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Graded levels of woodchip during wet feedlot conditions

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Abstract

This project was conceived to determine the production and management costs and benefits of providing woodchip bedding to feedlot cattle during wet feedlot conditions. A randomised block design using three treatments, each with ten replicate pens of ten cattle, was conducted over a 109 day experimental period during winter (May – September 2018). The project simulated wet winter conditions using an irrigation system that provided 74 mm of rainfall per 30 day period, applied over 16 rainfall days per period and which wetted the entire pen surface, all cattle and the feedbunk of each pen. The three experimental treatments were 1) no bedding (Control), 2) bedding provided at 54 kg/m^2, equivalent to a bedding cost of 30 c/head.day (W30) and 3) bedding provided at 108 kg/m^2, equivalent to a bedding cost of 60 c/head.day (W60).

Provision of woodchip bedding at 54 kg/m^2 (W30) increased average daily gain (2.43 kg/hd.d, cf. 2.27 kg/hd.d for control, $P = 0.003$) and HSCW, yielding an additional 9.3 kg of HSCW ($P = 0.001$) compared to the control. There was no additional production benefit of providing double the amount of woodchip (W60). Provision of woodchip bedding had no effect on dry matter intake. As a result, conversion of gain from feed improved for W30 (0.205) and further for W60 (0.217) compared to control (0.197) ($P = 0.012$). There was no relationship between treatment and any other carcase attributes apart from HSCW and raw eye muscle area. It was concluded that there was no overall effect of treatment on behavioural signs of cattle welfare. However, there was a numerical effect of treatment on relative adrenal weight, such that W60 cattle were lower than W30, which were in turn lower than control cattle, indicating reduced chronic stress in woodchip bedded cattle. Woodchip bedding improved the pad score, but after week 10, the score of the pad in W30 also began to worsen, indicating that for medium and long-fed cattle, additional woodchip application may be required.

There was a $74 increase in carcase value from applying woodchip bedding at W30 and W60 rates. Using the input costs of the experiment, there was a numerical net economic benefit from the W30 treatment over the unbedded cattle, but this was highly variable and sensitive to input costs. Future research is needed at commercial scale to fully understand the economic benefits of woodchip bedding in a range of production systems.

Executive summary

This project was conceived to determine the production and management costs and benefits of providing woodchip bedding to feedlot cattle during wet feedlot conditions. Problems with muddy pens and keeping cattle clean has been identified as one of the three most serious animal welfare issues related to outdoor feedlot beef production. A scoping study (B.FLT.0379, O'Keefe et al. (2013)) and follow-on case study report (B.FLT.0237, Watts et al. (2015)) reported industry interest in pen bedding, and that woodchips (broadly defined) were the most widely tested bedding type in the Australian feedlot industry. Further research was recommended to characterise bedding responses and return on investment in Australian feedlots (Watts et al. 2015).

The present study was a randomised block design using three treatments, each with ten replicate pens of ten cattle, where the pen was the experimental unit. The study was conducted over a 109 day experimental period during winter (May – September 2018) at the University of New England's Tullimba Feedlot. The project simulated wet winter conditions using an irrigation system that provided 74 mm of rainfall per 30 day period, applied over 16 rainfall days per period and which wetted the entire pen surface, all cattle and the feedbunk of each pen. A pre-hoc analysis of the value proposition of supplying woodchip bedding was conducted to determine appropriate woodchip bedding treatments. The three experimental treatments were 1) no bedding (Control), 2) bedding provided at 54 kg/m^2, equivalent to a bedding cost of 30 c/head.day (W30) and 3) bedding provided at 108 kg/m^2, equivalent to a bedding cost of 60 c/head.day (W60).

In the feedlot, the experiment measured animal production (liveweight gain, feed intake and efficiency), animal behaviour and use of pen space, and dag score; the condition of the pad; and yields, costs and composition of cleaned manure. At slaughter, pre-slaughter washing time, carcase characteristics and relative adrenal gland weight were measured. The experimental results were analysed for net profit.

Provision of woodchip bedding at 54 kg/m^2 (W30) increased average daily gain (2.43 kg/hd.d, cf. 2.27 kg/hd.d for control, $P = 0.003$) and HSCW, yielding an additional 9.3 kg of HSCW ($P = 0.001$) compared to the control. There was no additional benefit of providing double woodchip (W60) for growth. Provision of woodchip bedding had no effect on dry matter intake. As a result, conversion of gain from feed improved for W30 (0.205) and further for W60 (0.217) compared to control (0.197) ($P = 0.012$). There was no relationship between treatment and any other carcase attributes apart from HSCW and raw eye muscle area.

Woodchip bedding improved the pad score, but after week 10, the score of the pad in W30 also began to worsen, indicating that for medium and long-fed cattle, additional woodchip application may be required. The woodchip improved the pad surface primarily by reducing the penetrable depth of the pad, maintaining the cattle on a relatively clean surface. Additionally, control cattle had a higher dag score than woodchip bedded cattle until the end of the experiment.

There was no effect of woodchip treatment on animal health or mortality. Although unbedded control cattle spent most of their lying and non-active standing time in the middle and back of the pen, they were more likely than woodchip bedded cattle to use the front of the pen, where the concrete apron was located for these activities, indicating that they found the middle and back sectors of the pen

more aversive than woodchip bedded cattle. There was no indication that cattle found woodchip bedding to be aversive. More woodchip bedded cattle were observed lying during the experiment, but this difference was not biologically significant. Woodchip bedding did not affect the proportion of animals observed to be eating throughout daylight hours. It was concluded that there was no overall effect of treatment on behavioural signs of cattle welfare. However, there was an effect of treatment on relative adrenal weight, such that control cattle were significantly higher that W30, which were significantly higher than W60 indicating increased chronic stress in these cattle.

There was a $74 increase in carcase value from applying woodchip bedding at W30 and W60 rates. Using the input costs of the experiment, there was a numerical net economic benefit of the W30 treatment over the unbedded cattle, but this was highly variable and sensitive to input costs. Future research is needed at commercial scale to fully understand the economic benefits of woodchip bedding in a range of production systems. For a 109 day feeding period, there was no financial benefit from applying the higher rate of woodchip (W60, 108 kg/m^2). Applying commercial values to input costs, is likely to both increase the size and significance of the net profit of this bedding strategy for short-fed cattle. There may be greater benefits and reduced costs per head-day of woodchip bedding for longer-fed cattle, and this, along with the impacts of woodchip bedding on mortality and lameness, should be addressed with future research at commercial scale.

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1 Background

Problems with muddy pens and keeping cattle clean has been identified as one of the three most serious animal welfare issues related to outdoor feedlot beef production (Grandin 2016). Cattle themselves are significant contributors to moisture in pens, with cattle typical of short-feeding in Australia contributing 1.6 – 2.2 mm/day of moisture when stocked at 12.5 m^2/head (Watts *et al.* 2015). In dry conditions, this excreted moisture is readily evaporated, but in wet winters, such as those common in southern Australia, not only is evaporation reduced, but precipitation contributes additional moisture to the pen. This results in a wet substrate under foot, composed of manure and, depending on the pad base, eroded soil base. The direct consequences for cattle are a wet environment for standing and lying, and accumulated mud and manure attached to their hides (tags or dags).

A detrimental effect of muddy conditions on the performance of cattle is well documented, although Grandin (2016) critiques the lack of peer reviewed scientific studies on the effects of mud on lot-fed beef cattle housed outdoors, noting that a majority of the available information either draws from non-peer-reviewed publications, or from work on dairy cattle. Early work in California reported reduced liveweight gains of 30 – 40 % and lower efficiency of conversion of feed into gain when cattle were kept in a wet, dirty pen, compared to a concrete floored pen (Morrison *et al.* 1970). The National Research Council (1981) estimates a depression of intake of 5 to 15 % in mud of 10 to 20 cm depth, and a depression of 15 to 30 % in mud of 30 to 60 cm depth, without thermal stress. Dags on the hides of cattle pose a risk to meat safety, and although this relationship is not consistent, dag scores are considered to be a non-critical control point for meat processor HACCP plans (Van Donkersgoed *et al.* 1997).

The most common methods suggested for alleviating muddy conditions in feedlots are appropriate drainage and slope, diversion of run-off into the yard, mounding, and provision of bedding to soak up excess moisture (Pohl 2002; Grandin 2016). The most commonly tested bedding types for cattle in published reports are straws and woodchips, and these materials were also the most commonly utilised by commercial feedlots in Australia (O'Keefe *et al.* 2013). From a survey of Australian feedlots, O'Keefe *et al.* (2013) rated screened or graded woodchip as most suitable for Australian feedlots due to its durability, porosity, ease of handling, and availability. Woodchips have a high capacity for water absorbance: spruce, for example, is able to absorb water to reach a 69% moisture level after 48 hours soaking, without reaching an equilibrium (Kumar and Flynn 2006).

Woodchip pads are commonly used for winter bedding of cattle intensively housed outdoors on 'out-wintering' or 'stand-off' pads in the UK and New Zealand (Smith *et al.* 2010). These are generally engineered as a soil or concrete pad or metal grate with drainage systems installed at the base. Much of the work conducted overseas has compared woodchip bedded outdoor pads with concrete or slatted pads, or with indoor housing (O'Driscoll *et al.* 2009), or under freezing conditions, and there is relatively little work examining the use of woodchip bedding for lot-fed beef cattle under southern Australian conditions of cold, wet, but non-freezing winters on soil underbases, rather than concrete or slatted pens.

A scoping study (B.FLT.0379, O'Keefe *et al.* (2013)) and follow-on case study report (B.FLT.0237, Watts *et al.* (2015)) reported industry interest in pen bedding, and that woodchips (broadly defined) were the most widely tested bedding type in the Australian feedlot industry. Watts *et al.* (2015) recommended that bedding be targeted towards key areas of high traffic, or sensitive cattle (e.g. hospital and induction pens), but expressed concern that bedding would not be economically viable in production pens, except as mounds in cold, wet environments. Further research was recommended to characterise bedding responses and return on investment in Australian feedlots (Watts *et al.* 2015).

This project was conceived to determine the production and management costs and benefits of providing woodchip bedding to feedlot cattle during wet feedlot conditions.

2 Project objectives

2.1 Overall Project Objectives

1. Determine the effects of graded level of woodchip during wet feedlot conditions on feedlot cattle performance, animal health, non-invasive measures of animal welfare, and carcase characteristics.
2. Determine the effects of graded levels of woodchip during wet feedlot conditions on dag score, and pre-slaughter washing time and labour
3. Determine the effects of graded level of woodchip during wet feedlot conditions on pen cleaning (time, labour, equipment, volume and weight of fresh cleaned manure, and manure composition at cleaning).

3 Methodology

3.1 Animals and housing

The study was a randomised block design using three treatments, each with ten replicate pens of ten cattle, where the pen was the experimental unit. The study was conducted over a 109 day experimental period during winter (May – September 2018) at the University of New England's Tullimba Feedlot (30°28'49"S, 151°11'20"E, elevation 950m) with all procedures approved by the University Animal Ethics Committee. Tullimba is located in a summer dominant rainfall area, mean annual rainfall 767 mm.

320 *Bos taurus* steers of various breeds, 12 – 18 months of age, were transported to the feedlot between seven and three weeks prior to the start of the experiment, during which time they were kept in a paddock of dry grass supplemented with wheat straw and oaten hay. Two weeks before the start of the experiment, the cattle were inducted into the feedlot, receiving a unique visual ear tag, vaccination for clostridial bacteria (Ultravac 5in1, Zoetis Australia, Silverwater, NSW); topical treatment for external and internal parasites (Dectomax, doramectin 0.5% w/v, Zoetis Australia, Silverwater, NSW); vaccination for respiratory pathogens (Bovilis MH + IBR, inactivated *Mannheimia haemolytica* and Bovine Herpes Virus Type 1; Coopers Animal Health Intervet Australia, Macquarie Park, NSW; a second dose was administered on day 28 of the experiment, in conjunction with weighing); and a hormonal growth promotant implant (Component TE-200, 20 mg oestradiol 17β + 200 mg trenbolone acetate, Elanco, West Ryde, NSW). The cattle were then returned to the paddock for twelve days. Two days before the start of the experiment, the 320 cattle were weighed (average 381.02 kg ± 24.78; Ruddweigh 600mm Weigh Beam 2000kg weighing capacity (Ruddweigh, Guyra, NSW, Australia); Gallagher Weigh Scale readout W310 v2 to 2kg increments (Gallagher Australia, Epping, Vic, Australia)). The scales were calibrated by placing 20kg x 30 (600kg total) certified test weights onto the scale 30 minutes before each weighing. 300 cattle were then selected for the experiment and stratified by breed type (European / British), then weight strata, breed and weight, before allocation to 10 blocks. The cattle were housed in blocks in large feedlot pens and fed oaten hay until the start of the experiment two days later.

At the start of the experiment, the cattle were individually weighed and randomly allocated to one of three treatments within each block. Each block of cattle was housed in a group of 3 contiguous outdoor feedlot pens of identical dimensions (6.25 m x 20 m; slope 3˚ West to East (from front of pen to back), and 1° North to South, along the row of pens; 12.5 m^2/hd, 31.25 cm/hd bunk space; 1 fence line water trough shared between two pens = 3.0 x 0.7 m), built on a clay interface. Each pen had a concrete apron 3 m deep from the back of the feed bunk. The remainder of the pen surface was a manure interface above a compacted soil base of clay and natural rock. Each pen housed ten steers and was cleaned to the interface layer before the start of the experiment.

The weather conditions (air temperature, relative humidity, barometric pressure, wind speed, wind direction, rainfall, and solar radiation) were automatically measured and logged hourly with an ICT Weather Hub (ICT International, Armidale, NSW, Australia).

Cattle that were pulled to hospital pens for health treatments were noted with their diagnosis and treatment. Cattle that had recovered within 4 days were returned to their experimental pens. Cattle that had not recovered after 4 days were removed from the experiment. If the cull occurred within the first week of the experiment, the steer was replaced with a spare animal to maintain stocking density in the pen. Where cattle were culled after the first week of the experiment, they were not replaced, and instead the area of the experimental pen was reduced by cutting out an area equivalent of ~12.5 m^2 with cattle panels, so as to maintain the stocking density within the pen.

3.2 Treatments

A pre-hoc analysis of the value proposition of supplying woodchip bedding was conducted to determine appropriate woodchip bedding treatments. The three experimental treatments were 1) no bedding (Control), 2) bedding provided at 54 kg/m^2, equivalent to a bedding cost of 30 c/head.day (W30) and 3) bedding provided at 108 kg/m^2, equivalent to a bedding cost of 60 c/head.day (W60). The bedding was Eucalypt (hardwood) woodchip of average dimensions approximately 50 x 30 x 5 mm, and mean initial moisture 50.7 %. At a mean density of 480 kg/m^3, this gave a woodchip depth of approximately 15 cm in W30, and 30 cm in W60. The bedding was distributed over the entire pen surface, but not on the concrete apron in front of the feed bunk (an area 3.0 x 6.5 m^2). Due to the small size of the experimental pens, the bedding was laid with a front-end loader. The bedding was not initially spread to even depth (Figure 1), but once the cattle were placed in the pens, the woodchip depth quickly became evenly spread over the pen. To prevent woodchip spreading into adjacent pens, 40 cm rubber belting was installed along the sides of each pen. The back of each pen was uncontained, and free to drain out of the pen area.

Figure 1: Pens prior to cattle entry after woodchip applied (from top W30, Control, W60)

Being a summer rainfall district, thus naturally low rainfall in the experimental period, to simulate a cold wet winter environment similar to Southern Australia, the experimental pens were irrigated to supplement natural rainfall. Total precipitation (natural rainfall + simulated) was targeted to 74 mm of rainfall per 30 day period, applied over 16 rainfall days per period. This is aligned to fall between the decile 5 and decile 9 natural monthly rainfall for the feedlot.

