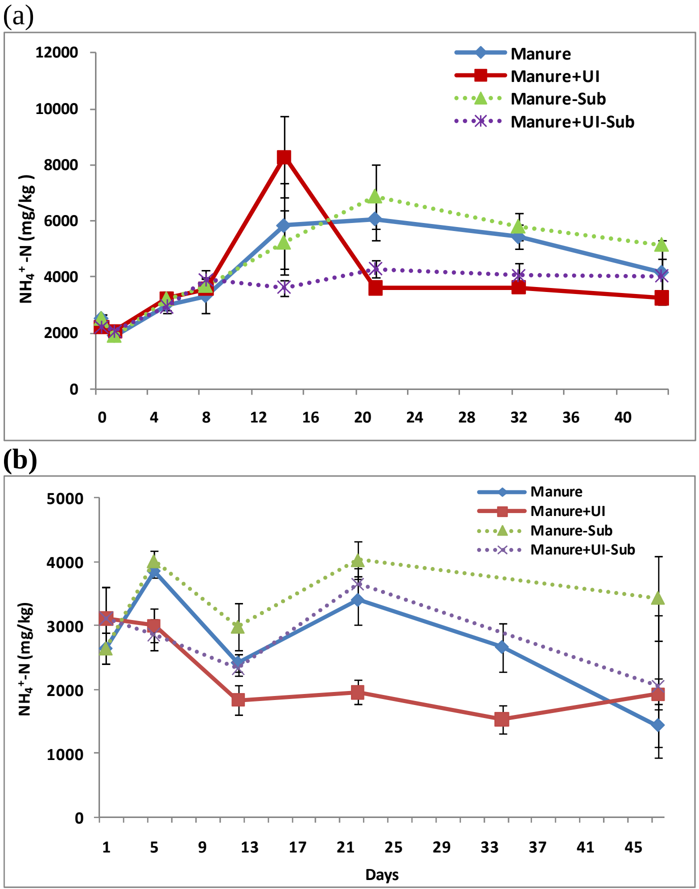

Figure 7: Concentration of NH_4^+-N (mg/kg manure) in both surface and sub-surface samples with and without UI over the (a) Winter 1 and (b) Winter 2 trial

Summer Experiments (2011)

There was a significant effect of UI-treatment on the build-up of urea in manure rings in both summer 1 (Figure 8a) and summer 2 (Figure 8b) experiments. In the second summer experiment there was significantly more ($p<0.05$) urea in surface samples than sub-surface samples. This was not observed in the first summer experiment which was drier than the second summer experiment (at least in the UI-treated manure). In both the trials there was a sharp decline in urea concentrations in manure, within in the first seven days, from 930 to 290 mg/kg (Figure 8a) and 3959 to 1200 mg/kg (Figure 8b), respectively. This sharp decrease suggests that effectiveness of UI decreased rapidly following manure removal from the pens.

The effect of this rapid decline in urea appeared to be reflected in an increase in NH_4^+-N concentrations (Figure 9). In the first summer experiment, with a more moderate decline (from 930 to 290 mg/kg), the increased NH_4^+-N concentration in the UI-treated manure was not significant. However, in the second summer experiment, with a greater net decline in urea (3959 to 1200 mg/kg), the increased NH_4^+-N concentration in the UI-treated manure was significant ($p<0.05$).

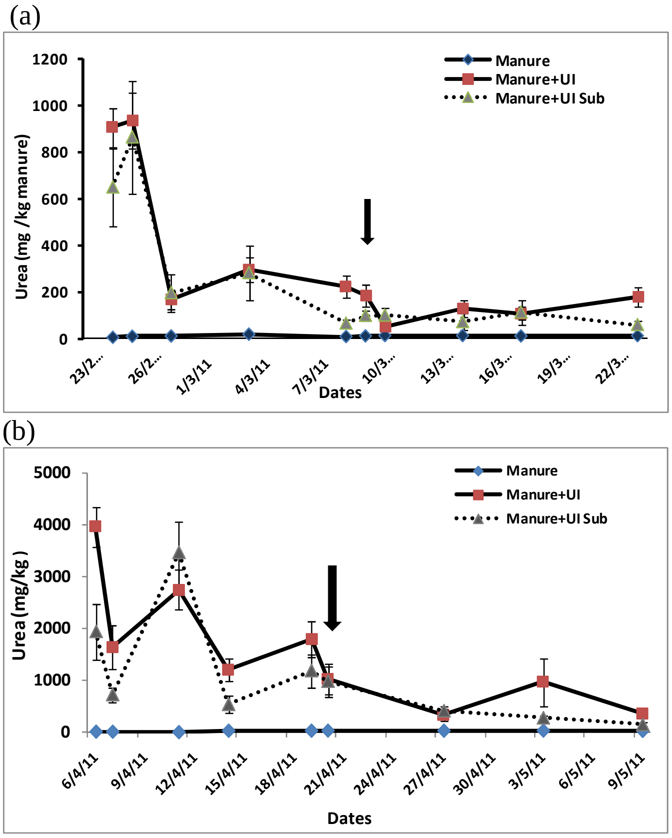

Figure 8: Concentration of urea (mg/kg manure) in surface and sub-surface samples with and without UI during (a) Summer 1 and (b) Summer 2 trials

