liveexport

LIVE.213B

Investigating odour from partly loaded sheep vessels

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Table of contents

1. Executive summary

- Dietary additives significantly reduced odour and ammonia emission from sheep urine and faeces mix. Gypsum consistently and significantly reduced ammonia emission from faeces and urine mix. Zeolite and, to a lesser extent, Yucca also had lower ammonia emissions but the difference was not significantly different from Control.

- All dietary additives (Yucca, Zeolite and Gypsum) reduced odour concentration by more than 50% at the 24 hour sampling point.

- None of the commercial bedding additives significantly reduced ammonia emission or odour concentration under the conditions described in this study.

- Based on data from this study and published reports, we recommend Gypsum and Zeolite for testing on board shipping vessels. These products are relatively cheap and nonhazardous. In this study Yucca extract reduced odour concentration by 86%, but the published evidence shows contradictory results. Considering that there is some evidence of it improving animal performance (in poultry), it is worth considering this product for further study to find out (1) the cause of the mixed results observed in earlier studies and (2) the repeatability of its dramatic effect on odour concentration.

- A long term solution to odour Control from livestock waste requires understanding the molecular-level mechanism of how the different additives work and how their effectiveness can be maximised. This is a major gap in our knowledge and deserves further research. The problems of livestock waste facing Live Export applies to all animal productions systems based on confined spaces (feedlots, piggeries, etc). We believe MLA/LiveCorp and PRDC can benefit from co-funding further research to find a solution to the problem of odour from livestock waste.

2. Abstract

An indoor feeding trial was conducted to evaluate the effectiveness of four dietary treatments and five bedding additives in suppressing ammonia and odour from sheep faeces and urine. There were four diets and four feeding periods (10 days each) in a replicated Latin Square of 8 sheep (i.e. two sheep per diet). Faeces and urine mix prepared from each sheep was sprayed with one of five bedding additives. The dietary treatments were Control (C, commercial pellet), Yucca (C+ Yucca Fibre (IM Sarasaponin 30), 0.013% total DM), Zeolite (C+ Zeolite at 5% total DM) and Gypsum (C+ Gypsum at 0.5% total DM). Yucca extract was provided by Integra Management (Suite 6, 10 Mary Street, Como, W.A. 6152), and all additives were added to ingredients used to produce the Control commercial pellet mix (Glen Forrest Stockfeeders, Glen Forrest, WA).

In the first feeding period two sheep each were randomly assigned to the dietary treatments and then each pair of sheep were rotated together to other dietary treatments during the subsequent three feeding periods. During each feeding period sheep had *ad libitum* access to their diet. Intake, faeces and urine outputs were recorded daily. On the last day of each feeding period, faeces and urine from each sheep were mixed in a ratio representing faeces and urine output over the previous 9 days. The mixture from each sheep was placed in a Petri dish and sprayed with one of the following five solutions of bedding additives: Control (distilled water), Qweller (Insight Environmental, Perth, Australia), McZyme solution (Ecogreen, Environmental Products Pty Ltd, Perth, Australia), GOE (World Waste Solutions Pty Ltd, South Fremantle, Australia), or Sentry 2000 (Environmental Process Solutions, Perth, Australia). Aerobic conditions were maintained by fitting each bucket with a tube that delivered air at 250 ml per minute (one air exchange per hour) and another hole at the centre of the lid for air exit. Ammonia levels were measured by inserting Drager tubes into the air exit hole 0, 4, 12, 24, 36 and 48 hours after the Petri dishes were placed in the ventilated bucket. During the 3rd period of feeding air samples were collected from each bucket 24 hours after incubation and submitted to The Odour Unit Pty Ltd (Perth, Australia) for odour analysis (to Australian Standard AS/NZS 4323.3:2001).

The level of ammonia (averaged across treatments) in the buckets generally increased from 112 (0 hour) to 435 ppm (12 hours) and then gradually declined and reached around 315 ppm at 48 hours. There was no difference in ammonia readings between any of the bedding treatments at any point during the 48 hours incubation. Initially ammonia levels from all dietary treatments increased linearly. The biggest divergence from the Control diet curve occurred at 12 hours. At the final 48 hour measurement the level of ammonia on all diets tended to come together. Twelve hours after incubation, there was a significant difference (P=0.033) in ammonia levels between Control buckets (525 $\pm$ 60 ppm) and those from Gypsum supplemented groups (377 $\pm$ 44ppm). Yucca (436 $\pm$ 65 ppm) and Zeolite (401$\pm$ 38 ppm) also had lower ammonia levels than the Control but the difference was not significant (P>0.05).

Odour test results also agreed with the ammonia measurement results. None of the bedding additives showed significantly lower odour levels than that observed on the Control. On the contrary, all dietary treatments had significantly lower odour units than Control buckets. The odour units observed after 24

hours incubation were 20360 ± 6247, 2780 ± 180, 7410 ± 830, 9080 ± 1724 for Control, Yucca, Zeolite and Gypsum treatments (P<0.05). At this sampling, the corresponding ammonia readings were 511 ± 11, 259 ± 5, 362 ± 6 and 294 ± 5 ppm (P<0.05). The odour units for bedding treatments were 12030 ± 6975, 14555 ± 7434, 7978 ± 1751, 9900 ± 3541, and 5075 ± 1874 for Control, Qweller, McZyme, Sentry 2000 and GOE, respectively (P>0.05). The corresponding ammonia readings were 364 ± 52, 336 ± 50, 354 ± 57, 370 ± 63 and 356 ± 57 ppm. From these data there is nothing to suggest that these bedding additives have any effect on ammonia emission from sheep faeces and urine. Three of them (McZyme, Sentry 2000 and GOE) tended to suppress odour, albeit none of them did it significantly. The key observation is the massive range in values.

We recommend Gypsum, Zeolite and Yucca (in that order) for consideration for testing on board vessels.