An irrigation system (Hunter MP3000, Hunter Industries, San Marco, CA, USA) was installed with rotator sprinklers mounted on the pen dividing rails which provided overlapping coverage over the entire pen surface, the cattle in the pen, and the feed bunks (Figure 2a). The irrigation distribution was validated using 14 sample pans evenly distributed over the surface of each pen during an irrigation test (Figure 2b), and showed that the mean application rate was 5.4 mm/hour (± 0.13 mm/hour S.E.M.). In the absence of natural rainfall, irrigation was applied up to four times per week in 4 mm events (Figure 3), commencing two hours after morning feeding. Irrigation was reduced to account for natural rainfall events, so that the target of 74 mm of precipitation per 30 day period was maintained.

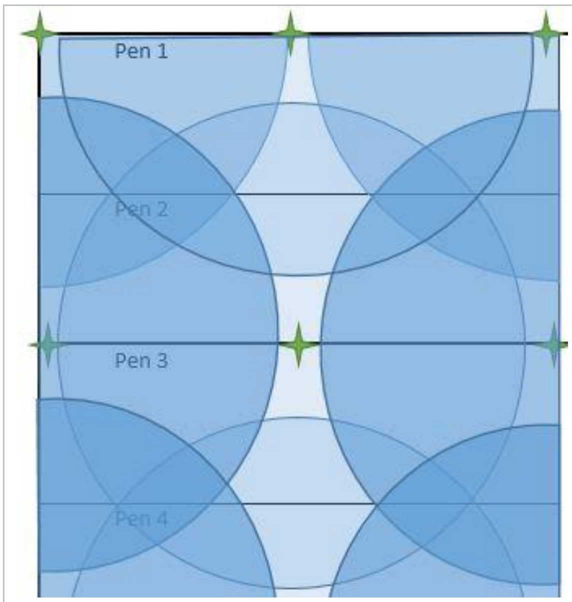


Figure 2 a: An example of the irrigation spray coverage of the first 4 pens.	b: Placement of pans to measure quantity of simulated rainfall.

Figure 3: Validating irrigation rates in pens, showing positioning of containers and raindrop effect of sprinklers.

3.3 Diet

The cattle were gradually adapted (Table 1) to a total mixed ration finisher diet (Table 2) containing 80.7 % grain on a dry-matter basis (as formulated) and 13.9 % moisture (mean as analysed). Step-up rations 1-3 were based on dry-rolled barley, and the finisher ration was based on tempered barley, but the moisture content of all rations was consistent at 18.5%. Cattle were fed as a pen, once per day, at 0730 h in pen order. Feed was mixed and delivered in a Rotomix TMR 4610 mixer (1 kg scale resolution) in two or three batches per feed delivery. Cattle were fed to meet the intake of the previous day's ration, which was targeted so that the cattle consumed all of their ration, except for a light sprinkling of crumbs (minimal residue) in the bunk at feeding time.

From each batch daily, 6-8 grab samples were collected from the length of the bunk after feed-out and bulked into a daily sample. A sub-sample of this was analysed for dry matter content by oven-drying at 80 °C for 36 hours. Daily ration samples were further bulked into a weekly sample which was analysed for nutrient composition by wet chemistry (results are presented in Appendix 1).

Table 1: Protocol for adapting cattle to grain-based finisher ration

Ration number	Grain content (%, dry matter basis)	Days fed
1	40.2	7
2	53.6	7
3	67.1	17
4 (finisher)	80.7	92

Table 2: Formulated ingredient and nutrient composition of finisher ration

Constituent	
Tempered barley (% DM)	80.5
Whole cottonseed (% DM)	10.9
Oaten hay chaff (% DM)	2.6
Wheat straw chaff (% DM)	2.5
Liquid supplement* (% DM)	3.5
Dry matter (%)	86.1
Grain (% DM)	80.7
Urea (% DM)	0.316
Monensin (ppm, DM)	18.45
ME (MJ/kg DM)	12.56
NE_m (Mcal/kg DM)	1.74
NE_g (Mcal/kg DM)	1.17
Crude protein (%)	14.77
Neutral detergent fibre (%)	26.66
Acid detergent fibre (%)	13.55
Crude fat (%)	3.42
Ash	4.71

*Including 33.29 % molasses and 18.00 % 50%-Urea, as mixed.

3.4 Cattle measures

3.4.1 Liveweight

The cattle were weighed individually, at day 0, day 28, day 56, day 92 and at the end (day 109) of the experiment. Weighing took place between 7:00 am and 12:00 pm, and pens were weighed in the same order, on each weigh day. Cattle were not held off-feed before weighing. Orts were removed and weighed on the final day (d109).

3.4.2 Hair coat score

The cattle were given a hair coat score on Day 0 and then at the end of the experimental period before slaughter on Day 109, using a scoring system (Table 3) adapted from Schleger and Turner (1960).

Table 3: Hair coat score (adapted from Schleger and Turner (1960))

Score	Description
1	Hairs extremely short and closely applied to the skin.
2	Coat sleek, hairs short and coarse, lying flat, just able to be lifted by the thumb.
3	General appearance smooth-coated. Hairs easily lifted, usually fairly coarse. 2cm
4	Coat not completely smooth, somewhat rough, patches of hairs being curved outwards, or whole coat showing sufficient length to be ruffled. 2-3cm
5	Hairs distinctly long and lying loosely; predominantly coarse. 4+cm
6	Hairs erect, giving fur-like appearance. Fingers are partly buried in the coat. Fine hairs of under-coat give soft handle. <2cm with undercoat
7	The more extreme expression of 6, with greater length and "body", and heavy cover extending to neck and rump. >2cm with undercoat

3.4.3 Behavioural use of pen space

On one day per week aerial images of the cattle in each pen were captured by use of an unmanned aerial vehicle (UAV, Mavic Pro Platinum, DJI, Shenzhen) at hourly intervals for seven hours. The animals were adapted to the UAV for two weeks prior to the start of the experiment so that the UAV could be flown at a height (25 metres) that did not disturb animal behaviour but still provided quality footage for image analysis. The trajectory was set to a specific flight path and would be flown with this same flight path at each observation period. The flight took approximately 9 minutes collecting a single image and 10 seconds of footage of each pen. The images were visually analysed for the distribution of the cattle within each pen (front, middle or back sectors, Figure 4) and the proportion of animals standing (but not eating), lying, or active (eating or drinking) (Figure 5) in each sector (Table 4). The consistency in relation to feeding time, human presence etc. was not controlled in relation to time of day therefore the images were not analysed to determine effects of time of day in relation to position and behaviour.

Figure 4: Definitions of Back, Middle, and Front of pen (L-R) for analysis of location within pen

Table 4: Behavioural ethogram for drone image analysis

Behaviour	Description
Position	
Standing	Steer standing on at least three legs; including animals that are grooming, locomoting and/ or exploring; excluding active behaviours
Lying	Animal lying down; in a recumbent position lying on side with all four legs stretched out; sitting up on haunches; or lying in an upright position with head in front of body or turned around and resting on forelegs or side.
Active	
Eating	Body standing perpendicular to trough; Head through rail and over bunk; head position down or lateral to body line
Drinking	Animal standing with head over trough directly above the water or head down and drinking the water in trough

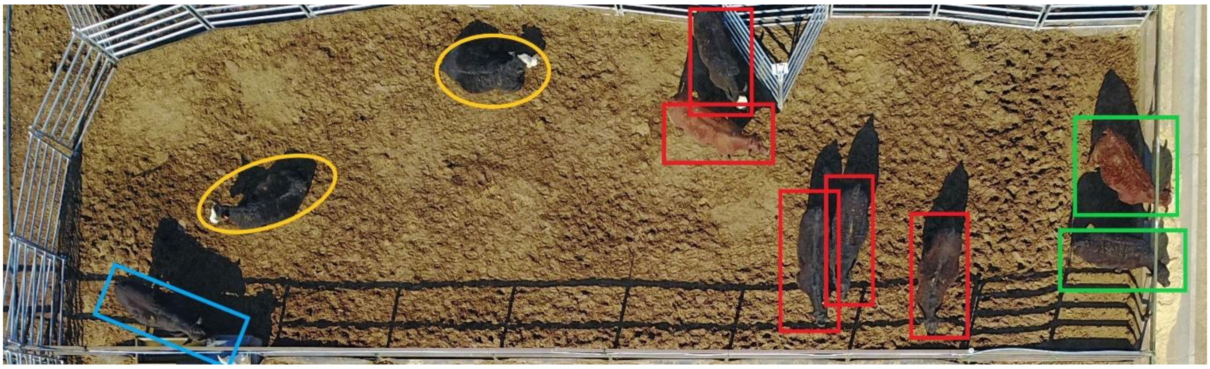


Figure 5: Example of drone footage analysis of animal behaviours (drinking (blue), lying (yellow), standing (red), eating (green))

3.4.4 Dag score

Coat condition was scored from 1-5, using the ordinal system of Watts *et al.* (2015) (Table 5) for coverage of the body with mud and dags on a weekly basis, except for weeks 5 and 13, recording the count of animals of animals of each coat condition score in each pen.

Table 5: Scoring system for coat condition, based on Watts *et al.* (2015)

Score	Description
1	No dag, clean hide
2	Small lumps of manure attached to the hide in limited areas of the legs and underbelly
3	Small and large lumps of manure attached to the hide, covering larger areas of the legs, side and underbelly
4	Small and large lumps of manure attached to the hide, in even larger areas along the hind quarter, stomach and front shoulder
5	Lumps of manure attached to the hide continuously on the underbelly and side of the animal from brisket to rear quarter

3.5 Pen measures

Depth of pad substrate

The apparent depth of the pad in each pen was scored visually using a 1-7 score, using the front legs of cattle as a relative measure (

Table 6) between 1-4 times weekly. One animal was chosen to be scored from each sector of the pen (front, middle and back). The selection of the animal to be used as a relative measure depended on the visibility of animals among the group, and varied from week to week. The ability to score in each sector of the pen was dependent on the location and body position, such as animals standing or lying, of cattle in each sector at the time of scoring, and so not every sector of every pen was able to be scored on every scoring day. At the end of feeding period a 1.5cm diameter metal spike was used to determine penetrable depth showing the depth the animal interacts with the substrate. The depth from the surface to interface layer was determined by using a plumber's shovel to dig down to the clay/rock interface layer, using a 30cm metal ruler to measure depth.

Table 6: Visual scoring system for the apparent depth of mud in each pen in relation to the front legs of cattle

Score	Description
1	Base of hoof
2	Fetlock
3	Top of dew claw
4	Half way up cannon bone
5	Middle of knee
6	Halfway between knee and elbow
7	Elbow

Pad moisture and bulk density

Samples from the pad were collected weekly, commencing after 12 days on feed, once manure had begun to accumulate and continuing until the day after the end of the feeding period. The collection day was fixed, but varied in relation to the watering schedule. The pens were divided into front, middle and back sections; excluding within 1 m of the water trough and the concrete apron next to the feed bunks; one sample was randomly taken from each section in each pen. In the woodchip treatments the substrate was not homogenous, and the structure of the woodchip caused difficulties in making straight edges to a sample of the full depth of the pen substrate. As a result, a separate 'surface sample' (surface to 6 cm depth) and 'deep sample' (6 cm depth to the interface layer) were taken at each sample site, using a plumber's shovel. The 'surface' and 'deep' layers were distinguished from each other visually, but reflected the animals' experience in that they tended to 'sink' down into the 'surface' stratum (which was a mix of woodchip and manure), but not into the 'deep' stratum of woodchip. The three samples from each stratum in each pen were bulked for the pen-stratum, mixed thoroughly in a bucket with a hand trowel, and subsampled for a single 'surface' and a single 'deep' sub sample for each pen. The substrate in the control pens was homogenous, therefore at each site a single sample was taken from the mud surface to the interface layer, bulked and mixed thoroughly with a hand trowel, and a subsample taken for each pen. Subsamples were taken by randomly taking grab samples from bucket containing the bulked sample and sealing in a plastic bag. The subsamples were immediately transported to the lab, where the subsample was split into one subsample which was refrigerated at 4 degrees in a sealed package then tested for bulk density, whilst the remainder was oven dried until there was no change in weight. Percentage moisture content was calculated using the following formula: change in weight (wet-dried) divided by initial sample weight x 100, and reported as percentage. The dried samples were stored in sealed plastic bags in case required. The samples collected from the control treatment pens in weeks 6 and 7 were discarded due to sampling error.

Due to the large particle size of the woodchips, BD could not be sampled *in situ* so the maximum BD was chosen using standard Proctor Hammer method (AS 1289.5.2.1). Samples were compacted on an as-received moisture basis, as this is what the cattle would be experiencing in the pen, then dried at 105 °C until no change in weight. For the subsample a relationship between BD and various moisture contents was established.

Twenty-four hours after the end of the feeding period, all pens were sampled using the weekly sampling procedure and analysed for moisture content and BD using the methods above; and for volatile solids (VS), carbon (C) and nitrogen (N) content. At the same time, the depth of the pen substrate was measured by insertion of a 2.5 mm steel spike to the interface at five points across a transect in each pen. There were difficulties in penetrating the full depth of the substrate to the interface through the deep woodchip layer in the W60 treatment, and so in those pens, depth of substrate was measured by first excavating to the interface with a plumbers shovel. The relative depth of each stratum in the woodchip bedded treatments was used to calculate mean moisture and VS content and BD for the woodchip substrate as a whole in each pen.

A 30 mL subsample of the end of feeding period sample was collected according to the moisture content sampling protocol (above) and stored in a screw-top container. These samples were immediately placed on ice, and frozen at -4 °C at the feedlot. They were later transported frozen to the laboratory and freeze dried at -50°C for seven days in an Alpha1-4 LDplus freeze drier (Martin Christ Freeze Dryers, Osterode, Germany). Due to the woodchips being thick and hard the samples were first ground through a grinder with a 5mm sieve, then a cotton mill grinder with a 1 mm sieve. Samples were split until a homogenous sample was obtained, which was analysed for VS, C and N content.

Volatile solids

For VS, following standard methods (APHA 2540E, 2000), the clean crucible was placed in a 550 °C muffle furnace for 10 minutes, cooled in a desiccator, then 2 g of sample was loaded in crucible and placed in 550 °C muffle furnace. The furnace gradually came to temperature allowing the sample to 'burn off', allowing complete combustion of the sample. The sample was removed and cooled in desiccator and weighed, and the process was repeated until the change was less than 5% difference in weight. Samples were performed in duplicate and mean has been presented. The ashed samples were then were categorised based on the Munsell Colour Chart for hue, value, and chroma (Oyama and Takehara 1970). The relative depth of each stratum in the woodchip bedded treatments was used to calculate a mean VS content for the woodchip substrate as a whole in each pen. To check for any loss of VS between the end of the feeding period and pen cleanout, grab samples were collected from bulked manure samples cleaned from each treatment on the last day of pen cleaning, and analysed for VS using the same procedure. A sample of clean woodchip bedding was also analysed for VS.

Carbon and Nitrogen

For C and N, approximately 0.15-0.20 g of ground sample was weighed to four decimal places and analysed for C and N content via combustion in a TruMac determinator (LECO Corporation, St Joseph, MI, USA). The relative depth of each stratum in the woodchip bedded treatments was used to calculate a mean C:N ratio for the woodchip substrate as a whole, in each pen.

Pen cleaning

At the end of the feeding period, the control pens were deemed too wet to feasibly clean so the treatments were cleaned in the order W60, then W30, then control. The pen substrate was removed using an SDLG front end loader. From the day the cattle left the pens until the last pen was cleaned, a period of 11 weeks elapsed, partially delayed by wet weather. The time taken to clean each pen was recorded as time spent in the front-end loader only. The fresh weight of material removed from each pen was weighed over a weighbridge. From each load, representative grab samples were collected, mixed and subsampled, and analysed for moisture content on the day of cleaning using the methods outlined above. Fresh weight of manure removed was then adjusted for the moisture content on the day after the end of the feeding period. Pen cleaning time on per head basis was adjusted for the total number of head-days of the pen, for pens where cattle had been removed during the experiment.

Pen interface

Immediately before the application of woodchip, drone footage was taken of the surface of each pen. After the pens were cleaned at the end of the experiment, the pens were again inspected for damage to the interface layer by two independent scorers, who took descriptive notes of the condition of every pen, independent of knowledge of the pen allocation to treatments. These notes were then analysed by another independent scorer whom analysed for comments recurring between pens within each treatment. Drone footage of the pen surface and photos from a digital cameras at ground level were taken during the inspection. Still images from the drone footage before and after the experiment were analysed by placing a grid of 165 squares over the images. Each square in this grid was scored on a 1-5 ordinal scale, taking account of the area and apparent severity of any damage to the interface layer. This data was processed into a proportional distribution of scores for each pen.