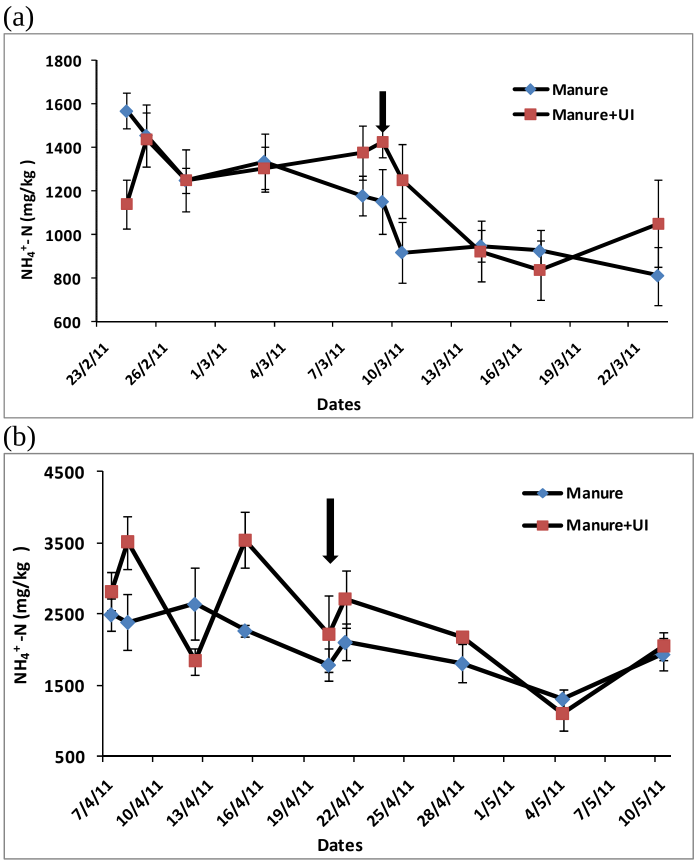

Figure 9: Concentration of NH_4^+-N (mg/kg manure) in surface samples with and without UI during (a) Summer 1 and (b) Summer 2 trials

During both the summer trials, NH_4^+-N concentration was significantly higher in sub-surface samples than surface samples (data not shown here).

4.3 Field – N_2O measurements in static chambers

There was no significant difference found in N_2O emissions from manure rings with and without UI treatment (Table 7). The total N_2O-N (mg/m^2 manure) emitted from manure rings irrespective of the treatment varied from 6.36 to 191.7 mg N_2O-N/m^2 and -5.83 to 17.0 mg N_2O-N/m^2, during Winter 1 and Winter 2 trials, respectively. Similarly, UI had no effect on CH_4 emissions from manure rings. There was high variability in the CH_4 emissions as well. The total CH_4 emitted from the manure rings over the experimental period varied from 0.032 to 5.63 g CH_4/m^2 and 276.9 to 429.7 g CH_4/m^2 during Winter 1 and Winter 2 trials, respectively. Measurements of N_2O were discontinued after 2010.

Table 7: The effect of UI-treatment and days on N_2O emissions during winter trials

Source	DF	*F* value	Pr > F
Winter 1			
treatment	1	0.08	0.7810
days	9	3.81	0.0007
Winter 2			
treatment	1	1.64	0.2180
days	5	0.74	0.6014

4.4 Glasshouse – Continuous flow chamber studies

There was no detectable urea in untreated control chambers, in either experiment. Thus, there was a significant effect of UI-treatment on urea concentrations (Table 8), with peak concentrations being 70 and 158 mg/kg manure in Experiment 1 and 2, respectively. However, even in the UI-treated manure, the concentrations of substrate urea (36.14 and 71.08 mg/kg respectively) were too small to make any real impact in NH_4^+-N pool which had concentrations from 940 to 2499 and 1166 to 3127 mg/kg manure in Experiment 1 and 2, respectively (Table 8). There was no significant treatment effect of UI-treatment on NH_4^+-N pool (Table 8). This is consistent with the lack of significant effect on NH_3 emissions, observed in both the experiments (Figure 10a and 10b).

Table 8: The effect of treatment and days on urea and ammonium-N concentration during both the experiments

Experiment 1	*Effect*	*df*	*F-Value*	*P > F*	*Means*
Urea	Treatment	1	39.52	< .0001	36.14 (Manure+UI)
	Days	4	11.17	< .0001	6.68 (Manure)
Ammonium	Treatment	1	0.66	0.4227	1316.2 (Manure+UI)
	Days	4	87.13	< .0001	1366.37 (Manure)
Experiment 2					
Urea	Treatment	1	22.83	< .0001	71.08 (Manure+UI)
	Days	5	3.35	0.0125	13.26 (Manure)
Ammonium	Treatment	1	2.91	0.0955	1682.6 (Manure+UI)
	Days	5	23.05	<.0001	1861.1 (Manure)