3. Introduction

There is increasing demand worldwide to minimise the environmental footprints of production activities. The Australian Live Export industry has attracted some attention with regards to animal welfare and odour from partly-loaded vessels docking near residential areas. Further, the Fremantle Port Authority (FPA) has been fielding an increasing number of complaints over recent years about odour from partly-loaded vessels coming to port on their way to Asia and the Middle East. Current steps taken to address these problems are based on managing the spread of odour, such as decreasing the stay of partly-loaded vessels, and vessel position in relation to wind direction. While such attempts may reduce the intensity of the odour released, they do not play any role in preventing odour emission. To investigate possible ways of further reduction or prevention of odour emission from partly-loaded vessels, the FPA, Meat and Livestock Australia (MLA) and LiveCorp funded the project: **LIVE.213, Investigations into Reducing Odour Emissions from Partly Loaded Sheep Vessels While in Port**. This project had two parts: a review of the literature and current industry practices contracted to Professional Agricultural Services Pty Ltd (2002, LIVE.213A) and an indoor animal experiment contracted to CSIRO Livestock Industries (CLI) (LIVE.213B), which compared dietary and bedding additives identified by Professional Agricultural Services Pty Ltd (2002). The following sections document the findings of the indoor animal experiment carried out at CLI, Floreat, Western Australia.

4. Materials and Methods

4.1. Selection of dietary treatments and bedding additives.

From the Professional Agricultural Services Pty Ltd (2002) review the dietary treatments recommended for indoor experimentations were Yucca extract, Zeolite and Gypsum. The use of a low nitrogen commercial pellet as a treatment, which was in the proposal, was discounted because the literature review indicated that its effect on ammonia (NH_3) release was the least ambiguous. Four different pellets were produced at Glen Forrest Stockfeeders (Glen Forrest, WA). These were Control (C, commercial pellet), Yucca (C+ Yucca fibre (IM sarsaponin 30) at 0.013% total dry matter, DM), Zeolite (C+ Zeolite at 5.0% total DM) and Gypsum (C+ Gypsum at 0.5% total DM). The nutrient composition of dietary treatment pellets are shown in Table 1.

Table 1. Nutrient composition of the four dietary pellets used in feeding trial.

Diet	Dry matter (DM), %	Organic Matter, %	Crude Protein, % DM	Ether extract, % DM	Neutral Detergent Fibre % DM	Acid Detergent Fibre % DM
Animal House mix	92.1	94.8	11.5	2.3	47.5	26.4
Control	92.9	93.6	12.3	2.1	55.3	29.7
Control + Yucca	93.8	94.3	11.7	2.0	55.3	30.4
Control + Zeolite	92.6	90.8	11.2	2.5	55.3	32.1
Control + Gypsum	92.8	94.7	11.8	2.3	54.1	29.6

Selection of bedding additives required interviews with proprietors due to lack of credible independent data on the performance of the products on offer. After interviewing a number of proprietors, four bedding additives were selected for investigation at CLI, Floreat. The report from Professional Agricultural Services Pty Ltd (2002) will have further details on the interview process and product selection. The four bedding additives selected were Qweller (Insight Environmental, Perth, Australia), McZyme (Ecogreen, Environmental Products Pty Ltd, Perth, Australia), Grease and Odour Eliminator, GOE (World Waste Solutions Pty Ltd, South Fremantle, Australia), and Sentry 2000 (Environmental Process Solutions, Perth, Australia). For each product a solution was prepared following the proprietor's recommendations (Table 2). A weighed amount was sprayed on to the surface of the sheep faeces and urine mix. The Control Petri dishes were sprayed with equivalent volume of distilled water to maintain similar level of moisture.

Table 2. The recommended rate of application of bedding additives.

Bedding additive	Recommended rate	Average amount sprayed on 100g faeces-urine mix
Qweller$^{\alpha}$	0.5L per metre^2 (3.54mL)	Qweller A 3.2mL Qweller B 3.2mL
McZyme$^{\beta}$	Enough to soak surface (1:1–aquasurvival : {1:5}Mczyme	3.3mL
Sentry 2000	1:3000 concentrate:dry matter (3.5mL of 1:500)	3.3mL
Grease and odour eliminator (GOE)	Enough to soak surface (1:40 mix)	3.3mL
Control	Distilled water	3.2mL

$^{\alpha}$Qweller manufacturers provided two products A and B to be applied an hour apart.

$^{\beta}$ McZyme was diluted 1:5 with deionised water and then mixed 1:1 with aquasurvival. The company suggested that McZyme eliminates odour and aquasurvival eliminates ammonia.

4.2. Outline of experiment

The indoor experiment was set up in a replicated 4 x 4 Latin Square design: four dietary treatments by four feeding periods (10 days each). Two sheep each were assigned to the four dietary treatments. Faeces and urine were collected in metabolism crates, mixed for each sheep in each period and the mix from each sheep was divided into 5 Petri dishes. Each Petri dish was sprayed with one of the five bedding additives and placed in a bucket. To maintain aerobic condition each bucket was fitted with a tube that supplied air at 250 ml per minute (one air exchange per hour) (Fig. 1). The lid of each bucket had a hole for air outlet, which was fitted with a long glass tube open at both ends (one end just above the Petri dish inside the bucket and the other end protruding out of the lid of the bucket and fitted with an open plastic tube) (Fig. 1). Each feeding period generated 40 buckets (2 sheep, 4 diets, and 5 bedding additives).