3.6 Cleaning of cattle in lairage

All steers were trucked to the processor overnight after 109 days on feed. The cattle were trucked (6 trucks in total with 2 trucks per treatment) and processed in lairage in their assigned truck groups. Treatment was identified prior to loading at the feedlot with a spot of coloured stock mark on the back of each individual (Control = Blue; W30 = Green and W 60 = Red). On arrival at the processing plant (Wingham Beef, Wingham, NSW), most cattle were allocated a lairage wash pen containing a single treatment (Control – 6 pens, W30 – 9 pens, W60 – 6 pens, containing between 8 and 20 head per pen) in the order they came off the trucks. The second truck was unloaded and sent straight down to dirt pen to be brought back up later in the day for soaking. The cattle in soaking pens were soaked with water from underbelly sprays located on the bottom rail of each pen which were manually turned on by stockmen (Figure 6). These wash pens had water troughs that cattle could access at all times. After soaking the stockmen would then turn off the underbelly sprays and manually wash each individual animal with a stronger flow hose (Figure 7). One pen of 10 animals from treatment group W30 were sent down to the dirt pens without having a manual hard hose from the stockmen due to miscommunication during shift change. Personnel from UNE recorded the time the animals spent in soaking and being manually hosed on a lairage pen basis. The cattle were inspected for coat cleanliness and once approved they were relocated to 7 dirt-base pens (only one treatment group per pen) to rest overnight before slaughter the following day.

On the day of slaughter, the cattle were randomly reallocated to 6 soaking pens per treatment, containing between 9 and 20 head per pen. The cattle were soaked with water again, manually washed with a hard hose, and then washed in a wash tub for 1 min 30 seconds (Figure 8). The time spent soaking and hosing was recorded on a lairage pen basis. Because of the low replication, remixing of groups within treatment, and subjective and/or arbitrary nature of decisions made in lairage about cleaning time, this data was not analysed with statistical comparisons.

Figure 6: Soaking sprinklers in lairage soak pens

Figure 7: Hard hose in lairage soak pens

Figure 8: Lairage wash tub

3.7 Carcase evaluation

After slaughter, all carcases were measured for Hot Standard Carcase Weight (HSCW) and all carcases except for carcase 213, as a result of an error at the processing plant, were graded for MSA index (including P8 fat depth, pH, MSA marbling score, eye muscle area (EMA), meat colour and cold rib fat depth). All carcases were sampled for end glycogen content. Both adrenal glands were collected from all carcases, stripped of external fat and weighed individually to the nearest 0.01g. The relative adrenal weight (g per 100 kg HSCW) was calculated from the heaviest adrenal gland weight (g) x 100 divided by HSCW (kg) (Wilson et al. 2002).

3.8 Net benefit analysis

Using the results of the cattle production, and pen cleaning measures, a net benefit analysis (NBA) was constructed on a per head basis. This analysis only included variables affected by the treatments, and not input costs which were fixed for all treatments, such as induction and transport. Assumptions used in the NBA are outlined in Table 7. Cost of plant and labour to apply woodchip was derived from interview with a feedlot currently applying woodchip at a rate approximate to W30. It could not be ascertained whether application costs varied with application rate, or were instead driven by animal numbers and therefore pen area. As a result, a fixed cost of woodchip application ($/head) was applied. Value of manure sold was derived from interview with a commercial composter purchaser of feedlot manure. Because of the resultant change in C:N ratio, woodchip was considered a manure contaminant and therefore a discount for increasing inclusion of woodchip was assumed. Other factors were derived from the observed results of this project.

Table 7: Assumptions used in benefit-cost analysis of the use of woodchip bedding for feedlot cattle in wet conditions

Factor	Assumed value
Stocking density (m^2/head)	12.5
Days on feed	109
Woodchip application rate (kg/m^2)	54 (W30), and 108 (W60)
Price of woodchip delivered ($/t)	50.00
Cost of labour to apply woodchip ($/head)	1.25
Cost of plant and fuel to apply woodchip ($/head)	3.75
Cost of labour for cleaning pens ($/hr)	30.00
Fuel consumption of front wheel loader (L/h)	15.0
Cost of diesel (c/L)	142.0
Value of manure sold, uncomposted ($/t FW)	12.00 (C), 9.00 (W30) and 6.00 (W60)
Ration cost ($/t as-fed)	470
Ration dry matter (%)	82
Cost of labour for hosing cattle at processor ($/hr)	22.00

The sensitivity of net benefit to independent variation in value of woodchip, diet, and uncomposted manure cleaned from pens was tested over a range of values considered to be realistic either from interviews with industry or from the report of Watts *et al.* (2015).

3.9 Statistical analysis

Production data – liveweight gain, intake and gain: feed

All production and slaughter statistics were conducted in R (R Core Team, 2013). Least squared means for each treatment were separated using pairwise comparisons with an *F*-protected Least Significant Difference (LSD) using Satterwhaite's method, and significance was declared at $P < .05$. A linear mixed effects model (*lme4* (Bates et al 2015)) was fitted to production data (cumulative liveweight gain, cumulative liveweight gain per head per day, adjusted liveweight gain, production value, cumulative feed intake, feeding costs and cumulative gain:feed (G:F)). Adjusted liveweight was computed from the HSCW divided by the mean dressing percentage for all cattle. Because cattle were fed on the morning of dispatch to slaughter, intake and G:F were calculated using 109 days of liveweight gain, and 110 days feeding days, with the extra feeding day included at the end of the feeding period. G:F in each pen was computed arithmetically for each weigh day as the cumulative feed intake per pen (kg DM/head.day) divided by the cumulative liveweight gain per pen (kg/head.day) for the period to the day of interest. Liveweight gain per day was analysed in two ways. Firstly, cumulative liveweight gain per pen per day was computed arithmetically for each weigh day as the cumulative liveweight gain per pen divided by the days from the start of the experiment to the weight day of interest. This data was analysed as least squared means in a linear mixed effects model, where pen is the experimental unit, treatment is a fixed effect and experimental block is a random effect. This model was used to analyse the cumulative liveweight gain per head per day as well as the dry matter intake per head per day, and G:F per pen for each weigh day (days 28, 54, 92 and 109). Secondly, a repeated measures linear regression model with a random intercept was fitted for each pen to the cumulative liveweight gains of individual cattle for all weigh days, and the average daily gain for the duration of the experiment was calculated from the slope of the regression equation (b_1). For this analysis, weighing day was considered to be a continuous variable, weighing day and the interaction for treatment x day were fixed effects, the day 0 liveweight was used as a covariate, block and pen are considered random effects, and a random slope and random intercept were fitted to pens over time. When the model was fitted with random intercepts, a linear model had a significantly better fit to the data than a quadratic model, but when fixed intercepts ($b_0 = 0$) were fitted, then a quadratic fit with an interaction of treatment by day improved the model. The decision was made to progress with a linear regression for the second model of liveweight gain per day.

Slaughter

Carcase evaluation results were analysed in linear mixed effects models. HSCW was analysed for least squared means in a linear mixed effects model, where pen is the experimental unit, treatment is a fixed effect and experimental block is a random effect. Eye muscle area was analysed with a model that included treatment and covariate HSCW as fixed effects and experimental block as a random effect, as well as with a second model that did not include HSCW. All other carcase evaluation data were analysed in a model with treatment as a fixed effect and experimental block as a random effect. Statistical comparisons of means were not applied to lairage cleaning data.

Net benefit analysis

The net benefit of the woodchip treatments were analysed as difference from the mean net benefit of the control treatment. A linear mixed effects model was used for analysis of net benefit, where treatment was a fixed effect, and block was a random effect.

Animal behaviour and position

All animal behaviour and position, and dag and pen mud score data was analysed in SPSS (v25, IBM Corp, Armonk, NY, USA). Animal behaviour and position data collected by the drone was an unbalanced repeated measures design, since there were an unbalanced number of observations. The images were visually analysed for the proportion of animals in each areas of the pen (front, middle or back) and the proportion of animals standing, lying, or eating and drinking, henceforth referred to as other. Animal behaviour and position data were analysed with a binary logistic regression and included week and hour as repeated measures with a first order autoregressive covariance structure. Fixed effects included treatment, time (week) and the interaction between the two. Time of day and block were included in all models as random factors. Multiple comparisons were adjusted with the LSD) method.

Dag score and pen measures

Median pen dag scores were calculated for each week and analysed with a generalised linear model with an ordinal distribution and logistic link function. Fixed factors included treatment, time (week) and the interaction between the two. Time of day and block were included as random factors.

Pen scores were averaged within a location (front, middle, back) for each pen for each week. Pen scores, moisture and BD of the pen substrate were analysed in a generalised linear model with an ordinal distribution and logistic link function. End of feeding period measures were analysed in a linear mixed models for least squared means.

4 Results

4.1 Feedlot performance

Results of average daily gain (ADG) in the first 28 days showed no effect of bedding treatment, but by day 54, the bedding treatments demonstrated a higher ADG than the control treatment (Table 8). This was not associated with a significant difference in DMI until the end of the feeding period (*P* = 0.056, Table 8), such that both woodchip bedded treatments had a higher DMI than the control treatment. As a consequence, the woodchip bedded treatments had a significantly improved efficiency of conversion of feed to gain (Table 8).

Table 8: Effect of the provision of woodchip bedding at 54 kg/m^3 (W30) or 108 kg/m^3 (W60) on feedlot performance (mean ± s.d.) of cattle in wet conditions

Treatment	Control	W30	W60	*P*
Body weight				
Initial BW (kg)	374.8 ± 24.18	380.4 ± 23.04	378.1 ± 23.23	0.380
d 28 BW (kg)	462.7 ± 31.64	462.4 ± 28.45	460.8 ± 27.25	0.822
d 54 BW (kg)	518.0^a ± 30.15	531.6^b ± 27.24	529.9^b ± 33.93	0.009
d 92 BW (kg)	590.4^a ± 36.02	613.8^b ± 26.22	614.7^b ± 34.97	0.0003
Final BW (kg)	622.3^a ± 39.11	647.3^b ± 28.32	648.3^b ± 36.77	0.0002
Adjusted final BW (kg)	626.3^a ± 37.94	644.2^b ± 23.00	646.6^b ± 33.10	0.003
ADG (kg BW/hd.d)				
d 0 to 28	2.99 ± 0.284	2.93 ± 0.237	2.95 ± 0.208	0.66
d 0 to 54	2.50^a ± 0.143	2.70^b ± 0.216	2.71^b ± 0.225	0.020
d 0 to 92	2.30^a ± 0.138	2.54^b ± 0.128	2.57^b± 0.141	0.000
d 0 to 109	2.26^a ± 0.163	2.45^b ± 0.100	2.48^b ± 0.132	0.000
Adjusted d 0 to 109	2.27^a ± 0.162	2.42^b ± 0.098	2.46^b ± 0.116	0.003
Regression (d 0 to 109)	2.18^a ± 0.151	2.43^b ± 0.214	2.46^b ± 0.214	< 0.001
DMI (kg DM/hd.d)				
d 0 to 28	9.48 ± 0.814	9.72 ± 0.720	9.19 ± 0.829	0.246
d 0 to 54	10.15 ± 0.712	10.51 ± 0.574	10.13 ± 0.823	0.136
d 0 to 92	11.03 ± 0.931	11.46 ± 0.575	11.17 ± 0.934	0.116
d 0 to 109	11.30 ± 0.974	11.79 ± 0.584	11.47 ± 0.920	0.056
Ratio gain:feed				
d 0 to 28	0.32 ± 0.026	0.30 ± 0.032	0.32 ± 0.014	0.627
d 0 to 54	0.25^a ± 0.016	0.26^{ab} ± 0.014	0.27^b ± 0.014	0.017
d 0 to 92	0.21^a ± 0.011	0.22^b ± 0.010	0.23^c ± 0.010	< 0.001
d 0 to 109	0.20^a ± 0.008	0.21^b ± 0.010	0.22^c ± 0.008	0.012
Adjusted d 0 to 109	0.20^a ± 0.011	0.20^a ± 0.013	0.21^b ± 0.016	0.004

Adjusted BW was calculated from HCW divided by the average dressing percent (52.48 %) of all steers, after which adjusted ADG and adjusted G:F were recalculated using the adjusted BW.

4.2 Carcase evaluation

Providing woodchip significantly increased the mean HSCW by 9.3 and 10.8kg for the W30 and W60 chip treatments respectively or approximately 3 % (*P* = 0.001, Table 9). W30 carcases had a significantly higher muscle glycogen content (*P* = 0.047, Table 9**Error! Not a valid bookmark self-reference.**) than the control and W60 groups, which did not differ from each other (Table 9). Raw EMA in W60 cattle was greater than in control carcases, and W30 was intermediate (*P* = 0.041) but when EMA was adjusted for carcase size, the difference was not significant (*P* = 0.087). Only one carcase, 484 (W60), was downgraded for pH > 5.70. There was no effect of woodchip bedding on other carcass quality attributes, or MSA Index (Table 9).

Numerically, relative adrenal weight was negatively correlated with woodchip bedding (*P* = 0.077, Table 9). The control treatment group had a relative adrenal weight which was 6.9% higher than the W60 group (Table 9). The W30 treatment was intermediate between control and W60.

Table 9: Effect of the provision of woodchip bedding on carcase attributes and relative adrenal gland weight (μ ± s.d.) in cattle in wet conditions

	Treatment			
	Control	W30	W60	*P*
HSCW, kg	$328.8^{a} \pm 19.90$	$338.1^{b} \pm 12.01$	$339.6^{b} \pm 17.37$	0.001
Dressing percentage, %	$52.8^{a} \pm 0.53$	$52.3^{b} \pm 0.82$	$52.4^{b} \pm 0.85$	0.023
P8 fat, mm	16.8 ± 1.84	17.3 ± 2.09	17.6 ± 2.30	0.320
Rib fat, mm	8.6 ± 1.03	9.1 ± 1.53	8.8 ± 1.82	0.680
MSA marbling score (100-1190)	398.0 ± 59.75	399.6 ± 26.84	398.6 ± 49.41	0.990
Eye muscle area*, cm^2	77.9 ± 3.27	80.2 ± 3.25	81.1 ± 3.35	0.087
Eye muscle area†, cm^2	$77.8^{a} \pm 3.26$	$80.3^{ab} \pm 3.11$	$81.3^{b} \pm 3.20$	0.041
pH	5.45 ± 0.02	5.45 ± 0.02	5.46 ± 0.02	0.290
Muscle Glycogen (%)	$1.29^{b} \pm 0.194$	$1.32^{a} \pm 0.200$	$1.26^{b} \pm 0.189$	0.047
Ossification score (100 – 500)	154.8 ± 9.00	156.3 ± 10.25	155.0 ± 8.37	0.870
MSA Index	56.7 ± 0.80	56.8 ± 0.29	56.8 ± 0.96	0.960
Relative adrenal weight (g/100 kg HSCW)	4.18 ± 0.289	4.09 ± 0.237	3.91 ± 0.232	0.077

* Eye muscle area analysed with HSCW as a fixed effect

† Eye muscle area, raw measurement

4.3 Weather and irrigation

Combined irrigation and natural rainfall was close to the target of 74 mm per 30 day period (Table 10, Figure 9).