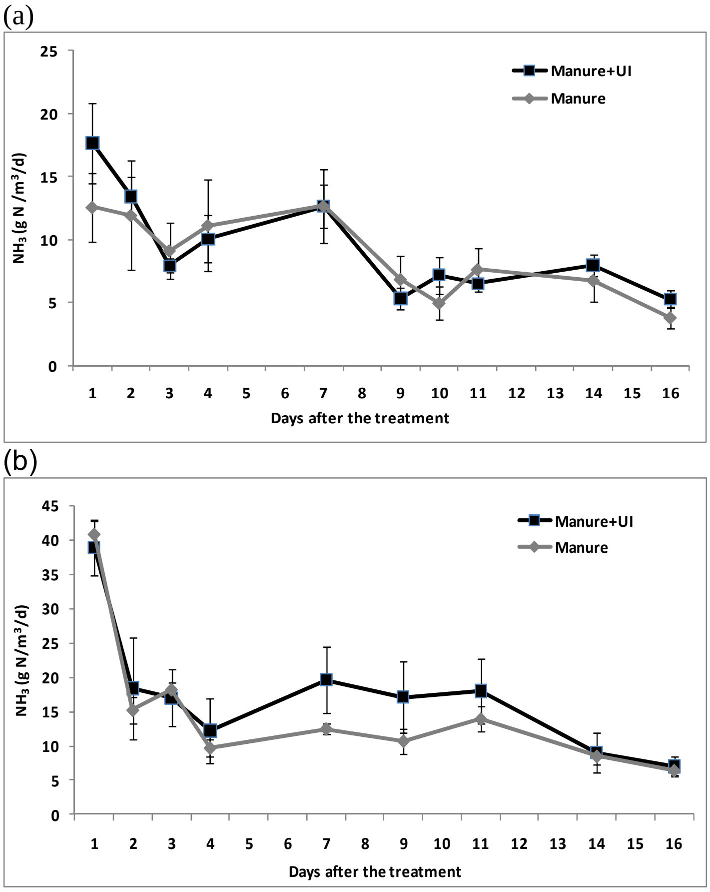

Figure 10: Variation of average daily NH_3-N emission rates from manure with and without Agrotain over the study period of 16 days for (a) Experiment 1 and (b) Experiment 2.

There was no effect of UI-treatment on N_2O emissions from manure in either experiment (Figure 11a and 11b). The mean N lost as N_2O emissions was 346.7 ± 62 and 463.4 ± 99 mg/m^3 of manure in treated and untreated chambers, respectively, in Experiment 1; and 342 ± 72 in both treated and untreated chambers in Experiment 2.

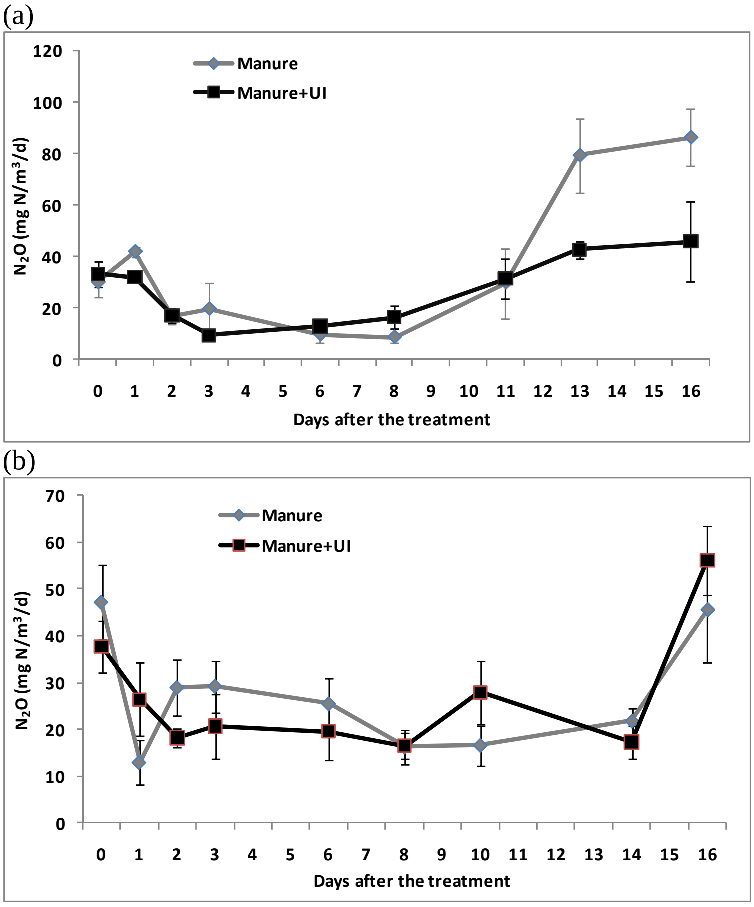

Figure 11: Variation of average daily N_2O-N emission rates from manure with and without Agrotain over the study period of 16 days for (a) Experiment 1 (b) Experiment 2

Thus it was concluded from this experiment that UI (Agrotain) should be applied to manure, prior to removal from the pens, where there is continuous addition of urine and faeces, rather than spraying on manure piles after pen-clearing, to see any effect on urea retention and NH_3 emissions. Agrotain is unlikely to show any effect on N_2O emissions from manure piles, though this needs to be tested on a larger scale in composting piles.