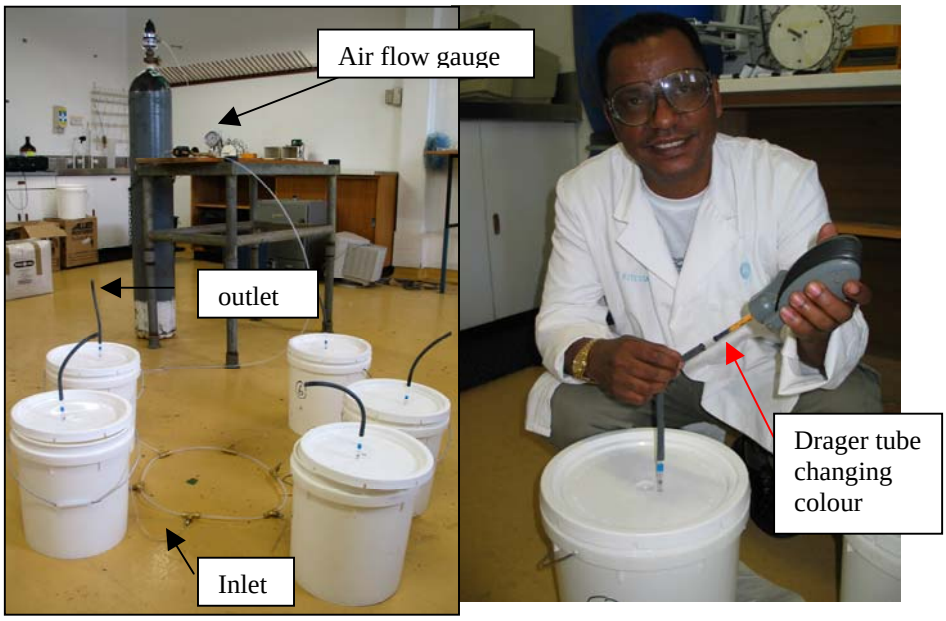

Fig. 1. The layout of buckets containing Petri dishes with faeces and urine mix and ammonia measurement procedure.

4.3. Animals and feeding procedures

Ten sheep were selected from the Yalanbee Research Station flock and brought to the CLI's Floreat Animal House facility, where they were housed in individual pens. They were offered Animal House loose mix (88% oaten hay, 10% lupins and 2% Siromin®) *ad libitum* during the indoor acclimatisation period (Table 3). Eight sheep that quickly adapted to indoor feeding were selected for experimental feeding. Before the trial proper was launched a preliminary feeding trial was conducted using these eight selected sheep on a commercial pellet to test the ammonia measurement technique, to determine how much faeces/urine mix to incubate, and to familiarise the sheep with faeces collection bags. All sheep were offered commercial pellets in metabolism crates during this preliminary period.

After the preliminary feeding trial, all sheep were removed from the metabolism crates and given a day to exercise in an adjacent paddock. The next day, they were brought indoors and housed in individual pens and offered Animal House loose mix. After seven days they were fitted with faecal collection bags, transferred into individual metabolism crates, and randomly assigned in pairs to one of the four dietary treatments. Feeding periods were separated by rest periods (Table 3); on the first day of the rest period they stayed in an adjacent paddock to allow them to move around freely. After the feeding experiment finished, all sheep were released to a paddock adjacent to the Floreat Animal House. They were taken back to the Yalanbee Research Station on 26/05/03.

Table 3. Schedule of Animal House feeding periods.

	Feeding period	Rest period*
Acclimatisation to indoor feeding	07/01/03 to 27/03/03	
Preliminary period	28/01/03 to 09/02/03	10/02/03 to 16/02/03
Period I	17/02/03 to 26/02/03	27/02/03 to 09/03/03
Period II	10/03/03 to 19/03/03	20/03/03 to 29/03/03
Period III	30/03/03 to 08/04/03	09/04/03 to 13/04/03
Period IV	14/04/03 to 23/04/03	

*Rest periods were varied to avoid weekend and holiday labour costs. The rest period after Period III shortened to the minimum allowable by the ethics committee to meet deadline. Total duration was 108 days.

4.4. Sample collection

During the experimental feeding periods each sheep was fitted with a faecal collection bag and a urine collection pouch fitted with a long tube that emptied into a 4-litre container placed under the metabolism crate. Faeces and urine output from each sheep was recorded daily and subsamples were collected for nitrogen and dry matter analysis. Each morning the total faecal and urine output per sheep was recorded and a subsample of 5% (faeces) and 10% (urine) were kept. The faecal subsamples were weighed fresh and then dried at 65°C over 72 hours. Dry matter content of faeces was determined from the fresh and dry weights of the subsamples. The daily urine subsamples were bulked into one container per sheep for each feeding period. Further subsamples for nitrogen percent in faeces and urine were obtained after bulking these daily subsamples and taking an aliquot for the assay. Fresh urine and faeces samples collected on the last day of each feeding period were mixed in a ratio representing faeces:urine output over the previous nine days for each sheep. They were then divided into five Petri dishes per sheep and placed in a bucket for ammonia and odour measurement.

4.5. Measurements and analysis

A. Ammonia. Ammonia level in each bucket was measured by inserting Drager™ tubes (CH 20501) into the plastic tube on the air outlet of the bucket. The Drager™ tubes were attached to a Drager hand pump and inserted into the air outlet. The air in the bucket was sucked into the tube by squeezing and releasing the hand pump (Fig. 1). The readings of ammonia levels were recorded for each sample at each of the six measurement points. All readings were within the range of the capacity of the tubes (5 to 700 ppm) with one pump. Ammonia level in air samples were calculated as:

Ammonia level (ppm) = Drager tube reading (ppm) x (10÷number of pumps)

Measurements were made at 0, 4, 12, 24, 36 and 48 hours after the faeces urine mix were placed in each bucket. Hence, each feeding period generated 240 data points for ammonia (40 buckets x 6 measurements).

***B. Odour*.** Odour measurement was carried out in Period III at 24 hour after incubation. Air samples (15 L) were drawn into a plastic bag from each of the 40 buckets (2 sheep, 4 diets, 5 beddings) by using a vacuum pump. The bags were taken to The Odour Unit (Showroom 1, 16-32 Hulme Court, Myaree, WA 6154), where the odour levels were analysed to The Australian Standard for the Determination of Odour Concentration by Dynamic Olfactometry (AS/NZS 4323.3:2001). Dynamic olfactometry involves the repeated presentation of both a diluted odour sample and an odour-free air stream to a panel of qualified assessors through two adjacent ports on the olfactometer. The method for odour concentration analysis involves the odorous gas sample initially being diluted to the point where it cannot be detected by any member of the panel. The panellists step up to the olfactometer in turn, take a sniff from each port, then choose which port contains the odour and enter their response. At each round of the testing process the concentration of the odorous gas is systematically increased (doubled) and re-presented to the panellists. A round is completed when all panellists have correctly detected the presence of the odour with certainty. The odour is presented to the panel for three rounds and results taken from the latter two rounds, as stated in the Australian Standard (AS/NZS 4323.3:2001). The Odour Unit used 5 trained assessors or panellists for this study, with four qualified panellists being the minimum allowed under the Australian Standard. Due to the high cost involved, air samples from half the buckets (20 samples) were submitted for odour analysis. This was done by randomly omitting buckets from either of the two sheep per dietary treatment (i.e., 1 sheep, 4 diets, 5 beddings).