Table 10: Temperature and precipitation on experimental pens from rainfall and irrigation per 30 day period

Period (Days)	T_A Max (°C)	T_A Min (°C)	Irrigation (mm)	Irrigation Days	Natural Rainfall (mm)	Rainfall Days	Total precipitation (mm)
d 1 – 30 (30 days)	15.0 ± 2.33	1.5 ± 3.44	68	17	5.0	4	73.0
d 31 – 60 (30 days)	15.5 ± 2.90	0.9 ± 5.02	48	12	31.5	5	79.5
d 61- 90 (30 days)	15.6 ± 2.98	-0.1 ± 3.68	44	11	28.0	4	72.0
d 91 - 109 (18 days)	18.8 ± 3.80	5.3 ± 3.70	20	5	21.0	4	41.0

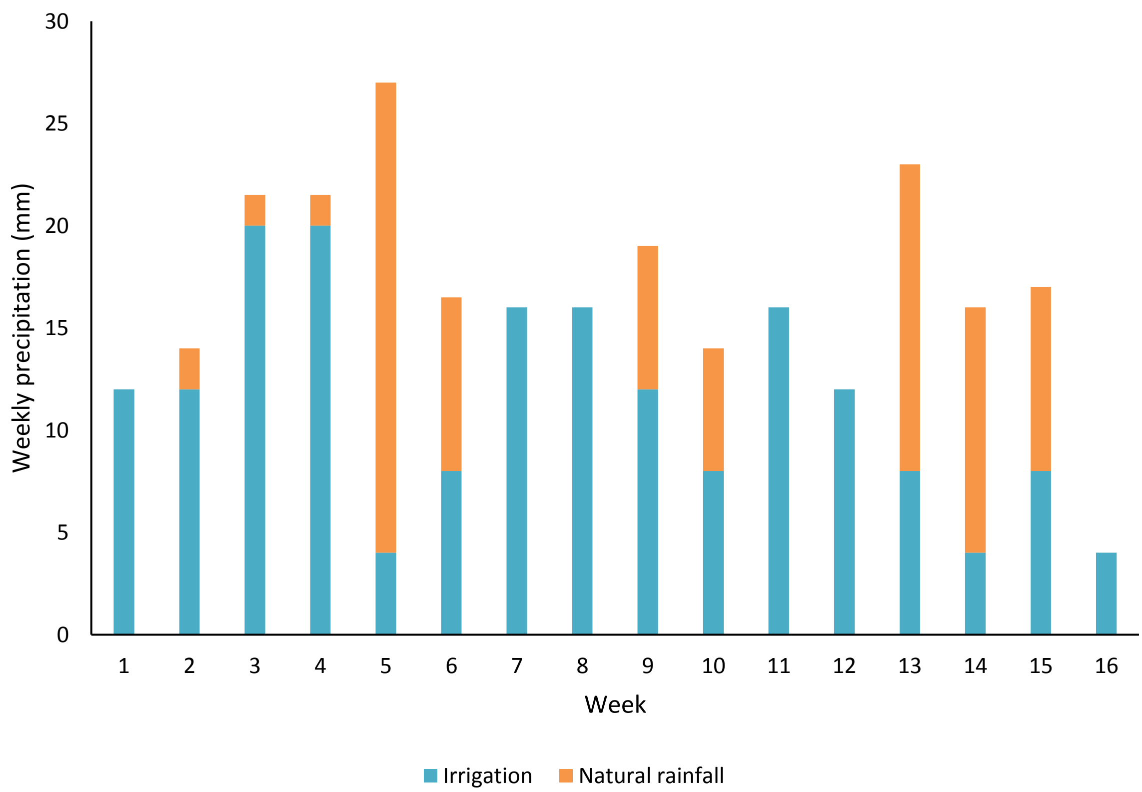


Figure 9: Contribution of irrigation and natural rainfall to weekly precipitation on pens

The weather during the experiment was cold and mostly dry, with few days above 20°C maximum until the end of the experiment, and 65 days of minimums less than 1 °C (Figure 10).

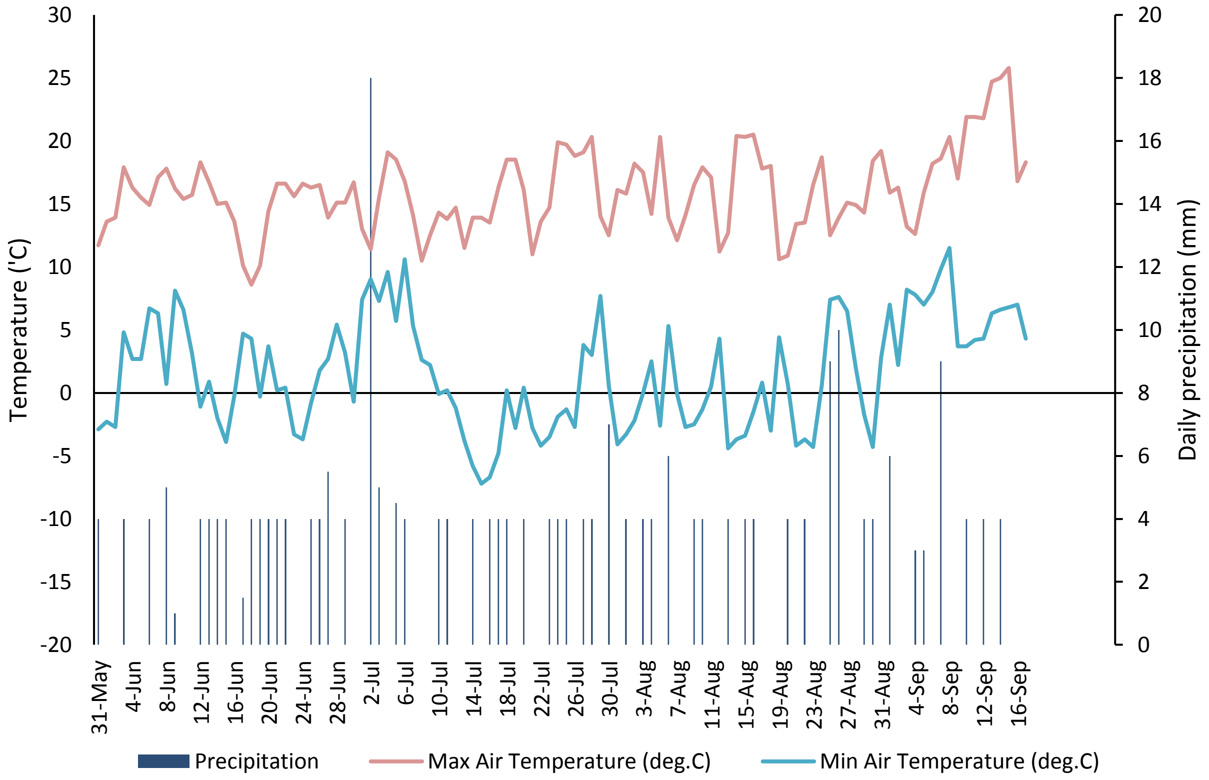


Figure 10: Daily maximum and minimum temperature (°C), and total precipitation (rainfall + irrigation, mm) on pens

4.4 Manure pad condition

There was no difference between mud scores of animals at the front, middle or back areas of a pen (*P* = 0.286) therefore median mud scores across the pen were compared between treatment and over time. Manure pad condition worsened over the course of the experiment (Figure 11, Figure 12, Figure 13). There was an interaction between treatment and week ($\chi^2_{(28,2461)}$=70.2, *P* < 0.0001). Mud scores of control animals were higher from week two compared to W30 and W60 animals (Figure 15). Individual pen mud scores reached 6 and 7 in the control pens, equivalent to approximately 60 cm of mud.

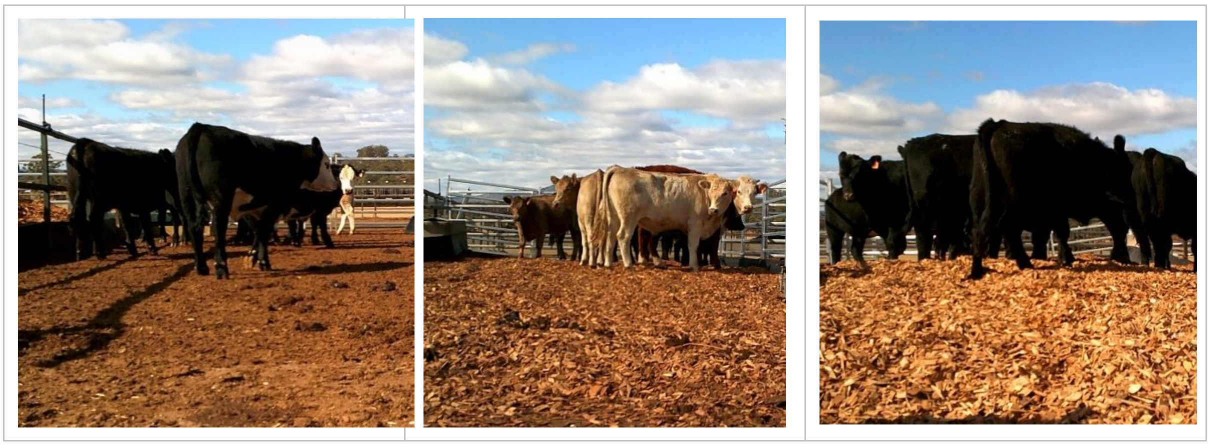


Figure 11: Condition of the pad on day 3, taken from feed bunk (from left to right, Control, W30, W60)

Figure 12: Condition of the pad on day 29, taken from feed bunk (from left to right, Control, W30, W60)

Figure 13: Condition of the pad on day 97, taken from feed bunk (from left to right, Control, W30, W60)

The manure pad in the control pens was a homogenous, single stratum of manure that was thoroughly mixed by cattle movement. In contrast, in the woodchip bedded pens, clear stratification of the pad substrate was observed, with manure accumulating on top, and relatively clean woodchip below (Figure 14). However, by the end of the feeding period, the W30 treatment strata were less defined than those in the W60 treatment. By experiment end, woodchip was well mixed with manure throughout the substrate in the W30 treatment, whereas the W60 treatment maintained a clean deep woodchip layer. This is reflected in significantly higher pen mud scores in W30 compared to W60 from week 10, and especially from week 13 onwards (Figure 15). Penetrable depth showed the depth the animal interacts with and showed a main effect of treatment, such that W60 was shallowest and control the deepest, with W30 intermediate.

Figure 14: Woodchip in W60 treatment showing manure on surface and darkening colour with cleaner woodchip in deeper stratum.

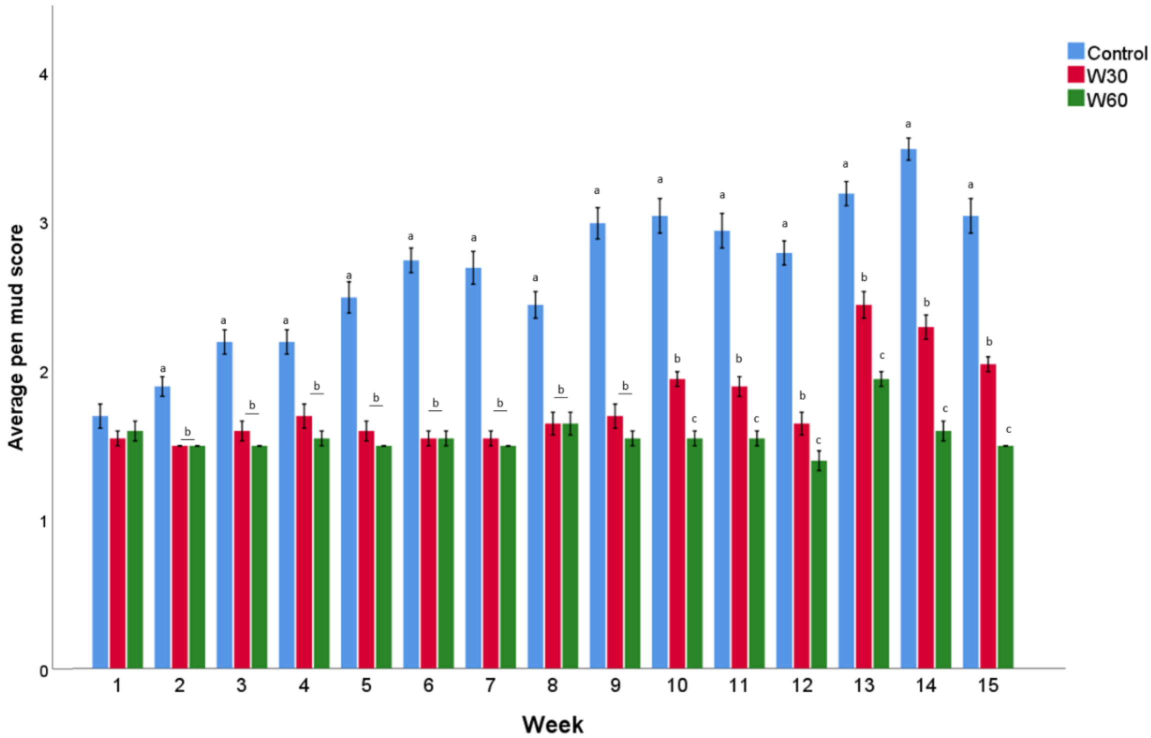


Figure 15: Weekly average pen mud score. Subscript with differing letters denotes a significant difference between treatment groups at each time point

The moisture content of the substrate in the control pens (65.4 ± 6.9 %) was significantly ($P < 0.0001$) higher than the surface or the deep samples of the woodchip bedded pens (55.9 ± 9.0 % (W30 Surface), 53.7 ± 8.7 % (W60 Surface), 52.5 ± 9.0 % (W30 Deep), and 49.8 ± 8.1 % (W60 Deep)), for the entirety of the experimental period. The W60 deep samples were significantly drier than the W30 Surface samples ($P < 0.0001$). Whereas the control pens maintained a consistent moisture for the majority of the experiment, from the first sampling, the moisture content of the woodchip bedded pens' substrate increased gradually over the first 4 weeks of the experiment. In the last two weeks of the experiment, warmer temperatures, high winds and therefore higher evaporation reduced the moisture content of the pen substrate (Figure 16).

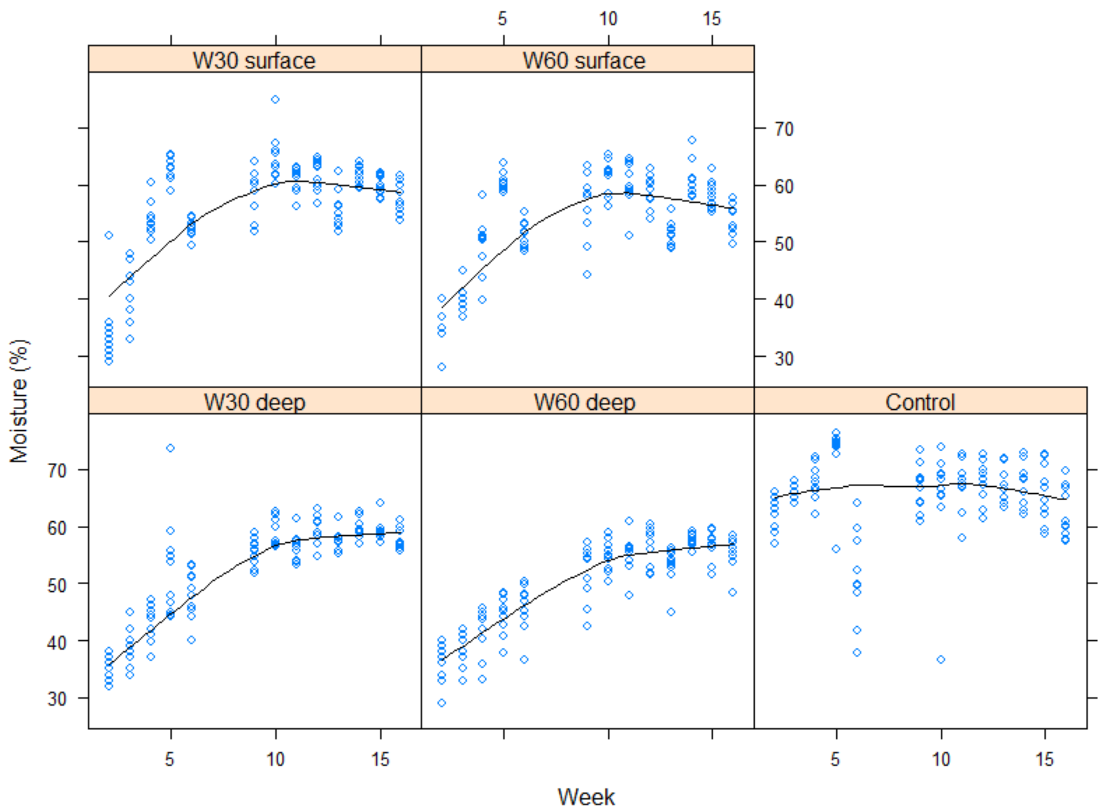


Figure 16. Pen substrate moisture over the duration of the experiment. Black line is smoothed mean, blue points are samples. A single moisture content sample was taken for the control pens, since the substrate was homogenous. The W30 and W60 pens were bedded with woodchips, with a distinct layering between the surface and deep stratum.