4.5 Laboratory - Artificial urine “spiking” experiment

Urea concentrations in the boxes untreated with Agrotain did not differ from zero except on a few days when manure was analysed immediately after application of artificial urine (Figure 12). This indicates that little to no urea accumulates in feedlot manure when no urease inhibitor is applied. This is relevant because 60-80% of the total nitrogen excreted by cattle is in urine, and urine contains up to 97% urea nitrogen (Bierman et al. 1996; Van Horn et al. 1996). Surface application of Agrotain at day 0 for both A7 and A14 treatments increased urea concentration on the manure surface above untreated samples (Figure 12). Peak urea concentration for both the Agrotain treatments was observed on day 7 (77-78% of the total urea added so far). After the second application of Agrotain at day 7 for the A7 treatment, urea started building up again and peaked on day 14. However, the urea concentration continued to decrease in the A14 treatment after day 7 until it was reapplied at day 14. As the application of Agrotain was discontinued in A7 after the 7th day, urea concentrations started diminishing in the A7 treatment after the peak of day 14. The mean urea concentrations in the second week (7-14 days) suggest that Agrotain applied every seven days accumulates significantly more urea than if it is applied after 14 days (Table 9). As also found by other workers like Varel (1997) and Singh et al. 2009, UI was still effective in accumulating urea as compared to control, 14 days after the application (Table 9).

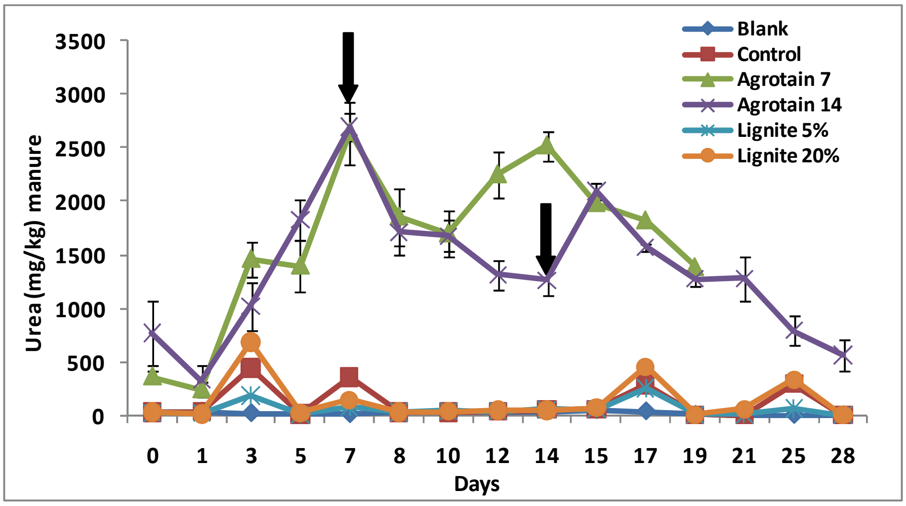

Figure 12: Effect of surface application of Agrotain @0.08mL/kg and Lignite @5 and 20% (v/v) on manure urea concentration over the experimental period.(arrows denote Agrotain application)

The greater concentration of NH_4^+-N on day 0 in all the treatments was due to fresh manure from the pens (Figure 13a and 13b). The sharp drop in NH_4^+-N concentration during the first 5 days occurred in all the treatments however, the treatments with Agrotain showed lower NH_4^+-N concentration than the control during this time (although not statistically significantly different).