C. Diet composition. The four dietary treatment pellets and the Animal House loose mix were subsampled for determination of the nutritional profile of the diets (see Table 1). Dry matter percent was determined by drying weighed aliquots (2 g) at 90°C for 24 hours. The dry samples were weighed and then ashed at 600°C for 5 hours to determine percent organic matter in the dry matter. Crude protein percent was determined by multiplying nitrogen percent by 6.25. Nitrogen content of feed, faeces and urine samples were determined by the Combustion Method (Leco NS2000), where 300 mg of sample was combusted (Sweeney, 1989). Fibre profiles of feed samples were determined by the ANKOM method on 0.5 g of sample in duplicate (ANKOM200/220 Fibre Analyser, http://www.ankom.com).

***D. Intake, liveweight change and nitrogen balance*.** Feed offered and residue was recorded daily for each sheep. Dry matter intake was obtained by difference. Animals were weighed before and after each feeding period. Nitrogen percent in the diet, faeces and urine was determined. Apparent nitrogen retention was determined by subtracting faecal and urinary nitrogen losses from that in the diet consumed. Urinary samples used for nitrogen balance were collected into a container containing 100 mL of hydrochloric acid (2 moles per litre, i.e. acid trapping). Acid trapping was not used on samples on the final day of each feeding period, as samples on the final days were used for measurement of ammonia release and odour analysis.

4.6. Statistical analysis

A. Dietary treatments. The effect of dietary treatments on ammonia release was analysed by using a replicated 4 x 4 Latin Square analysis of variance (Systat® 6.0 for Windows, SPSS Inc., Chicago, USA). There were 8 values in each dietary treatment mean ammonia level. Orthogonal mean comparison was also performed using the same statistical application. The effect of dietary treatments on odour was analysed using Student's T-test (5 observations per mean).

B. Bedding additives. The effects of bedding additives on ammonia levels was analysed using a Student's T-test. Values were averaged across dietary treatments for each sheep (hence 8 values per bedding additive mean). The effect of bedding additives on odour was also analysed using Student's T-test (4 values per mean). It must be noted that the odour unit reported back for each bucket itself is an average of 5 panellists.

All animal handling and sampling procedures undertaken in this study were approved by CLI's Animal Ethics Committee, which follows the Australian National Health and Medical Research Council's recommendations for use of animals in an experiment.

5. Results and Discussion

5.1. Ammonia levels

The ammonia levels for each dietary treatment at each of the sampling points averaged across bedding treatments are shown in Fig. 2a. The corresponding values for bedding additives averaged across all dietary treatments are shown Fig. 2b. In both cases, ammonia level generally increased over the first 12 hours and then declined. There was no indication of any of the bedding treatments having any effect on ammonia emission from the sheep pads.

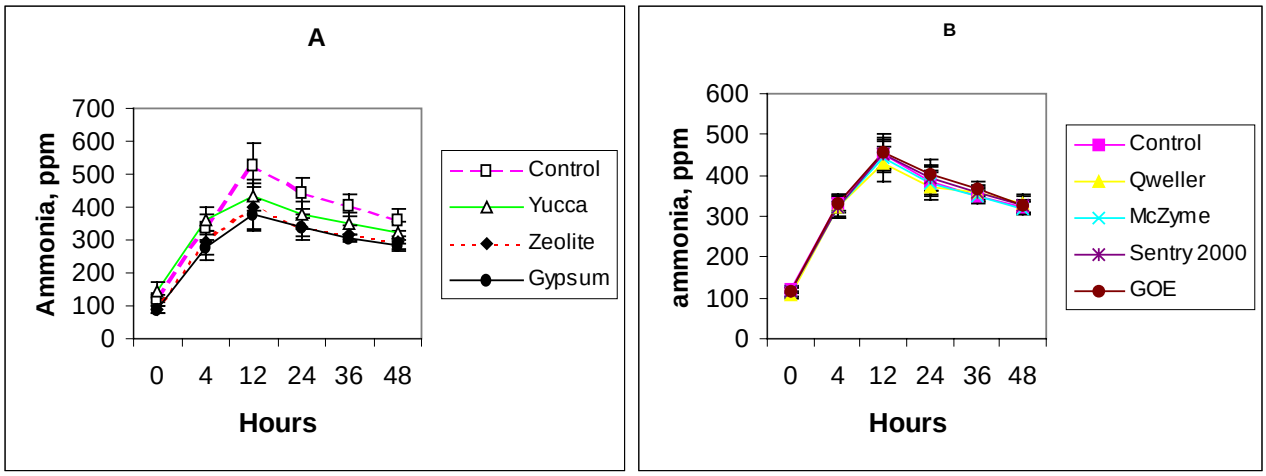

Fig. 2. The level of ammonia measured in buckets containing sheep faces and urine from different dietary and bedding treatment origins.

The Latin Square analysis of variance for dietary effects was carried out on data collected at 12 hours after incubation - the point of greatest divergence among treatments (Fig. 2a). Despite the trends shown

in Fig. 2a, the effect of dietary treatments was not significant (P=0.081). However, orthogonal mean comparison (Control versus all treatments) was significant (P=0.03). When each dietary treatment was compared against Control in orthogonal mean comparison, only the Gypsum-supplemented diet had a significantly lower ammonia level than the Control diet. The others had lower ammonia than Control but the differences were not significant (P>0.05). The convergence of ammonia values after 24 hours (Fig. 2a) is supported by other studies. For instance, McGinn et al. (2002) reported odour intensity declined to roughly the same values after 24 hours where they compared different nitrogen levels in the diet in relation to concentration of odourants from cattle manure.