Control substrate samples showed a relationship between moisture content and BD (y=-15.096x + 1377.8, r2 = 99%), so final bulk density for that treatment was converted to 54% as-received moisture. There was a significant main effect of treatment ($P < 0.0001$) on BD of the pen substrate, such that the woodchip bedded treatments were of significantly greater BD than the control. There was no difference of main effect between W30 and W60. There was a significant interaction between treatment and week ($P < 0.001$), such that BD in the control pen was lower than in the woodchip bedded pens for the first half of the experiment (Figure 17). There was no difference between W30 and W60 for the interaction of treatment and week for BD.

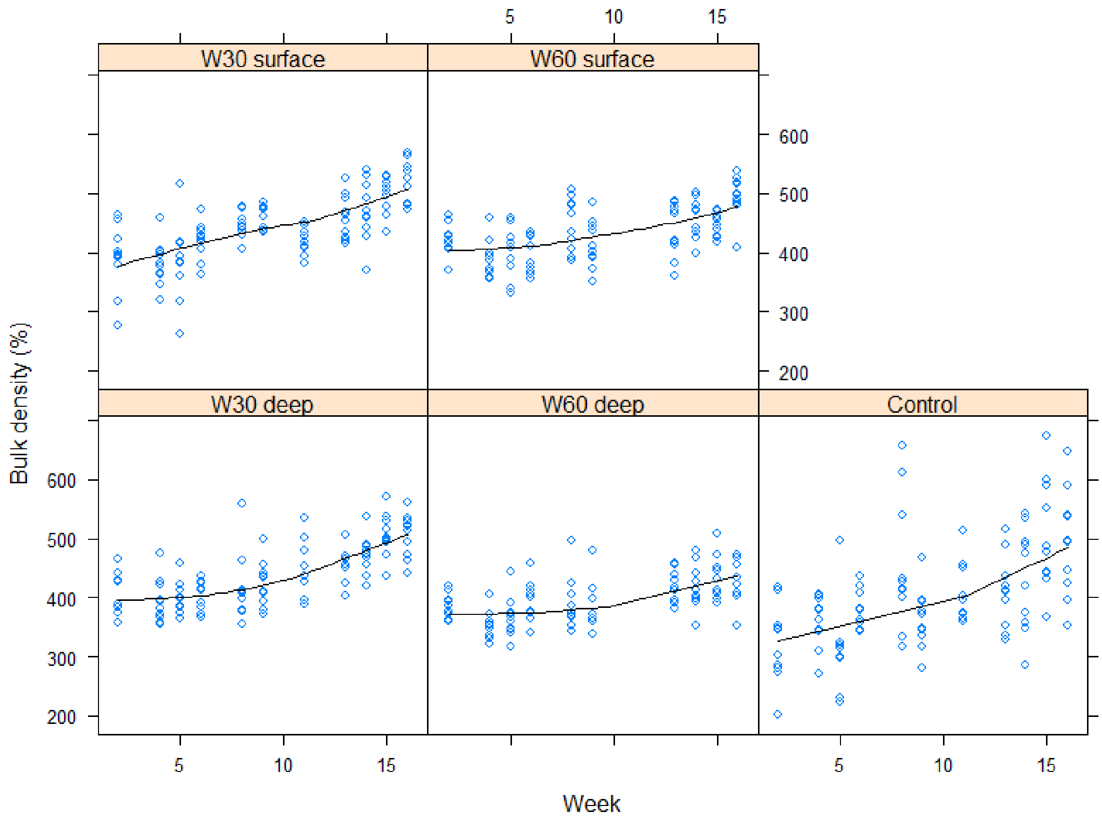


Figure 17: Pen substrate bulk density (%) as received over the duration of the experiment. Black line is smoothed mean, blue points are samples. A single bulk density sample was taken for the control pens, since the substrate was homogenous. The W30 and W60 pens were bedded with woodchips, with a distinct layering between the surface and deep stratum.

4.4.1 End of feeding period pen-substrate analysis and pen cleaning

Measured depth from surface to interface showed W60 had the deepest substrate, but cattle only interacted with the top 6cm. The volatile solids were significantly lower for control and showed clay material remained in crucible. The colour of the ash was examined and showed colour similar to the clay and rock substrate in some of the control pens which correlated with a decrease in volatile solids (Figure 18). The VS content of the clean woodchip was 99.85 ± 0.07 % (μ ± s.d.). There was no significant change in VS between the end of the feeding period and the end of the cleaning period (Table 11 , P = 0.628 (Control), 0.187 (W30), and 0.987 (W60)).

Table 11: Weight, volume and composition of pen substrate at the end of the feeding period, day of cleaning, and end of the cleaning period, and time taken to clean each pen (µ ± s.d.) for woodchip bedding provided at 54 kg/m^3 (W30) or 108 kg/m^3 (W60).

Treatment	Control	W30	W60	*P*
At end of feeding period*				
Penetrable‡ depth of substrate (cm)	20 ± 1	14 ± 2	6 ± 1	< 0.0001
Depth (surface to interface, cm)	20 ± 1	14 ± 2	33 ± 1	<0.0001
Sampling proportion surface (%)	100	43	18	
Sampling proportion deep (%)	0	57	82	
Moisture (%)				
Surface	59.2^a + 6.1	50.2^b + 6.6	45.2^c + 4.1	0.0001
Deep	-	53.9 + 4.2	55.7 + 3.0	0.284
Surface to interface**	59.2^a + 6.1	51.8^b + 4.7	53.8^b + 3.0	0.006
Volatile solids (%)				
Surface	-	89.9^a ± 2.7	92.6^b ± 0.5	0.006
Deep	-	88.1 ± 3.1	96.7 ± 1.1	0.477
Surface to interface**	66.8^a ± 10.6	89.9^b ± 3.7	93.1^b ± 3.7	<0.001
Bulk Density as received (kg/m^3)				
Surface	-	523 ± 11	496 ± 12	0.47
Deep	-	506^a ± 12	430^b ± 12	0.0004
Surface to interface	492 ± 29	515 ± 11	468 ± 10	0.211
At day of cleaning				
Moisture (homogenous sample, %)	54.2 + 4.8	54.0 + 2.4	54.2 + 2.2	0.980
Weight removed				
Fresh weight (t)	10.2^a ± 1.7	17.1^b + 1.2	25.8^c + 1.1	<0.001
Dry weight (kg/head.d)	4.7^a + 1.1	7.8^b + 0.7	11.8^c + 0.9	<0.001
Fresh weight – adjusted° (kg/head.d)	11.4^a ± 1.8	16.5^b ± 1.5	23.8^c ± 1.4	<0.001
Calculated bulk density at clean out† (kg/m^3)				
Surface to interface	519† ± 40	515 ± 38	510 ± 41	0.23
Fresh volume removed				
Volume per pen (m^3)	19.8^a ± 3.3	36.1^b ± 2.6	59.8^c ± 2.5	0.000
Volume (m^3 x10^{-2}/head.d)	1.82^a ± 0.31	3.31^b ± 0.24	5.52^c ± 0.24	0.000
Cleaning time (min/head)®	5.16^a ± 1.98	8.2^b ± 2.49	14.9^c ± 3.6	0.000
At end of cleaning period				
Volatile solids (homogenised sample, %)	64.5^a ± 8.9	88.6^b ± 2.2	93.1^c ± 1.7	0.000

[a, b, c] Denotes significantly different means within a row

*Sampled 24 hours after cattle left the pen

‡There were difficulties in penetrating the full depth of the substrate to the interface through the deep woodchip layer in the W60 treatment using a spear, and so depth of substrate was measured by excavating to the interface with a plumbers shovel and using a metal ruler to measure depth

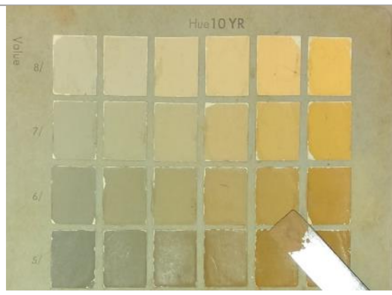
** For Control - as sampled; For W30 and W60 - calculated from 'Surface' and 'Deep' samples, according to sampling proportion

°Adjusted to moisture at end of feeding period (day after cattle left pens)

†Control showed a relationship between moisture content and bulk density (y=-15.096x + 1377.8, r^2 = 99%), so final bulk density was converted to 54% as-received moisture

®Adjusted for head-days

Pen 8 (Control)
Hue 2.5Y Value 5 Chroma 1 Yellowish grey



Pen 30 (Control)
Hue 10YR Value 6 Chroma 6 Bright yellowish brown

Pen 1 (Treatment W60 deep)
Hue 10YR Value 6 Chroma 1 Brownish grey

Pen 14 (Treatment W60 deep)
Hue 10YR Value 5 Chroma 1 Brownish grey

Figure 18: Example of colour of volatile solids ash categorised based on the Munsell Colour Chart for hue, value, and chroma (Oyama and Takehara 1970)

There were no quantitative differences between pens in scoring of the extent of damage to the interface layer after cleaning, however the pen inspections described an interface layer that was very thin or missing in the control pens, whereas in the woodchip bedded pens, the original interface was still evident (Table 12). The operator cleaning the pen reported that removing the woodchip was quite difficult, and as a result, some damage to the interface occurred in pushing the tractor bucket under the manure mixed with woodchip. Prior to the experiment start, there was no difference to the condition of the interface (1.2 ± 0.13, μ ± s.d), showing that the pen condition deteriorated as a result of the wet conditions and the woodchip bedding.

Table 12: Score of damage to pen interface after cleaning (1-5 ordinal scale, incorporating area and apparent severity of damage), and common or notable descriptors from a qualitative inspection of pens where woodchip bedding was provided at 54 kg/m^3 (W30) or 108 kg/m^3 (W60).

Treatment	Score (μ ± s.d)	Description
Control	2.0 ± 0.29	More extensive damage to interface than W30 and W60. Interface was very thin – 1 - 2 mm or non-existent in large areas.
W30	1.9 ± 0.34	Overall, interface 2.0 - 3.0 cm deep, medium sized crumble. Interface damage ranging from very little to moderate. Some deep holes where rocks had been pulled out in cleaning.
W60	1.9 ± 0.36	Overall, interface 1.5 - 2.0 cm deep, dinner plate sized crumble. Interface damage ranging from very little to moderate. One pen with a large hollow. Light distribution of woodchip remaining throughout pens.

The control pen substrate (manure only) had a substantially lower carbon:nitrogen ratio than the woodchip bedded pens, as a result of the high carbon content of the woodchip bedding (Table 13). The C:N ratio of the woodchip bedded pens aligned with visual observations of the pen substrate at the end of the feeding period, with the strata in the W30 pens becoming mixed, and the W60 pens maintaining differentiation between the manure stratum and the clean woodchip stratum. The carbon content of the control pens had a higher variance than that of the woodchip bedded pens. However, there was no relationship between ash content at end of the feeding period, and scores of pen damage (r = -0.02, p (two-tailed) = 0.9).

Table 13: Carbon and nitrogen content (%,W/W, DM-basis ± s.d.) of the pen substrate sampled after 109 days of feeding with woodchip bedding provided at 54 kg/m^3 (W30) or 108 kg/m^3 (W60). The control pens had a homogenous substrate from which a single bulked sample was analysed. The W30 and W60 pens had distinct layers of manure and woodchip, and these strata were sampled and analysed separately.

Treatment	Control	W30	W60	*P*
Carbon (%, W/W)				
Homogenous sample	31.7^{a} ± 4.7	-	-	
Surface stratum	-	43.4^{b} ± 1.3	44.1^{b}± 0.5	<0.0001
Deep stratum	-	42.3^{b} ± 1.6	46.6^{c} ± 0.8	
Nitrogen (%, W/W)				
Homogenous sample	2.3^{a} ± 0.3	-	-	
Surface stratum	-	1.3^{b} ± 0.3	1.4^{b} ± 0.3	<0.0001
Deep stratum	-	1.4^{b} ± 0.3	0.7^{c} ± 0.3	
C:N				
Homogenous sample	14.1 ± 0.7^{a}	-	-	
Surface stratum	-	32.6^{b} ± 7.0	32.7^{b} ± 6.8	<0.0001
Deep stratum	-	31.0^{b} ± 8.4	81.0^{c} ± 33.4	

^{a,b,c} denotes significantly different means between all samples for each test.

4.5 Animal health

Morbidity and culls in the experiment were low, and did not appear to be related to treatment. Four cattle were culled during the experiment (2 from W60, and 2 from Control). Three cattle were temporarily pulled from the experiment for health treatment and were returned to the experiment within 4 days. Steer number 245 was removed from pen 3 (Control) on day 7 of the experiment, for acidosis, and was replaced with steer 132 to maintain stocking density. Steer number 214 was removed from pen 20 (W30) for respiratory disease, and returned to the pen after 4 days in Week 3. Steer number 98 was removed from pen 27 (W60) for respiratory disease and returned to the pen after 3 days in week 4. It was removed for a second time for a foot abscess treatment on day 56 for one day, and returned to the pen. This steer was again removed from pen 27 (W60) a third time on day 87 (also for foot abscess) and was not returned to the experiment thereafter. Steer number 100 was removed from pen 26 (Control) for respiratory disease on day 28 and returned to the pen after 4 days. This steer was again removed from pen 26 (Control) for a second time for ill thrift and infection on day 74, and was not returned to the experiment (pen area was adjusted to maintain stocking density). Steer number 235 was removed from pen 22 (W60) for a jaw infection on day 75, and was not returned to the experiment (pen area was adjusted to maintain stocking density).

4.6 Cattle behaviour

Overall, cattle were more likely to lie in the middle of the pen compared to the front (Figure 19). However, the preference was weaker for control cattle as more cattle stood at the front of the pen than for woodchip treatments (Figure 20). Furthermore, there was no difference between the proportion of cattle lying at the middle and back for control animals, but a preference to lie in the middle of the pen for animals that received woodchips, particularly W30 animals.

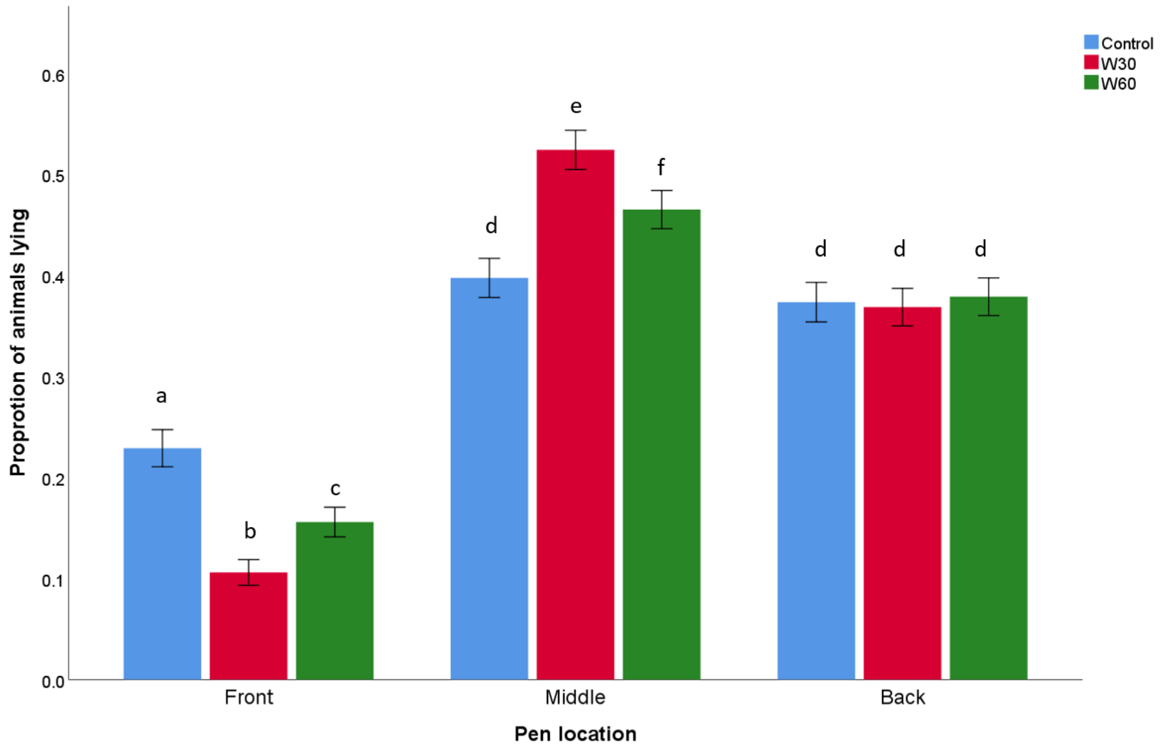


Figure 19: Main effects of woodchip bedding on proportion of lying animals by location.