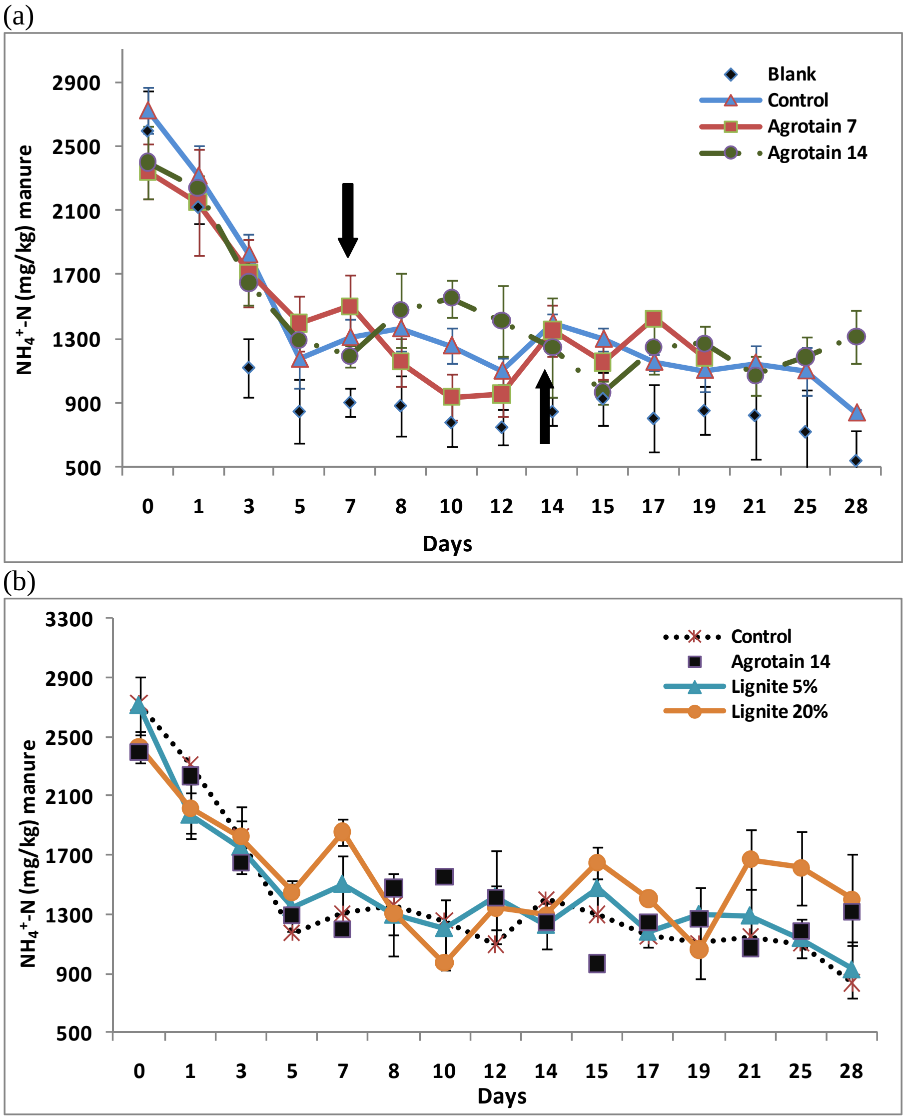

Figure 13: Concentration of ammonium-N in feedlot manure samples after the application of (a) Agrotain once every 7 days in Agrotain 7; once every 14 days in Agrotain14 treatments and (b) Lignite application @ 5% and 20% (v/v)

As Agrotain was reapplied on day 7 in the A7 treatment, the NH_4^+-N concentration was found to be lower than the control until day 12 (Figure 13a). However, as the Agrotain treatment effect started diminishing, NH_4^+-N concentration started building up and was equal to or more than the control after day 12. A similar trend was observed in the A14 treatment, where NH_4^+-N concentrations started building up more than the control, as the effectiveness of UI decreased with time (here after 5-6 days) until reapplication. Agrotain application decreased the NH_4^+-N concentration in both A7 and A14 treatments, but the differences were not significant (Figure 13a). As the chambers were open and manure was susceptible to ammonia volatilisation, NH_4^+-N concentrations did not give the true measure of reduction in ammonia losses but were only indicative. Similar observations were reported by Singh et al. (2009) where statistically significant differences in NH_3 emissions with NBPT were not replicated in TAN, pH and other manure properties over time. Similar results have been reported by other researchers on cattle manure (Varel 1997, Varel et al. 1999, Parker et al. 2005) and agree with the fact that if urease inhibitor is not frequently applied, the urea build-up will eventually result in greater ammonia emission than would have occurred had no urease inhibitor been applied.

The manure samples treated with Lignite 20% (v/v) showed higher NH_4^+-N concentration than control during most of the experiment (Figure 13b). However, NH_4^+-N concentration in Lignite 5% (v/v) did not differ much from control. The low manure pH associated with Lignite 20% (Table 9) would reduce NH_3 emissions by shifting the balance from dissolved NH_3 towards more NH_4^+ and retaining more N in cattle manure. But this needs to be further verified in more detailed experiments and under actual field conditions.

Table 9: Least square means of pH, NH_4^+-N and urea of manure treated with different treatments.

Treatment	Weeks	pH	NH_4^+-N (mg/kg)	Urea (mg/kg)
Control	1	7.87^{b}	1869.7^{a}	176.7^{b*}
A7		7.83^{b}	1821.3^{a}	1220.5^{a}
A14		7.84^{b}	1754.4^{a}	1328.9^{a}
L 5% (v/v)		7.82^{b}	1869.9^{a}	63.5^{b}
L 20% (v/v)		7.70^{a}	1916.4^{a}	180.8^{b}
Control	2	7.71^{b}	1279.6^{a}	39.76^{c}
A7		7.83^{b}	1100.4^{a}	2078.7^{a}
A14		7.77^{b}	1372.1^{a}	1472.9^{b}
L 5% (v/v)		7.69^{b}	1285.9^{a}	43.2^{c}
L 20% (v/v)		7.54^{a}	1188.2^{a}	42.2^{c}
Control	3-4	7.95^{b}	1106.5^{b}	109.3^{b}
A7		-	-	-
A14		7.88^{b}	1167.5^{b}	1045.3^{a}
L 5% (v/v)		7.89^{b}	1217.9^{b}	64.8^{b}
L 20% (v/v)		7.69^{a}	1467.5^{a}	155.1^{b}

*The same alphabet denotes no significant difference between the values within that week

The following conclusions were drawn from this glasshouse study:

- The surface application of Agrotain has a significant effect on the build-up of urea in feedlot manure.
- Agrotain must be applied at a frequency less than 14 days (at the mean temperature 22^0C) in order to be effective at reducing NH_4^+-N concentrations and thus N emissions.

The use of Agrotain for reducing NH_3 emissions from beef cattle pens looks promising based on the results of this study. However, the possible build-up of urea could result in larger NH_3 emissions if Agrotain is not reapplied or the treated manure is not incorporated into the soil.