5.2. Odour concentration

The odour concentrations (odour units) in air samples drawn at 24 hours after incubation in Period III is shown in Fig. 3a,b. There was significant suppression of odour and the corresponding ammonia levels by all the dietary treatments (Fig. 3a,b). On the contrary, none of the bedding additives significantly reduced either odour or the corresponding ammonia levels at 24 hours after incubation (Fig. 4a,b). An optimistic interpretation of the results would be to consider GOE for further consideration in relation to odour suppression (Fig. 4a), but the statistical evidence indicates it could be random error. Of particular interest is that the data presented here support the use of ammonia level as an indicator of odour concentration for future studies. The conclusions drawn about efficacy of treatments based on ammonia levels were supported by those drawn from the odour analysis. This agreed with McGinn et al.'s work where the highest odour intensity coincided with the highest ammonia emissions. The correlation coefficient between ammonia levels and odour concentrations was 0.79. It appears detailed studies can be done using ammonia as an indicator and using odour analysis on selected samples to overcome the substantial cost involved in undertaking the latter. However, McCrory and Hobbs' (2001) review of this area warns that a good marker that consistently predicts the outcome of odour analysis by panellists is yet to be determined.

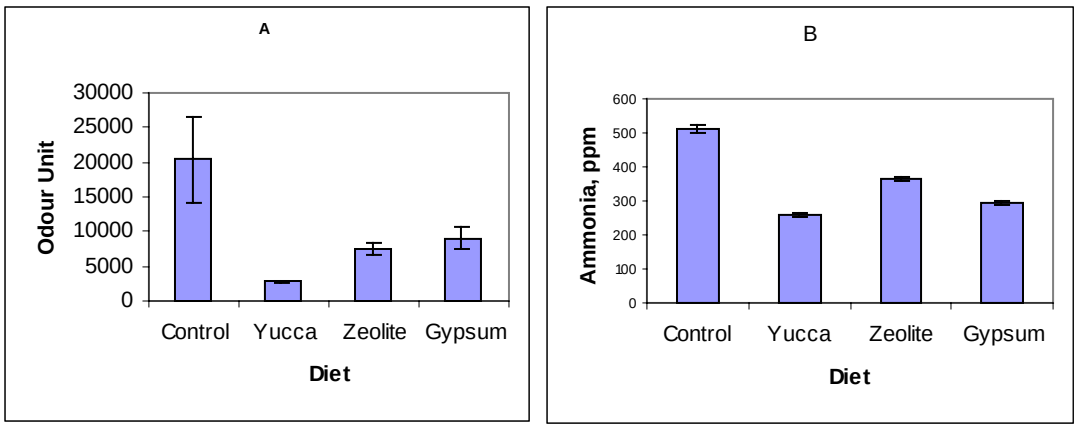

Fig. 3. The level of odour (A) and ammonia (B) measured in buckets containing faeces and urine collected from sheep on different dietary treatments. (**N.B. After 24 hours of incubation**).

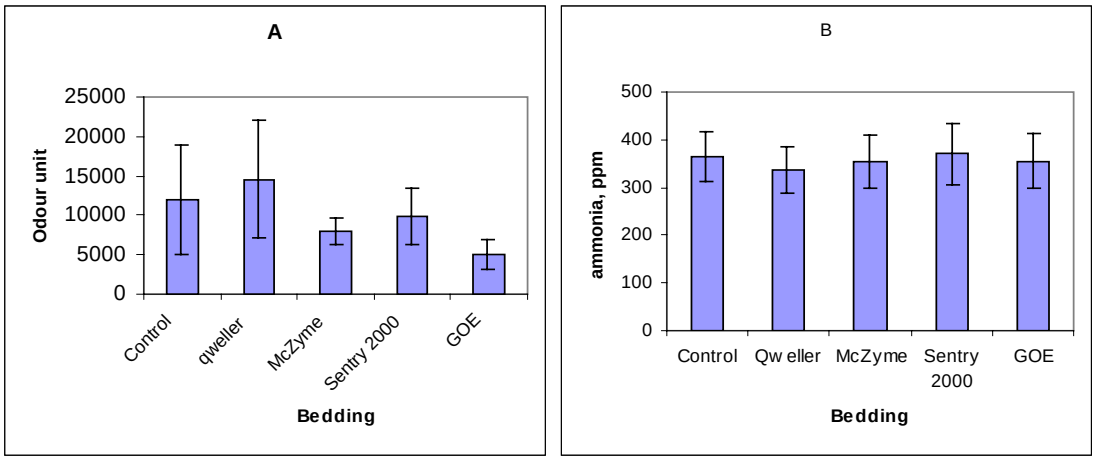

Fig. 4. The level of odour (A) and ammonia (B) measured in buckets containing faeces and urine sprayed with different bedding additives. **(N.B. After 24 hours of incubation).**

It should be noted that the ammonia levels recorded in this study were generally higher than that recorded on any voyage (Professional Agricultural Services Pty Ltd, 2002). This was because the rate of air exchange in this study (one per hour) was much lower than what usually happens on voyages over the sheep pad (30 per hour). The experimental set up was intended to provide treatments with greater opportunity for impact, as it was feared that a more dilute level of ammonia and odour would not enable measurement of treatment differences.

5.3. Intake, liveweight (LW) and nitrogen balance

There was no apparent trend in intake, LW change or nitrogen retention (Table 4). Although the sheep generally lost weight during the feeding periods, the average weight when they exited the experiment (61.4 kg) was about 3 kg more than the average LW at the beginning of the experiment (58.3 kg). On all diets and across all feeding periods, the sheep had a positive nitrogen balance (Table 4). There was nothing peculiar in the intake, LW and nitrogen balance data that may have adversely influenced the ammonia and odour data. The difference in LW change between treatments was not significant and the small weight loss observed is not uncommon when animals are in metabolism crates and being subjected to frequent handling. In fact, the weight loss situation fortuitously reflects what happens when animals are on voyage. This provides confidence in the applicability of the results to animals on voyage.