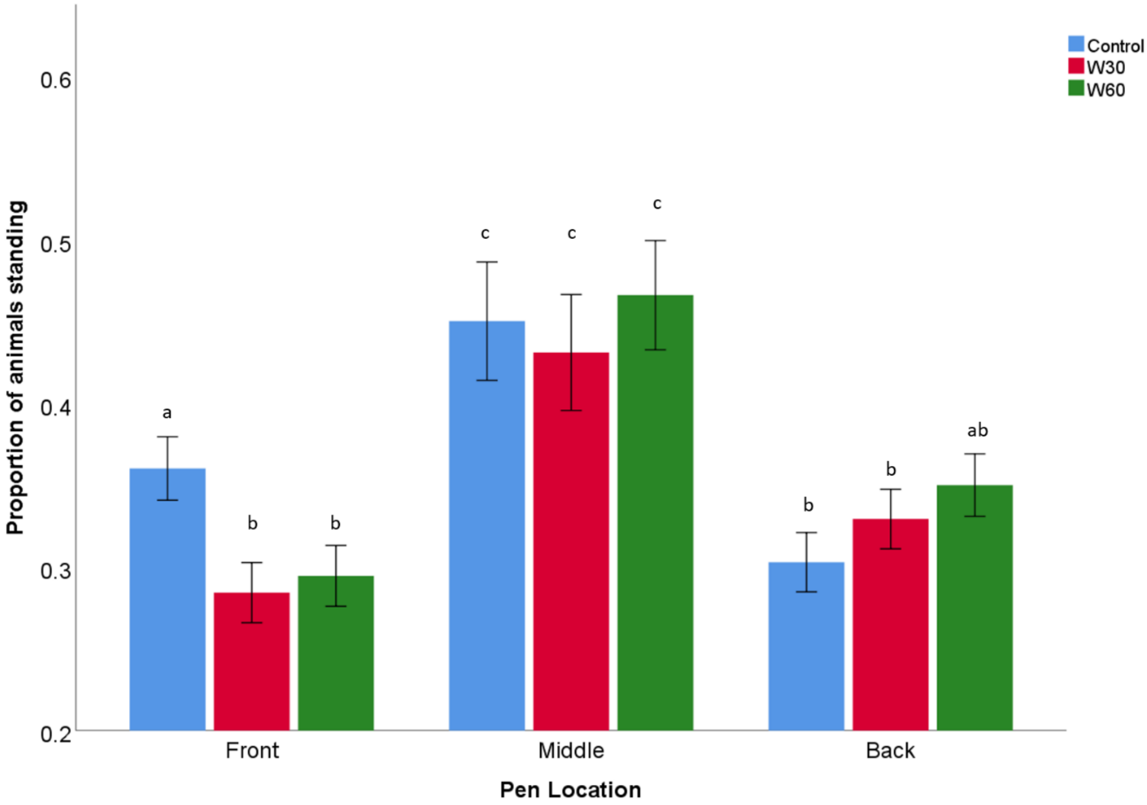


Figure 20: Main effects of woodchip bedding on proportion of animals standing (not eating or drinking) by location.

Lying increased over time ($F_{(13,3306)}$=23.6, $P < 0.0001$) but there was no interaction between treatment and week on lying behaviour (P = 0.119, Figure 21). There was a main effect of treatment on lying behaviour ($F_{(2,3306)}$=4.18, P = 0.015) such that more control animals were lying than W30 (t=2.81, P = 0.005) and W60 (t=1.94, p = 0.053), however this was numerically very small (Control 39 %; W30 36 %). Standing (without eating) decreased over time ($F_{(13,3306)}$=18.3, P = 0.003) However, there was no interaction between treatment and week on standing behaviour (P = 0.22) or main effect of treatment (p = 0.194).

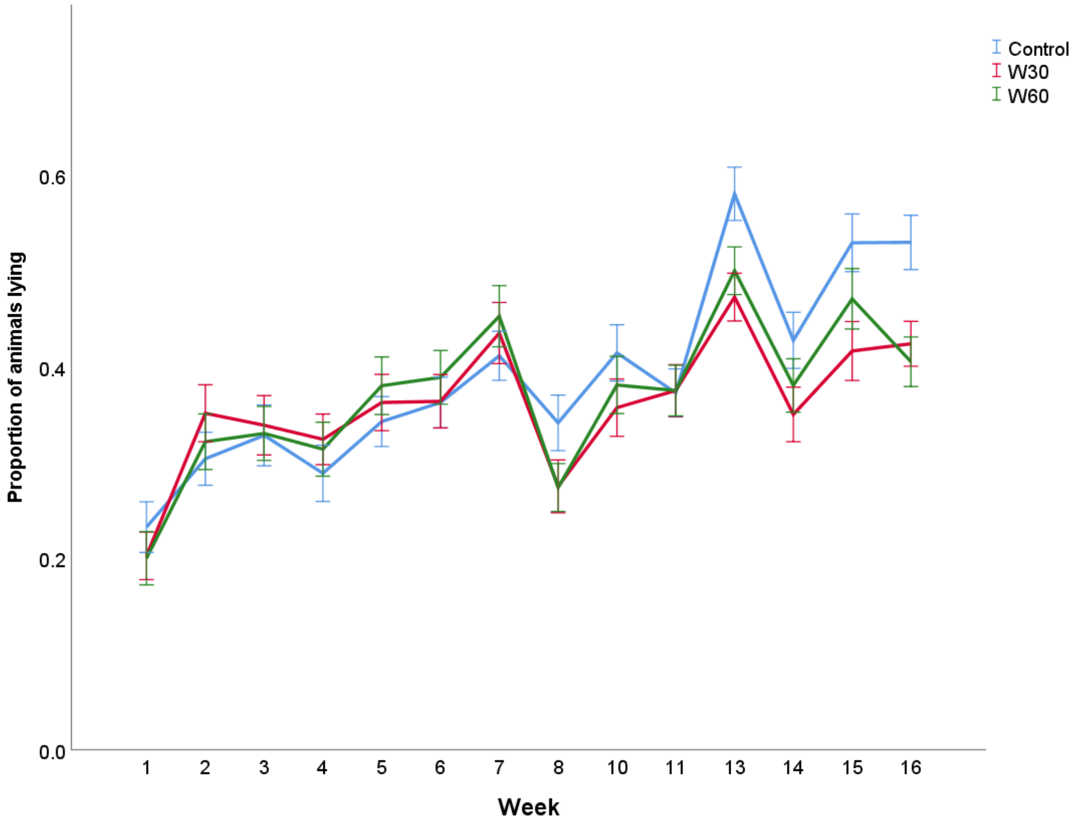


Figure 21: Interaction of time with woodchip bedding on the proportion of animals lying in the pen.

There was a significant interaction between treatment and pen location ($F_{(4,8534)}$=57.2, $P < 0.0001$) for lying behaviour. More control animals lay down at the front of the pen compared to W30 animals ($t_{(1,8534)}$=11.3, $P < 0.001$) and W60 animals ($t_{(1,8534)}$=6.7, $P < 0.001$, Figure 22). Conversely, fewer control animals lay in the middle of the pen compared to W30 animals ($t_{(1,8534)}$=-9.6, $P < 0.001$) and W60 ($t_{(1,8534)}$=-5.8, $P < 0.001$). More W30 animals lay in the middle of the pen and fewer at the front of the pen compared to W60 animals (middle: $t_{(1,8534)}$=3.8, $P < 0.001$; front ($t_{(1,8534)}$=-4.6, $P < 0.001$). There was no effect of treatment on the number of animals lying at the back of the pen ($P = 0.386$).

There was an interaction between treatment and week on the proportion of animals lying at the front of the pen ($F_{(26,2810)}$=3.77, $P < 0.0001$). Such that, the proportion of animals lying at the front of the pen did not differ between treatments until week six. More control animals were lying at the front of the pen than W30 from weeks 6 to 16 and from W60 animals from weeks 7 to 14 and week 16 (Figure 22). There was also an interaction between treatment and week on the proportion of animals standing at the front of the pen ($F_{(26,3150)}$=1.9, $P = 0.003$). Such that, the proportion of animals standing at the front of the pen did not differ between treatments until week six. More control animals were standing at the front of the pen than W30 and W60 from weeks 6 to 15 ($P < 0.05$; Figure 23).

There was no interaction between time and treatment ($P = 0.467$) or a main effect of treatment on eating behaviour ($P = 0.430$).

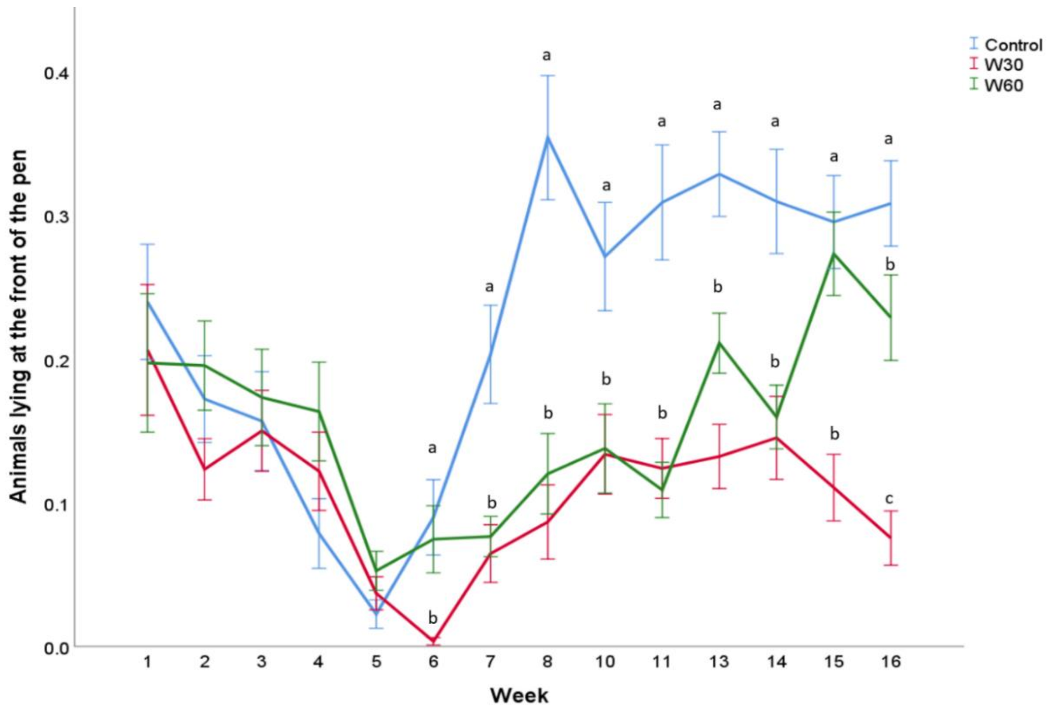


Figure 22. Animals lying at the front of the pen over time, expressed as a proportion of all animals lying. Subscript with differing letters denotes a significance difference between treatment groups at each time point.

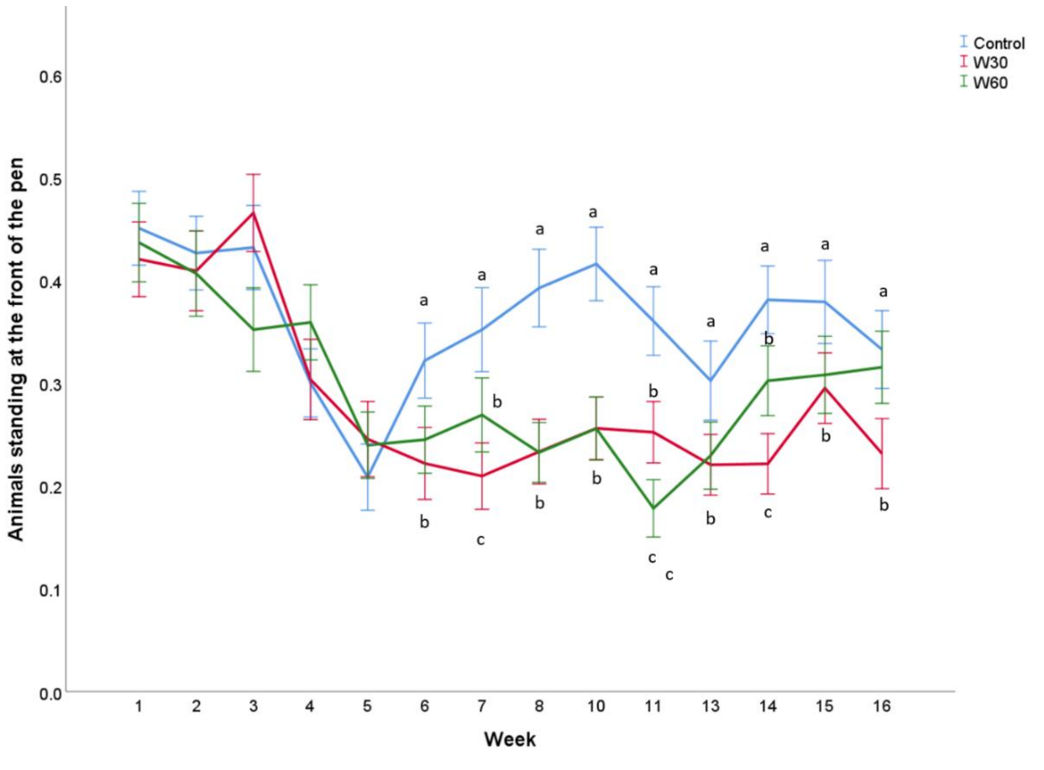


Figure 23. Animals standing at the front of the pen over time, expressed as a proportion of all animals standing (not eating). Subscript with differing letters denotes a significance difference between treatment groups at each time point.

Further analysis shows that the Control treatment cattle clustering at the front of the pen were more likely to be lying down, rather than eating there, as the experiment progressed (interaction between behaviour, treatment and week: $\square^2_{(65,7680)}$=620.9, $P < 0.0001$). However, this did not seem to be related to the pad conditions in their pens, since a similar pattern was observed in cattle in the bedded treatments (Figure 24**Error! Reference source not found.**).