4.6 Cost of application of Agrotain to beef cattle feedlot manure

Results so far have suggested that the use of Agrotain to mitigate NH_3 volatilisation from pens and stockpiles of beef cattle feedlots would require early and regular application of the UI in pens and stockpiles, prior to final removal of manure from the site and incorporation in the field. A brief economic analysis (Table 10) suggests that simply appending Agrotain application to the existing feedlot operations, sufficient to treat all manure, at the label rate, would cost an additional $38 per turned out steer.

Table 10: Additional cost ($ per turned out steer) of treating feedlot manure with Agrotain at label rate.

Variable	symbol	units	value
price of Agrotain	A	$/mL	0.01
staff wages & overheads	B	$/hour	100.00
machine hire	C	$/hour	100.00
pen retention time	D	weeks	8.00
stockpile retention time	E	weeks	9.00
cattle	F	n	110.00
average bodyweight	G	kg $_{\text{steer liveweight}}$	300.00
manure excretion rate	H	kg $_{\text{fresh manure}}$/kg $_{\text{steer liveweight}}$/week	0.23
UI application rate	J	mL $_{\text{Agrotain concentrate}}$/kg $_{\text{fresh manure}}$	0.08
spray application time	K	hours	1.00
number of staff	M	n	1.00
application frequency	N	weeks per application	1.00
Agrotain	P = A*[J*(H*G*F*D)*(((0.5*D)+E)/N)]/F	$/steer $_{\text{turned out}}$	7.48
Wages	Q = [(M*B)*((D+E)/N)*K]/F	$/steer $_{\text{turned out}}$	15.45
Machinery	R = [C*((D+E)/N)*K]/F	$/steer $_{\text{turned out}}$	15.45
Total Cost of UI application	**T = P+Q+R**	**$/steer $_{\text{turned out}}$**	**38.39**

The calculation is based on total nitrous oxide emissions of 5.06 g/head/day, which was derived from previous whole-feedlot work (FLOT.331), and consists of 3.3 g/head/day of direct nitrous oxide emissions, plus 1.76 g/head/day of indirect nitrous oxide emissions (i.e. 1% of the NH_3 emissions, via deposition and re-emission) (Chen et. al. 2009). Therefore it represents a back calculation from whole of feedlot measurements/estimates. Utilising these figures, the amount of nitrous oxide abated by UI application over the 56 day feed period is 87.84kg CO_2-e. The cost of $38.39 per turned out steer is the cost of carrying out the Agrotain application per animal over a 56-day period (i.e. 1/110th of the cost of the whole pen. Therefore the cost of greenhouse gas mitigation, using UI-application would, in the best case scenario, cost $437 per tonne CO_2 –e.

This is more than an order of magnitude greater than the current nominal price of carbon, and it is difficult to see how UI-application could be developed as a viable methodology in the Carbon Farming Initiative (CFI), (DAFF, 2011).

In a response to this report, Charlton Feedlot suggested changes to some of the underlying assumptions of this economic analysis, including greater animal live-weights, longer animal retention times, and a slightly cheaper unit price for Agrotain (Appendix 4). This resulted in even greater costs, i.e. $58 per turned out steer, or $703 per mitigated tonne CO_2 –e. Thus the figures reported here remain the more optimistic of the two estimates.

5 Conclusions

UI-application is unlikely to be a cost-effective manure management strategy for reducing ammonia and greenhouse gas emissions, within the existing operational framework of the feedlot. The current study showed no consistent, significant effect of UI application on NH_3 emissions from manure stockpiles beyond the cattle pens. The study did show effective, albeit transient, retention of urea when UI was applied to fresh manure, while still inside the pens. We therefore speculate that UI could technically be a potential management tool for reducing NH_3 emissions from manure, if applied early and regularly, from the animal pens through to field incorporation. However, retention of urea in the manure as it is removed, stockpiled and ultimately incorporated into agricultural soils would remain an operational challenge. Moreover, even if all-weather access for pen machinery was feasible, the additional cost of implementing Agrotain-application within the existing operational framework would be considerable.

Limited economic modelling of the cost of implementing early, regular UI-application, at the label rate, within the existing operational framework, revealed that the additional cost would be considerable, at approximately $38 per turned-out steer, or $459 per tonne of mitigated CO_2-e. Reliable resolution of ammonia emissions from within the pens was not achieved in this study, but would be a necessary step to confirm the correlation between urea retention in manure and reduced ammonia emissions. This may require experimental treatments applied, on a large enough scale with sufficient instrumentation, that variation in background emission sources can be either controlled, or adequately quantified, for atmospheric dispersion modelling.

Thus, there are three recommendations for future work arising from this project. The first is further work on application method. Additives need to be applied early, while manure is still in the pens, using an operationally feasible, weather-proof application method. The second recommendation is further work on choice of additives. A suitable additive needs to be effective and resilient enough to retain a reasonable proportion of ammoniac nitrogen, as manure is moved from pens to stockpiles, and ultimately into the field for incorporation. The third recommendation is further work in operational scale trials.