Table 4. Dry matter intake, liveweight change (initial minus final) and nitrogen retention of sheep on different diets during the four feeding periods.

Variable	Mean	s.e.m.
DM intake, g/d		
Control	1592	114
Yucca	1670	46
Zeolite	1639	112
Gypsum	1500	75
Liveweight change, kg		
Control	0.4	0.41
Yucca	-0.6	0.82
Zeolite	-0.6	0.47
Gypsum	-0.6	0.34
Nitrogen retained, g/d		
Control	7.2	1.62
Yucca	5.5	0.21
Zeolite	5.1	1.95
Gypsum	5.6	0.89

s.e.m., standard error of the mean.
Individual period values are given in Appendix 2.

5.4. Comparative summary of effectiveness and mode of action

A comprehensive review of additives to treat livestock waste has been published recently (McCrory and Hobbs, 2001; McCarthy, 2002). The results from this study will be compared with some of the findings of those reviews.

Yucca. This is a widely used commercial additive to reduce ammonia volatilisation. Its effectiveness is based on saponins extracted from the sap of Mohave Yucca (*Yucca shidigera* Roezl ex Ortgies). Saponins are high molecular-weight glycosides, consisting of a sugar part linked to a triterpene or steroid aglycone (McCrory and Hobbs, 2001). It is suggested that they act by binding NH_4^+ (Kemme et al. 1993). Their application has had mixed results: 23% reduction in NH3 emission from a piggery (Kemme et al. 1993), 50% reduction in ammonia emission when fed as additives to broilers (Amon et al. 1997), no effects as feed additives to broilers (Johnston et al. 1981), and no effects as livestock slurry additives (Martinez et al. 1997). In this study their effect on ammonia levels was the least consistent of the three dietary treatments (Appendix 1). The reason for the inconsistency between and within experiments is difficult to pin down. It is possible that their very low level of inclusion (<1% total dry matter) requires optimum mixing condition to achieve uniform distribution. This may not have been equally achieved in all experiments and even in all batches of feed within an experiment. It is not known if all extracts are of equal potency. An additional angle for this product is that there is some claim for improved animal performance as a result of its use in stock feeds. The optimum level for NH_3 suppression and increased feed efficiency is yet to be determined. Further studies addressing these issues are needed before this product can be recommended for industry application. A similarly effective and nonhazardous plant that can be used as a livestock waste additive that is not considered in this study is peat (*Shagnum fuscum)*.

Its effectiveness arises from its adsorptive capacity for NH_3. It can adsorb 2.5% of its dry weight in NH_3-N (Peltola, 1986). If it can be economically grown in Australia, it is worth considering for further research, especially as a fast suppressant on entry to port.

Zeolite. These are naturally occurring alumino silicate minerals with high cation exchange capacity (McCrory and Hobbs, 2001). There are several species of Zeolites (>50) each with a unique crystalline structure and specific affinity towards different cations. Clinoptilolite is the species with affinity for NH_4^+ ions (Beck, 1974). This Zeolite has been investigated as both a livestock feed and waste additive. Its application in previous studies has consistently produced positive results in reducing NH_3 emissions. Its application to dairy slurry (1-4%, w/v) reduced ammonia emission by 60% (Miner et al. 1997). It also reduced ammonia emission from broilers by 8 (as feed additive) to 35% (as litter additive) (Nakaue et al. 1981). In this study, the ammonia data from Zeolite supplemented sheep was consistently lower than Control (Appendix 1), but it was not significantly lower when data from the four periods was combined. Since it significantly reduced odour concentration in this study and because of its consistent positive results from several other studies, we recommend this product for consideration for further research to determine the optimum rate of application in diet versus waste and best route of application (feed versus waste additive). It has the advantages of being nonhazardous and some evidence that the nitrogen trapped in its structural channels is physically protected from oxidation to nitrate (McCrory and Hobbs, 2001).

Gypsum. This is a natural form of an anhydrous calcium sulphate ($CaSO_4$). It is one of the base precipitating salts used to Control ammonia volatilisation through pH Control. Base precipitating salts are less effective than acidifiers (sulphuric, hydrochloric, nitric, etc) in stabilising livestock slurry pH, but they are relatively cheaper and nonhazardous to use. Gypsum was the most consistent and the only treatment that significantly reduced both odour and ammonia levels. Based on our results we recommend the use of Gypsum. Other researchers also recommend the use of base precipitating salts for short-term reduction in NH_3 (McCrory and Hobbs, 2001). The comparative effectiveness of Gypsum as feed and bedding additives needs to be determined in future research.

Bedding Additives. None of the proprietors who submitted their products disclosed what was in them. Hence, it is difficult to comment why the bedding additives used in this study did not have any effect on ammonia and very little, if any, effect on odour. To hazard a guess, they may be aimed at increasing decomposition of non-nitrogen or low-N components (sugars, lipids, fibre, etc), they could be stimulating bacteria involved in immobilisation of NH_4^+, or they could be producing labile carbon sources (e.g. lactic acid producing bacteria). McCrory and Hobbs (2001) summarised that the performance of digestive additives are very poor, more so under laboratory trials than field trials. It was postulated that a greater proportion of additive to waste is required as the volume of the livestock waste is reduced (Ritter, 1981). This is because of increase in surface area of waste. Perhaps this is one possible area that affords the benefit of the doubt for those who supplied products for this study. There was not a single product to be recommended from those considered in this study, at least at the rate recommended for application.