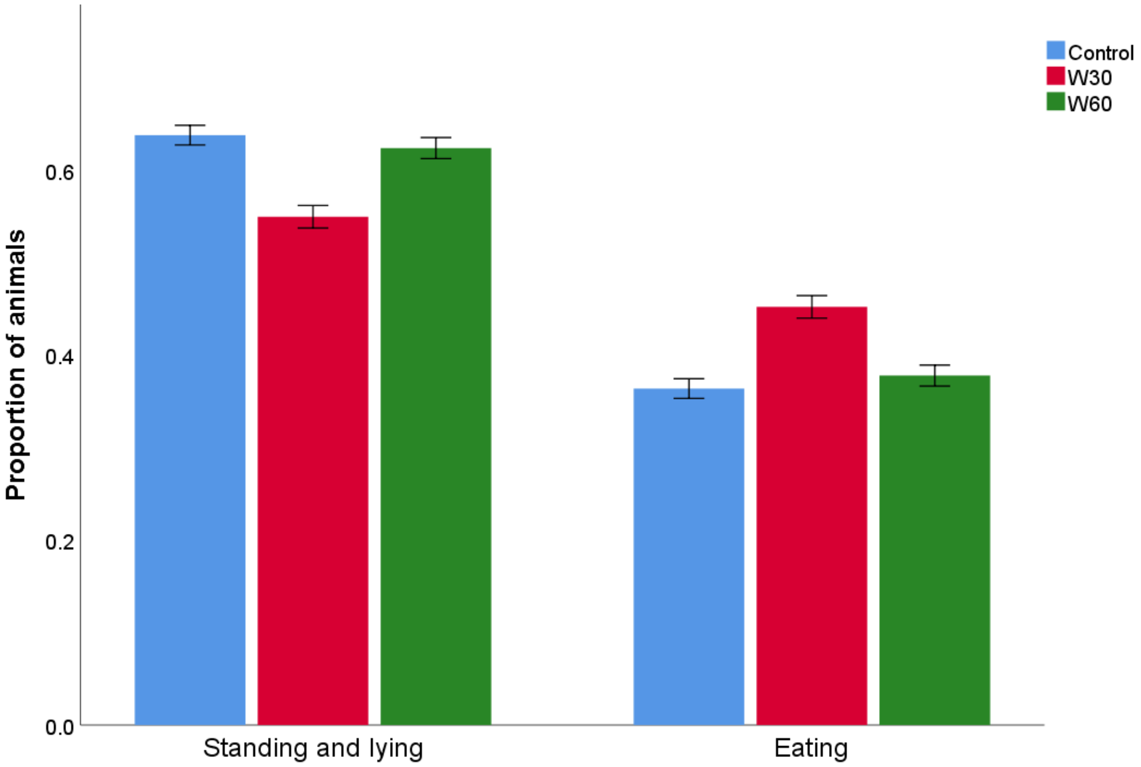


Figure 24: Main effects of woodchip bedding on animal behaviour at the front of the pen

There was no main effect of treatment (p = 0.430) or interaction between time and treatment (p = 0.467) on the proportion of animals observed to be eating during scans (Figure 25).

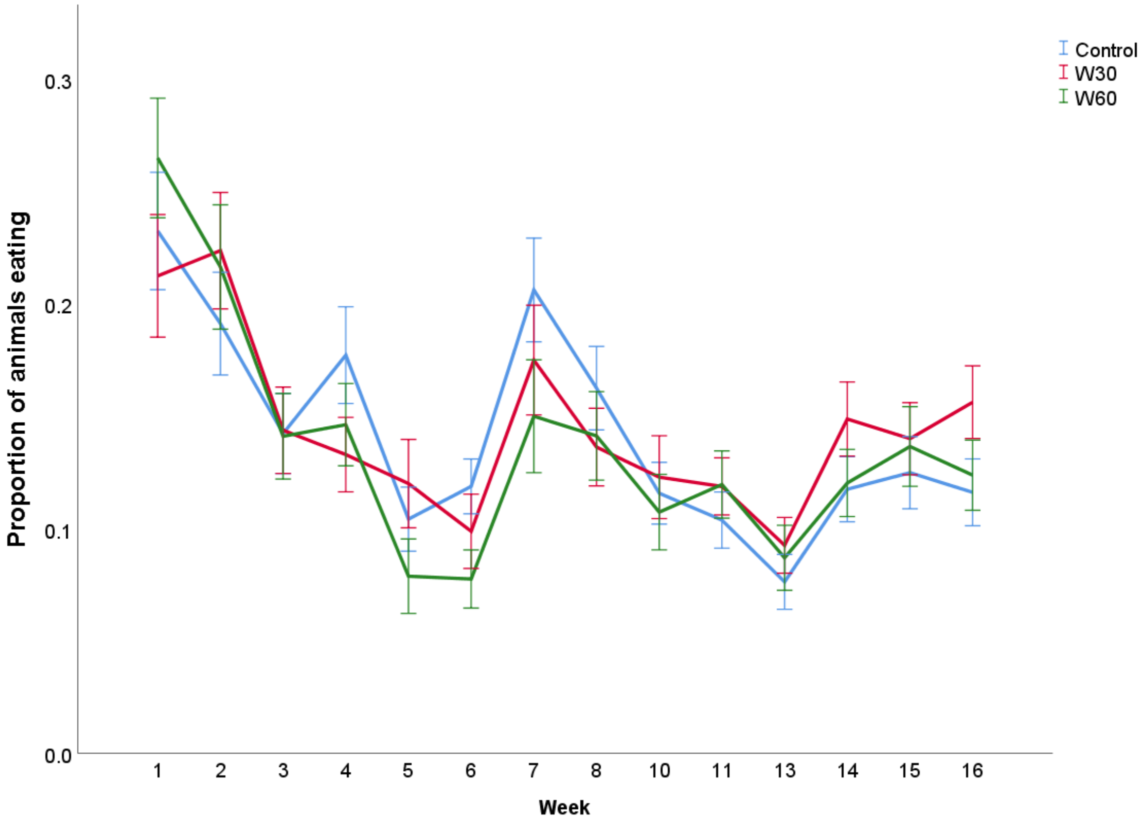


Figure 25: Proportion of animals eating during hourly scans during daylight hours.

4.7 Dag score

By the end of the feeding period, the cattle had begun to shed their coats as days lengthened and temperatures increased (Table 14).

Table 14: Mean coat scores at beginning and end of experiment

Treatment	Control	W30	W60
At induction	5.03 ± 0.92	5.05 ± 0.87	5.04 ± 0.91
At end of feeding period	2.96 ± 0.57	2.94 ± 0.58	2.92 ± 0.60

There was an interaction between treatment and time on dag scores ($F_{(24,1405)}$=49.6, p = 0.002). As such, control animals had a worse dag score earlier in the study than animals provided with woodchips and at weeks 8, 10 and 14 (Figure 26). There was no association between dag score and G:F for any treatment group (r^2 = 0.03, 0.00, and 0.01 for control (P = 0.62), W30 (P = 0.91), and W60 (P = 0.24), respectively).

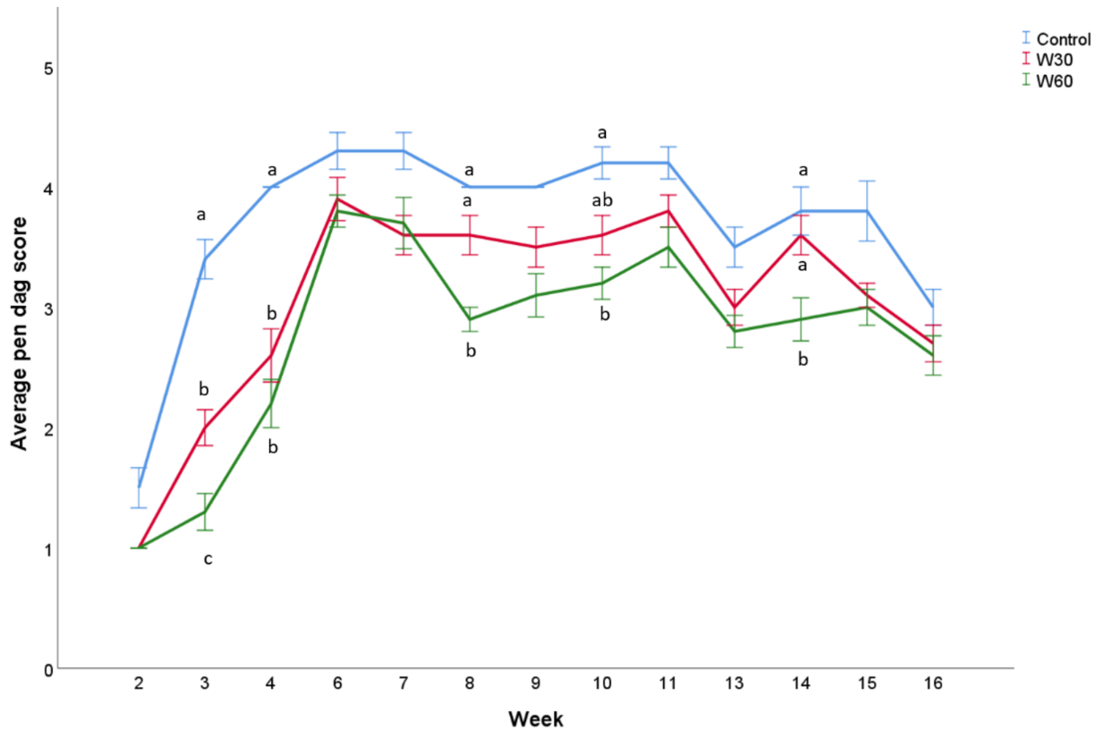


Figure 26: Average weekly pen dag score (1 – 5 ordinal scale).

4.8 Pre-slaughter washing time and labour

There was an interaction between treatment group and day for duration of soaking such that the group with the longest period of soaking on day 1 (control) had the shortest period of soaking on day 2 (Table 15). The duration of soaking time was shortest for W60 on day 1 and longest for W60 on day 1 (Table 15).

A similar pattern was evident for hosing on Day 1 such that the control groups were hosed for longer than the other two treatments. There was small difference on day 2 between W30 and W60 in average time spent hosing the cattle and the control group was hosed on average for the shortest duration of time on day 2 (Table 15).

Table 15: Effect of the provision of woodchip bedding at 54 kg/m^3 (W30) or 108 kg/m^3 (W60) on pre-slaughter cleaning time

	Control	W30	W60
Time spent soaking (mins/pen)			
Day 1	189 ± 29	159 ± 7	90 ± 0
Day 2	71 ± 12	106 ± 24	148 ± 39
Time spent hosing (mins/head)			
Day 1	1.07 ± 0.19	1.03 ± 0.54	0.86 ± 0.32
Day 2	0.17 ± 0.05	0.26 ± 0.04	0.25 ± 0.10

4.9 Net benefit analysis

Providing woodchip significantly increased the mean HSCW by 9.3 and 10.8kg for the W30 and W60 chip treatments respectively or approximately 3 % (*P* = 0.001, Table 9). W30 carcases had a significantly higher muscle glycogen content (*P* = 0.047, Table 9Error**! Not a valid bookmark self-reference.**) than the control and W60 groups, which did not differ from each other (Table 9). Raw EMA in W60 cattle was greater than in control carcases, and W30 was intermediate (*P* = 0.041) but when EMA was adjusted for carcase size, the difference was not significant (*P* = 0.087). Only one carcase, 484 (W60), was downgraded for pH > 5.70. There was no effect of woodchip bedding on other carcass quality attributes, or MSA Index (Table 9).

Numerically, relative adrenal weight was negatively correlated with woodchip bedding (*P* = 0.077, Table 9). The control treatment group had a relative adrenal weight which was 6.9% higher than the W60 group (Table 9). The W30 treatment was intermediate between control and W60.

Table 9A higher HSCW resulted in a higher grid price and production value for woodchip bedded cattle (Table 16). Carcase downgrades were mostly for low carcase weight, predominantly in the control treatment, resulting in a significantly lower grid price for that group (Table 16). Despite a substantial increase in the yield of substrate from the woodchip bedded pens (Table 11), as a result of the lower N content (Table 13) of the woodchip-contaminated substrate, a 33 % discount was applied to the value of the cleaned pen substrate from W30, and a further 33 % discount applied to W60, causing a significant reduction in revenue from cleaned manure (Table 16). In addition to the purchase costs of the woodchip, the increased time required to clean pens containing woodchip (in labour and fuel) drove an increase in cleaning costs (Table 16). These costs resulted in W60 returning net benefit to producers very similar to that of control (Table 16). W30 returned a numerical marginal benefit of $5.60 per head over the control treatment, however variation in net benefit was large (*P* = 0.147). There was considered to be no effect of treatment on the labour cost of manual hosing in lairage, and so analysis of net benefit to the value chain stopped at the farm gate, apart from value of carcase passed back to the feedlot.

Within the range of expected variation of woodchip, feed and uncomposted manure values, net benefit of woodchip bedding was most sensitive to variation in cost woodchip (Table 17). Using values from this experiment, woodchip cost $55/t, equivalent to $33.75/head for W30 and $67.50/head for W60. Within the range of expected variation, W30 was an economically advantageous strategy until the price of woodchip reached $40/head (Table 17). W60 became economically advantageous for a 109 day feeding period once the price of woodchip fell below ~$30/head or $20/t. This experiment assumed a discounted value of woodchip contaminated manure, but with the C:N ratio of W30 manure still within a range suitable for composting, it is possible that an informed purchaser would be willing to pay a higher price for the uncomposted manure from that treatment. Therefore, a sensitivity analysis was conducted on a range of values for the manure, demonstrating that W60 only became economically advantageous for a 109 day feeding period at a manure value of $15/t.

Table 16: Effect of the provision of woodchip bedding for 109-day-fed cattle in wet conditions on variable costs and benefits to feedlot producers, using experimental values

	Treatment			
	Control	W30	W60	*P*
Carcase value, $/hd	$1864^{a} \pm 133$	$1938^{b} \pm 75.4$	$1939^{b} \pm 106$	0.002
Grid price, $/kg HSCW	$5.67^{a} \pm 0.1$	$5.73^{b} \pm 0.03$	$5.71^{b} \pm 0.05$	0.015
Manure revenue, $/hd	$22.1^{a} \pm 7.79$	$16.7^{c} \pm 5.61$	$11.6^{b} \pm 3.35$	0.000
Feed cost, $/hd†	706 ± 60.9	737 ± 36.6	717 ± 57.5	0.31
Cleaning cost, $/hd	$4.38^{a} \pm 1.68$	$6.97^{b} \pm 2.12$	$12.7^{c} \pm 3.05$	0.000
Net benefit*, $/hd	0.00 ± 74.40	5.59 ± 53.20	-12.00 ± 58.30	0.5933

*Net benefit was calculated for individual pens and then analysed as difference from the mean of the control
†Because there was no experimental difference between feed intake, the overall experimental mean for feed costs was applied.

Table 17: Sensitivity of net benefit of woodchip bedding for 109-day-fed cattle to independent variation in value of woodchip and uncomposted manure, compared to unbedded control. All other values are as per experimental results.

	Treatment		
	Control	W30	W60
Varying cost of woodchip ($/head)[1]			
20	-	23.34	20.46
30	-	14.34	0.46
40	-	4.34	-19.54
50	-	-5.66	-39.54
Varying value of uncomposted manure ($/t)[2]			
5	-3.14	2.25	-10.00
10	1.33	10.33	2.63
15	5.80	18.41	15.25
20	10.26	26.49	27.88
Varying feed costs ($/t, as fed)[1]			
375	-	11.90	-9.86
400	-	10.24	-10.44
425	-	8.58	-11.01
450	-	6.92	-11.58
475	-	5.26	-12.16

[1]Difference from mean net profit of control for each variable value
[2]Difference from mean net profit of control, where value of control uncomposted manure = $12/t

Additional costs and revenue incurred in this project are presented in Table 18.

Table 18: Other costs and income incurred

Item	Per head
Cattle purchase (Incl. Transport cost to feedlot)	$1082.00
Processing Costs	$2.90
Medication Costs	NA
Miscellaneous Costs (e.g. wood chip bedding)	$38.75 (W30) $72.50 (W60)
Yardage costs	$1.15/head.day
Purchase interest	NA
Operating interest	NA
Transportation to slaughter	$62.63
Levy costs	$5.00
Commission costs (if applicable) purchase	$1.35
Carcase sales	$2240
Manure sales	NA

5 Discussion

5.1 Successful Completion of Project Objectives

5.1.1 Determine the effects of graded level of woodchip during wet feedlot conditions on feedlot cattle performance, animal health, non-invasive measures of animal welfare, and carcase characteristics.

Cattle performance and carcase characteristics

This project has shown that provision of woodchip bedding at 54 kg/m^2 (W30) increased average daily gain and HSCW. There was no additional benefit of providing double woodchip (W60) for cattle performance. Provision of woodchip bedding had no effect on dry matter intake. As a result, conversion of gain from feed improved for W30 and further for W60 compared to control. There was no relationship between treatment and any other carcase attributes apart from HSCW and raw EMA. Raw EMA is confounded with HSCW (larger animals have larger *L. dorsi* muscles). Therefore, in line with normal practice, HSCW was included in the statistical model for EMA, revealing no specific effect of treatment on EMA, independent from HSCW. There was no effect of woodchip treatment on animal health or mortality. It was concluded that there was no overall effect of treatment on behavioural signs of cattle welfare. However, there was an effect of treatment on relative adrenal weight, such that control cattle were significantly greater than W30, which were significantly greater than W60, indicating increased chronic stress in these cattle.