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7 Appendices

7.1 Appendix 1: Progress on Milestones 10.1 to 10.6

10.1 Evaluation of greenhouse gas reduction strategies for cattle feedlots

Milestone delivered. The project concluded that UI-application was unlikely to be a cost-effective strategy for mitigation of NH_3 emissions from cattle feedlots, in the current operational framework. Although technically possible, significant operational challenges remained. These challenges included lack of all-weather access to pens for early and regular application of UI; the transient effect of UI (in this case Agrotain), particularly as it is moved from pens to stockpiles and ultimately into the field for incorporation; and the additional operational cost of regular application of UI, under label rates, within the current operational framework of the feedlot.

10.2 Recommendations for feedlot managers on effective greenhouse reduction strategies

Milestone delivered. No conclusive recommendations to feedlot managers on effective greenhouse reductions arose from the project, other than the doubt surrounding the cost-effectiveness of UI (Agrotain) for this purpose. The cost of application per turned-out-steer was estimated at $38. The cost of mitigating emissions per tonne CO_2 – e was estimated at $459, an order of magnitude greater than the nominal price for carbon. Thus UI-application is unlikely to be a viable methodology under the Carbon Farming Initiative. Notwithstanding, three recommendations were made to further this work. The first is further work on application method. Additives need to be applied early, while manure is still in the pens, using an operationally feasible, weather-proof application method. The second recommendation is further work on choice of additives. A suitable additive needs to be effective and resilient enough to retain a reasonable proportion of ammoniac nitrogen, as manure is moved from pens to stockpiles, and ultimately into the field for incorporation. The third recommendation is further work in operational scale trials, with sufficient instrumentation, so that background concentrations could be controlled, or at least adequately quantified.

10.3 Validation of modelling of greenhouse gas emissions and treatment effects from cattle feedlots in collaboration with Agriculture and Agri-Food, Canada

Milestone delivered. Validation of UI-treatment effects in this project, in collaboration with Agriculture and Agri-Food Canada (AAFC), did not eventuate as anticipated, principally because there were no positive UI-treatment effects to guide collaborative effort. However, collaboration with AAFC did proceed in the modelling of GHGE emissions based on an understanding of the synchronisation of release of C and N from the ration in the rumen. This work was an earlier focus of the manure management project (Milestone 4.2), which was discontinued when the link between C:N in manure and the C:N animal model was found to be weak. The work, and the collaboration with AAFC, were nevertheless continued in other forms by S. Muir and J. Hill, and included a collaborative visit to Canada by S. Muir.

10.4 Details of, and feedback from, communication activities with feed-lot managers, the regional farming community and scientific conferences

Milestone delivered. A draft copy of this report was circulated to Charlton Feedlot for comment. Their full response is included in 7.4 (Appendix 4). In that response the Feedlot made some suggestions for varying assumptions, including animal live-weight, animal retention time in the pens, and cost of

Agrotain. When these suggested changes were made in the economic analysis, the additional cost of implementing UI-application, at the label rate, became \$58 per turned-out-steer, or \$700 per tonne of mitigated CO_2-e. Essentially they agreed with the main conclusion of the report and suggested that the “protocol which would need to be followed to ensure the effectiveness of such an inhibitor is far from practical and very expensive…. An extra cost of \$38 per turned out steer or \$459 per tonne of mitigated CO2-e is simply not feasible.”

10.5 Financial Report submitted and accepted by MLA for the Project

Milestone due from University Financial Operations.

10.6 Final Report received and accepted by MLA on achievement against prior Objectives and Objectives 1, 2 and 3 also including Summary Report, Feedback article, web abstract and draft scientific papers

Milestone delivered, upon acceptance of this final report. The Summary Report is reproduced from the Executive Summary, in Appendix 2. Because of the inconclusive recommendations to feedlot managers and farmers, no article arising from feedback is anticipated. The web abstract is reproduced from the Abstract, in Appendix 3. No draft scientific papers have been submitted to date.

7.2 Appendix 2: Summary Report (reproduced from Executive Summary)

The objective of the project was to examine manure management strategies for reducing greenhouse gas emissions from a beef cattle feedlot. The focus of the work was on the effectiveness of operational application of urease inhibitor (UI) to cattle pens and manure stockpiles, in reducing ammonia (NH_3) and nitrous oxide (N_2O) emissions.

The study employed atmospheric dispersion modelling, field sample extractions and laboratory incubations to characterise the effect of UI-application (NBPT-Agrotain) on ammonia emissions, and mineral nitrogen and urea concentrations, as manure was removed from cattle pens and stockpiled in the field.

Application of UI to cattle pens was found to have a significant effect on urea content in manure, but retained urea was rapidly depleted within the first days after pen-clearing and manure stockpiling. Moreover, despite some increased retention of urea in UI-treated manure, ammonia emissions from manure stockpiles were not significantly and consistently reduced by UI treatment. Rather, given the large existing pool of ammonium (NH_4^+) already in the manure, emissions were more strongly affected by temperature, wind-speed and moisture status of the manure. Average NH_3 emissions from manure stockpiles ranged from 61 to 88 mg NH_3-N / $kg_{dry\ manure}$ /day, in the first and second summer experiments respectively. This was equivalent to a loss of 3.0 and 4.3 % of initial total nitrogen, from manure, within the first 7 days following removal from the pens.