6. Conclusions and recommendations

- From these data it can be stated with confidence that dietary manipulation provides an opportunity for lowering ammonia release and odour emission from sheep pads. The Gypsum results corroborate cattle results from previous MLA/LiveCorp-sponsored work conducted at Murdoch University. Faeces and urine mix from Gypsum-supplemented sheep had lower ammonia than that from sheep on Control pellets during all the four feeding period. We conclude that Gypsum consistently and significantly reduces ammonia and odour emission from sheep pads. The evidence for efficacy of Zeolite from this study is not as good as that reported in other studies. Yet, it had consistently lower ammonia during all feeding periods. Its nonhazardous nature and cheapness make it one to be considered for further evaluation on board vessels. Although Yucca had a dramatic effect on odour levels, its effect on ammonia was the least consistent across the four feeding periods. Further study is needed before this product can be recommended with confidence.
- The data do not support the use of any of the bedding additives considered under this study for suppression of odour or ammonia release. It is suggested that they would have even less impact on board vessels where the air exchange rate is about 30 per hour. We believe the experimental set up used in this study (one air exchange per hour) offers greater opportunity for all treatments to have an effect. It must be noted that we used only one rate of application of the products offered to us. However, it is reasonable to assume that both the rate suggested by the proprietors and the product quality offered for testing would be the best each company had to offer.
- **Recommendations:**
  - Gypsum and Zeolite provide a realistic opportunity for lowering ammonia release from sheep pad. They are cheap, nonhazardous and their mode of action is fairly well understood. Success with Yucca has been inconsistent, once the reasons behind these inconsistencies are identified it can be optimised to a cost effective long term strategy.
  - We advise producers and exporters engaged in the Live Export industry against the use of any product that is not tested independently for its efficacy.
  - Our recommendation to the proprietor's of bedding additives considered in this study is to re-consider (1) the effectiveness of their product, (2) their optimum application rate, and (3) whether they need to create special products for the ruminant industry, as most of their products may have been developed with other industries and operations in mind. We recommend for close and open collaboration between these proprietors and MLA/LiveCorp. The experience of these companies may be essential in creating effective bedding additives.
  - **Future research**:
    - A long term solution to livestock waste requires understanding the molecular-level mechanism of how the different additives work and how their effectiveness can be maximised. This requires further investment in basic research and a change in view from the industry. The problems of livestock waste facing Live Export applies to all animal productions systems based on confined spaces (feedlots, dairying, etc). We believe MLA/LiveCorp and PRDC can benefit from co-funding further research to find a solution

to livestock waste. For instance, there is some evidence Yucca extracts increase livestock performance and feed efficiency. If we can pin down how this can be achieved consistently and cost-effectively, it will provide a solution that increases performance while reducing environmental impact of livestock.

7. Acknowledgements

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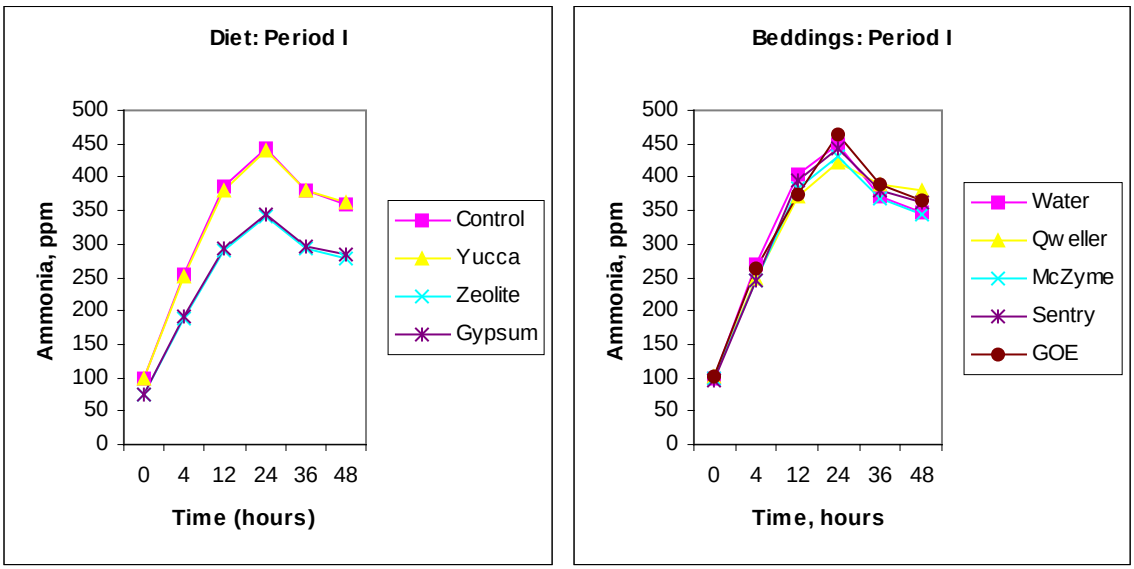
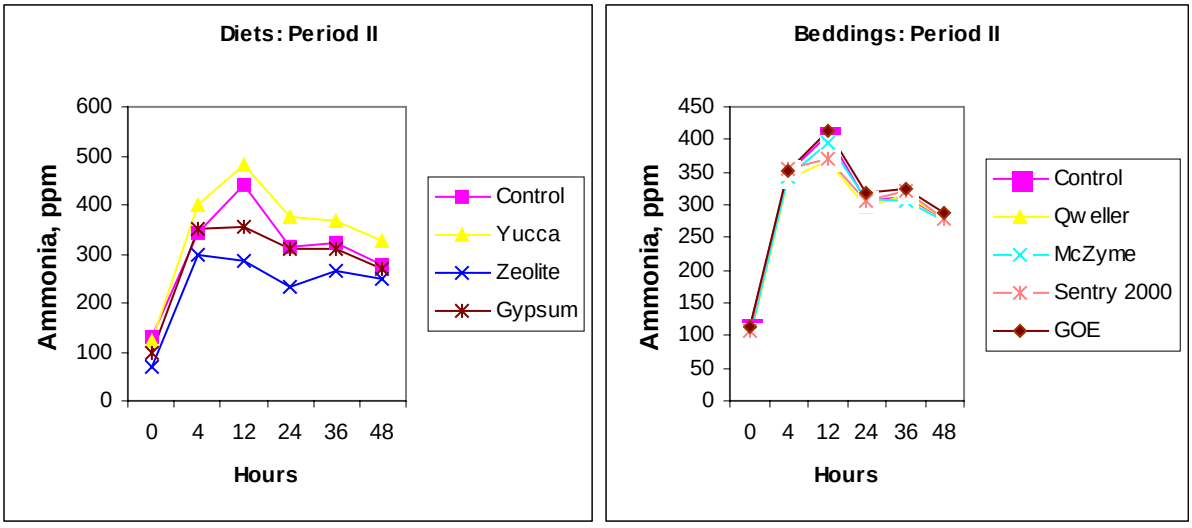
9. Appendices