Given the increased urea retention in UI-treated pens, UI-application might (technically) be a potential management strategy for reducing NH_3 emissions from manure. However some considerable challenges remain. First, direct measurement of ammonia emissions within treated and untreated cattle pens was not achieved in this study, and further work on emissions measurement within the cattle pens would be recommended, to confirm a link between UI-application and NH_3 emissions within the pens. Second, access of application machinery to cattle pens remains problematic in wet weather, and further work to improve application methods would be recommended. Third, the transient effectiveness of UIs (Agrotain for example) would necessitate a sustained schedule of UI-application that, at the label rate, could increase operational costs by $38 per turned-out-steer. More resilient additives, with more cost-effective methods of application would be recommended. Furthermore, mitigation of greenhouse gas emissions (direct and indirect) by this method would cost an estimated $459 per tonne of mitigated CO_2-e, an order of magnitude greater than the nominal price of carbon. Thus UI-application is unlikely to be a viable methodology under the Carbon Farming Initiative. The study concluded that Agrotain was unlikely to be a cost-effective manure management strategy for reducing ammonia and greenhouse gas emissions, within the existing operational framework of the feedlot.

7.3 Appendix 3: Web Summary (reproduced from Abstract)

The project assessed the feasibility of application of urease inhibitor (UI) to cattle pens and manure stockpiles, as a strategy for reducing ammonia (NH_3) and nitrous oxide (N_2O) emissions. The study included a combination of atmospheric dispersion modelling, mineral nitrogen analysis and laboratory incubations. UI-application to cattle pens was found to have a significant effect on urea content in manure but, even after treatment, retained urea was rapidly depleted within the first days after pen clearing and manure stockpiling, and UI-treatment could not be reliably linked to reduced NH_3 emissions from manure stockpiles. Sustained retention of urea in the manure as it is removed, stockpiled and ultimately incorporated into agricultural soils remains an operational challenge, because of the transient effect of the UI, and pen-access difficulties in wetter months. Moreover, even if practicable, the additional cost of implementing UI-application, at the label rate, was estimated at $38 per turned-out-steer, or $459 per tonne of mitigated CO_2-e. In conclusion, cost-effectiveness of UI-application for mitigation of ammonia and greenhouse gas emissions seems doubtful, however recommendations to progress this work include more resilient additives, cheaper and more reliable application methods, and improved emissions measurement within the pens.

7.4 Appendix 4: Industry Comment on Draft Report – Charlton Feedlot

This report demonstrates that the use of Urease Inhibitors such as Agrotain may assist in reducing greenhouse gas emissions from feedlot manure to some extent but at this stage, only if a particular protocol is followed. However this protocol which would need to be followed to ensure the effectiveness of such an inhibitor is far from practical and very expensive.

Under commercial feedlot conditions, particularly in southern Australia where winters tend to be very wet and cold, the ability to access a pen and effectively apply the inhibitor (or any additive for that matter) is virtually impossible. Under winter feedlot conditions, even tasks such as pen cleaning using heavy duty machinery such as front end loaders are extremely challenging. In order to effectively apply such an additive a method would need to be developed that would ideally allow the pen to be sprayed without actually entering the pen.

The other significant downfall of the discussed treatment program is that it needs to be a regular and ongoing component of everyday feedlot operations. Trying to carry out this methodology on one or two feedlot pens is one thing. Trying to carry it out over an entire feedlot plus the manure stockpile is going to require a significant labour input. An extra cost of $38 per turned out steer or $459 per tonne of mitigated CO2-e is simply not feasible.

Regarding the assumptions behind these calculations, you are using a trade animal scenario. The average liveweight for a trade steer/heifer over their feeding period would be more like 400kg which would increase the Agrotain required and ultimately the cost of the Agrotain by approx one third.

Should you wish to apply the methodology to a shortfed animal (100 day feeding program as opposed to 60 day feeding program) then a weight of approx 550kg would be more appropriate. You would also need to extend the pen retention time to 16 weeks. This gives a cost for Agrotain alone of around $27.50 per steer turned off.

As far as the number of head per pen goes, a better number for use in these calculations would be 160hd as most of the feedlot pens we use are comfortably 160hd capacity. This obviously doesn't impact on Agrotain cost but will have an effect on the labour and machinery input costs – reducing them by approx 30%.

There is some discrepancy in the calculations where the Agrotain Cost appears to utilise a 2 weekly application in pen then a weekly application during stockpiling (i.e.13 weeks) but the labour and machinery calculations appear to be utilising a weekly application both in pen and in stockpile (totalling 17 weeks).

I also have a discrepancy in the calculation of the Agrotain cost. I come up with $5.74 per head using your assumption values as opposed to $7.48 which is your cost per head for Agrotain. I could be wrong and most likely are, but given the costs are so high any reduction due to a calculation error would no doubt be beneficial so it would be worth a double check.

Overall, this project has made some headway into the assessment of opportunities for reducing greenhouse gas emissions from feedlot manure. This is an important issue for feedlots and will become more important as we move into a "low carbon" future. Unfortunately however, this trial has demonstrated that we still have a long way to go before a feasible method is found to help resolve this issue. Charlton Feedlot looks forward to assisting in whatever way we can to further this research and development into reducing greenhouse gas emissions and would hope to lead the industry in the uptake of future innovation when a suitable solution is identified.