Appendix 1. Ammonia data: periods I to IV

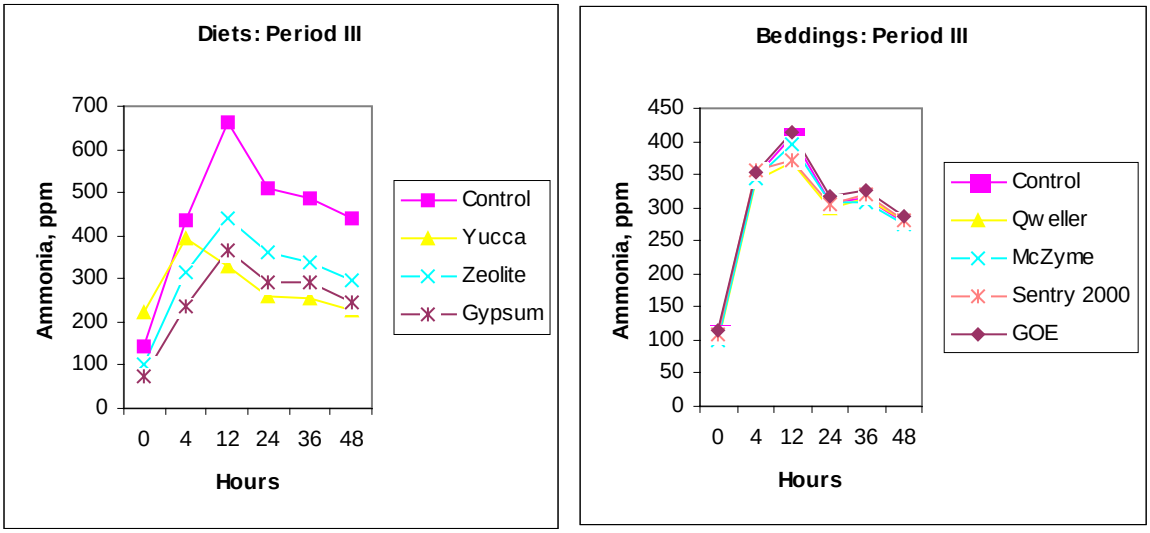
Appendix 1 a. Ammonia levels during Period I



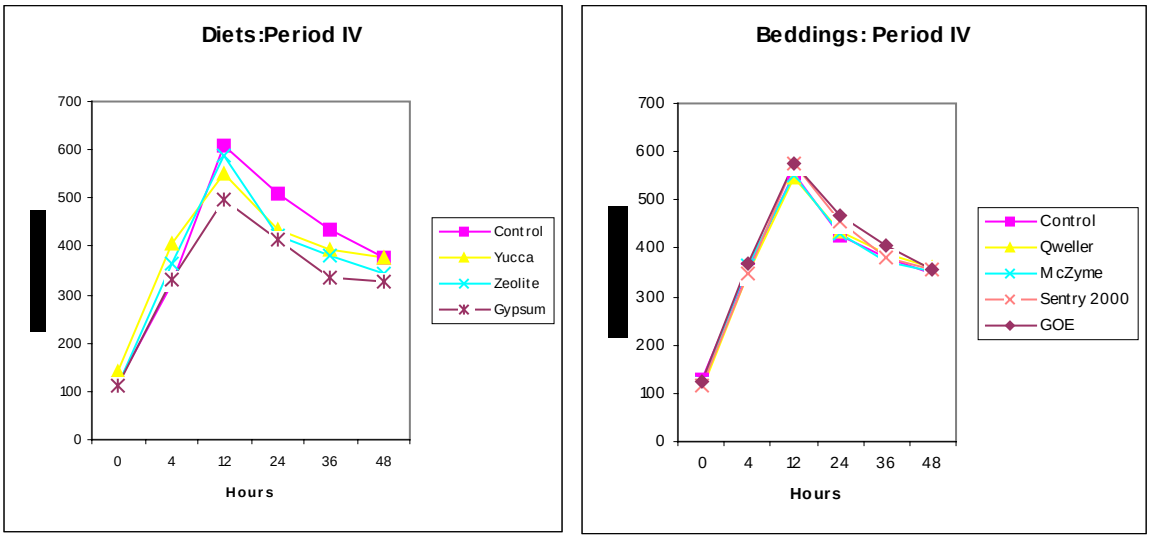
Appendix 1b. Ammonia levels during Period II



Appendix 1c. Ammonia levels during Period III



Appendix 1d. Ammonia levels during Period IV.



Appendix 2. Dry matter intake, liveweight change (initial minus final) and nitrogen retention of sheep on different diets during the four feeding periods

	Period I	Period II	Period III	Period IV
DM intake, g/d				
Control	1608 ± 116	1306 ± 90	1863 ± 71	1589 ± 82
Yucca	1565 ± 80	1788 ± 85	1658 ± 61	1669 ± 92
Zeolite	1864 ± 96	1341 ± 98	1745 ± 98	1607 ± 64
Gypsum	1281 ± 95	1618 ± 93	1539 ± 63	1562 ± 93
Liveweight change, kg				
Control	-0.6	0.5	1.4	0.3
Yucca	-2.6	-0.1	-1.1	1.3
Zeolite	-0.9	-1.2	-1.1	0.8
Gypsum	-1.5	-0.8	0.1	-0.3
Nitrogen retained, g/d				
Control	9.4	3.0	6.2	10.0
Yucca	5.2	5.2	5.6	6.1
Zeolite	9.8	0.8	3.3	6.5
Gypsum	3.2	7.3	5.5	6.5