There was no effect of woodchip bedding on proportion of animals eating during scan samples or on feed intake in this experiment. There are frequent assertions made without data, that under muddy conditions, cattle have a tendency to reduce their intake, and/or eat less frequently (Mader 2011; Watts *et al.* 2015), purportedly as a result of discomfort from walking through deep mud. National Research Council (1981) estimate a 5 – 30 % depression in intake, depending on depth of mud, but provide no experimental results to support this. The slight effect of woodchip bedding on intake, even at W60 rates, suggests that these estimates may need to be reviewed with further research. A review of the available literature found no previous experimental results to support the convential wisdom that intake is depressed by mud, but a number of studies which showed no beneficial effect of bedding in cold and wet conditions on dry matter intake by cattle. In a trial of straw bedding that improved lot condition from 100 % mild mud (3-7 inches deep) to 50% no mud (<3” deep) and 50% mild mud, there was no effect on dry matter intake (Mader and Colgan 2007). Regular provision of straw or newspaper bedding from November to May in South Dakota, USA, resulted in no change in feed intake, compared to unbedded cattle (Birkelo and Lounsbery 1992). That study did not report on the conditions of the pad underfoot, but the bedding treatment was designed to provide a relatively dry, manure-free area large enough for all steers to lay down in simultaneously, and reported that unbedded cattle carried more mud (Birkelo and Lounsbery 1992). Steers finished on unbedded pads in a North Dakota, USA, winter were were no different in their intake from steers provided with modest or generous straw bedding (Anderson *et al.* 2011). Again, the conditions of the mud underfoot were not reported, and at the time of year when the study was conducted, it is possible that the ground was frozen, rather than muddy. It is difficult to separate the effects of mud, rain, cold, and low atmospheric pressure, since these regularly coincide. Research using simulated rainfall, without associated low atmospheric pressure, has had mixed results. A short-term, 22 hour exposure to simulated rain (Schütz *et al.* 2010) caused dairy cows to reduce their feed intake by approximately 30 % for the day. However, long-term simulation of rainfall (10 minutes every hour for 84, 112, and 139 day periods) did not cause a reduction in intake in beef cattle (Morrison *et al.* 1970), possibly either due to a lack of aversiveness of the pattern of simulated rainfall on feeding, the ability of the cattle to shift their feeding times to periods without simulated rainfall, or adaptation of the cattle to the simulated rainfall, so that it was no longer aversive. The modest level of simulated rainfall in this present experiment (approximately 45 minutes of irrigation, on ~16 days out of 30) was sufficient to produce muddy conditions underfoot, but may not have been sufficent to make conditions (wet feed, falling rain) aversive enough to discourage feeding.

In this project, there were consistent benefits of woodchip bedding for feed conversion efficiency. The improvement in feed conversion with little difference in feed intake suggests that woodchip bedded cattle had a reduced maintenance energy requirement compared to control cattle. This is could be due to reduced effort to walk around the pen, and improved thermoregulation. In other research, regular provision of straw bedding to feedlot cattle over winter improved liveweight gain for the first 34 and first 71 days on finishing, and feed:gain ratio from days 0 to 71 (Mader and Colgan 2007), however, the benefits were not sustained after that point.

Cattle welfare and behaviour

The high growth rates observed in all pens suggests that the wet and muddy conditions of this experiment were not a serious threat to animal welfare, even in the control pens. Because of the control cattle's ability to compensate for muddy conditions by maintaining their lying behaviour budget through adaptation to the pad and shifting their location of resting, we conclude that this experiment has shown no behavioural signs of an effect of woodchip bedding in wet feedlot condition on cattle welfare. However, an increased relative adrenal gland weight in control cattle is an indicator of increased quantity of stress over an extended period in these cattle (Wilson *et al.*, 2002), indicating that the deeper mud levels and perhaps the greater quantity of dags were affecting the quantity of adrenaline generated and released.

Muscle glycogen is an indicator of stress during the pre-slaughter period. It was hypothesised that the control group would have lower muscle glycogen contents due to increased washing/cleaning time and lower basal muscle glycogen before transport, however this was not supported by the results. The W30 carcases had the highest muscle glycogen content, whereas W60 carcases were lowest in glycogen content indicating they had the highest risk of dark cutting. The one animal that had a high carcase pH was in the W60 group which could have influenced the result for that group if all other animals were relatively consistent. The muscle glycogen results indicate that it was not an effect of treatment, but variation in temperament or indiviual responses to stressors (such as washing) applied immediately prior to slaughter to the different treatments. The pH results supported the glycogen results showing that there was no variation between groups as all groups had sufficient glycogen to produce adequate lactic acid post-mortem.

It was hypothesised that additional strain energy on control cattle, caused by walking in deep mud may increase skeletal ossification (Carter and Wong 1988), but there was no effect of treatment on ossification, marble scores, pH, rib or rump fat.

Only one animal was pulled from the experimental pens for lameness, and this experiment did not score individual cattle for lameness. Since the depth of mud affected how the cattle walked around the pen, was not possible to accurately assess gait or walking while cattle were in the pens. However, removal of a sub-sample of individuals from the pens to walk a gait/lameness assessment course on a regular basis would be a valuable addition to future research. The tendency for lying behaviour in the control treatment pens to increase over the experiment may indicate that the cattle in those pens were experiencing foot soreness, but this is untested. The lack of effect of bedding on animal distribution through the pen or visits to the feedbunk suggest that lameness was not an issue serious enough to affect the control animals' ability to access feed or water. In commercial scale pens, however, a difference may be more easily detected.

In both woodchip treatments, cattle were on average located evenly throughout the pen. All groups had more cattle clustering at the front of the pen in the first six weeks of the experiment, and in the early weeks, there was no difference between treatments in the proportion of cattle clustering at the front of the pen. This is consistent with the behaviour of cattle adapting to grain feeding. From week 6 onwards, cattle in the control treatment clustered at the front of the pen on the concrete bunk apron, whereas there was no particular clustering of cattle in W30 and W60. Watts *et al*. (2015) reported anecdotal evidence of cattle being more willing to spread out across the whole pen when bedding was provided, and this research provides data to support those observations. Due to the small size of the experimental pens, the bunk apron takes up a much larger proportion of the total pen area than in a commercial pen, and it is possible in some commercial configurations that the bunk apron would not provide sufficient space for all cattle in an unbedded pen to camp.

Overall, more control cattle laid down during the experiment than W30 and W60 cattle. However, numerical difference (3 %) was very small. Explanations for increased lying by control cattle may be due to fatigue from the effort required for the animals to walk throughout the pen, or from foot soreness. It was observed on many occasion the increased effort control cattle required not only to walk but also to stand from a lying position as the animals braced themselves from slipping in the deep substrate. This arduous task of moving through the control pen surface was also observed by personnel that entered the pen conditions for data sampling and daily husbandry tasks such as trough cleaning ("gumboots pulled off by mud"). This may also relate to the reduced feed conversion ratio of the control animals and increased maintenance energy requirement. These results contrast with anecdotal reports that cattle in bedded pens increased their sitting and lying behaviours (Watts et al. 2015). The drier conditions reported in that study may have limited the depth and wetness of mud in non-bedded comparison pens.

The increased lying in control cattle is mostly an effect of increased lying at the front of the pen after week 6. This correlates with worsening pad condition in control pens, especially from week 6 onwards. Although the pad scores in the front of the pen were no different from those in other parts of the pen, this indicates that the cattle perceive the front part of the pen to be less aversive. The reasons for this are not tested here, but the increased amenity offered by the front part of the pen could be related to the concrete apron, a higher point for drainage, increased amenity to the feedbunk, among other reasons. This finding also demonstrates that control cattle are not restricted in their ability to lie, because they can change their preferred lying area to this part of the pen. Similarly, when beef cattle in muddy pens were provided with a shelter with either a wooden floor or a mud floor, they used the shelter with the wooden floor for 73 % of daylight hours between 0700 and 1900 h, compared to 3 % for the mud floored shelter (Morrison *et al.* 1970). However, New Zealand dairy cows kept outdoors on a woodchip wintering pad for 17 hours per day, and those kept in a cultivated fodder-beet paddock (which is likely to have substantial mud, although this was not quantified) did not differ in the time spent lying (10.1 hours per day) (Al-Marashdeh *et al.* 2017), which indicates that cattle may adapt to lying in muddy conditions if they have no choice.

The lack of preference for any particular part of the pen for lying by W30 and W60 cattle indicates that woodchips are a more comfortable surface for cattle than the unbedded substrate. Research in other production systems had previously shown that woodchip bedding is not aversive for animal lying compared to other bedding types: When barn-housed sheep were provided with large woodchip bedding of similar dimensions to this experiment, the number of animals resting was no different to pens of sheep provided with bedding of straw or small woodchips (2.5 cm) (Wolf *et al.* 2010; Hansen *et al.* 2012). There was a similar pattern for the three treatments in how the proportion of cattle observed to be lying varied from week to week. Lying behaviours are often affected by weather conditions and a spike in the proportion of all animals lying in week 13 may be associated with natural rainfall during that week.

5.1.2 Determine the effects of graded levels of woodchip during wet feedlot conditions on dag score, and pre-slaughter washing time and labour

Dag score

This project has determined that woodchip bedding improved the pad score, but after week 10, the score of the pad in W30 also began to worsen, indicating that for medium and long-fed cattle, additional woodchip application may be required. The woodchip improved the pad surface primarily by reducing the penetrable depth of the pad, maintaining the cattle on a relatively clean surface. Additionally, control cattle had a higher dag score than woodchip bedded cattle until the end of the experiment. There was no consistent effect of treatment on pre-slaughter washing time and labour.

Dag score for all groups increased up to week 6 of the experiment. Although control cattle had significantly higher dag scores than W30 and W60 cattle, the numerical difference was only approximately 1 score out of 5, with woodchip bedded cattle around a score 3 (small and large lumps of manure attached to the hide, covering larger areas of the legs, side and underbelly) and control cattle around a score 4 (small and large lumps of manure attached to the hide, in even larger areas along the hind quarter, stomach and front shoulder). Previous work has found that straw bedding, regularly applied to unsheltered outdoor pens, did not affect the dag score or pad score for feedlot cattle, and that stocking density was a more effective way to minimise both of these indicators (Mader and Colgan 2007).

The regular application of simulated rainfall kept the dags attached to the body of the cattle moist, increasing the potential for evaporative heat loss, compared to cattle with fewer dags. It has been proposed that these wet dags may increase the rate of heat production, and thus maintenance energy requirement (Watts *et al.* 2015), however this present experiment found no relationship between dag score and efficiency of conversion of feed into gain, suggesting that maintenance energy requirement was not directly related to dag score specifically.

The reduction in dag score over the last few weeks of the experiment may be attributed to a two factors. Firstly, the increasing day-length and temperatures as spring approached caused the cattle to begin to lose their winter coats, and with it, the accumulated dags. Secondly, as the dags become very large, they may have been torn out of the cattle coats due to their weight, or the abrasive nature of the woodchips (O'Keefe *et al.* 2013).

Lairage cleaning

The time each lairage pen was subjected to soaking sprays had a poor relationship to the dag score and the pen bedding treatment. There was not a specified time or consistent decision-making process that the soaker sprays were turned on and off and this was very much a decision made by each stockmen that were in control of the lairage facility for the particular shift. However, greater attention to animal cleanliness was given when the stockmen were hand hosing each individual animal manually. This allowed the hosing staff to exercise their judgement on whether each pen was cleaned sufficiently to progress to the next stage in lairage cleaning. The method of hosing was also dependent on the operator of the hose as it was noted that one operator would hose only from the mid line of the animal down to the hooves whereas another operator would hose from the centre of the backline and down to the hooves to try and remove a higher proportion of excess winter coat for ease of slaughter. As a result, hosing time bears a stronger relationship to the cleanliness of the cattle than does soaking time. As a result of the subjective and arbitrary nature of the time for cleaning, statistical comparison tests were not conducted for this data.

5.1.3 Determine the effects of graded level of woodchip during wet feedlot conditions on pen cleaning (time, labour, equipment, volume and weight of fresh cleaned manure, and manure composition at cleaning).

Pen condition

The stratification of the woodchip bedding into surface and deep strata in this experiment reflected the observations of Watts *et al.* (2015). This stratification, and the penetrable depth of the pen substrate at the end of the feeding period, reflects the experience of the cattle, in that in control pens, cattle sank deep into the mud, to the interface layer, whereas in the woodchip bedded pens, the cattle stood on a 'solid' sub-layer of woodchip. The results of penetrable depth align with the visual mud scores. There were observed areas of the pen that had quite wet surfaces or 'hot spots', this may be attributed to the pooling of liquid after rainfall or irrigation events or where the cattle were favouring places to sleep and therefore creating hollow areas for the water/ liquid to pool.

Visual observations of woodchip showed the deep stratum was clean, but there was an interaction of treatment and time. The control was homogenous, the cattle's hooves sunk the clay/rock interface as evidenced by the high pen mud scores for that treatment. This lead to an increase in sediment in the samples which was evidenced by the lower volatile solids. The cattle hooves did not penetrate the woodchip substrate in W60, which had a defined surface and deep layer, but in W30, towards the end of the experiment, there was visual evidence of 'churning' of the manure and woodchip strata evidenced by the woodchip being coated in manure and N content being significantly higher in the deep W30 than deep W60; and the W30 surface and deep having similar amount of N. This aligns with increasing pen mud score in W30 from week 10 onwards, and a penetrable depth equal to the substrate depth at the end of the feeding period. Decreased VS in control pens may be associated with degradation of the interface, and mixing of soil with the manure substrate in those pens, as shown by the increase in clay colour in the ash.

However, differentiation of the strata was considered important, particularly in relation to moisture and BD, as this reflected the condition of the part of the pad substrate that cattle interacted with. In the present experiment, the surface stratum was almost always wetter than the deep stratum. After the first 4 weeks of the experiment, the surface moisture fluctuated around 55-60 % for both woodchip bedded treatments. The moisture content of the deep stratum of the woodchip bedded substrate was on average 5-10 % lower than the surface stratum. However, the case study cited by Watts *et al.* (2015) reported that the moisture passed through the surface layer of woodchips, and drained in the deep stratum. As a result, the surface of the woodchip in the observations of Watts *et al.* (2015) was much drier than the underlying woodchip stratum. The reason for the higher moisture of the surface layer in the present experiment is likely to be a result of the consistent application of irrigation and excreted moisture from the cattle, whereas the case studies of Watts *et al.* (2015) were conducted in much drier conditions. The substrate sampled on day 35 showed a temporary decline in the surface moisture of the woodchip-bedded treatment pens and the control pens and this most likely reflects time since the last irrigation event, and potential evaporation.

End of feeding period manure removal

In this experiment, precipitation (natural + artificial) was equivalent to 2.46 mm/day. By the end of the feeding period, the cattle themselves would have been contributing approximately 2.2 mm of moisture per day to the pad. The 24 hours which elapsed from the removal of the cattle from the pen to the end of feeding period sampling would have stopped the continuous addition of this endogenous moisture. This, combined with warm and windy conditions, explains why the moisture content of the substrate at the end of the feeding period was lower than the last weekly measurement.

There was no overall effect of treatment on the BD of the pen substrate at the end of the feeding period, however, BD of the deep stratum of the W30 pens was increased compared to W60 pens. This aligns with observations of manure becoming well mixed with the woodchip, reducing the porosity of the deep stratum.

As a result of the high moisture and soft consistency of the control pad substrate at the end of the feeding period, an operational decision was made to defer cleaning of the control pens, and to clean the pens in treatment order W60, then W30, then control. There was an increase in moisture between the last day of feeding and the day of cleaning in the W60 which was cleaned out first. The Q30 of W60 was within 1% of last day (53%) and clean out (54%). The control pens dried from 59% to 54% by day of cleaning, which allowed the manure to be removed from the pen.

There was significantly more substrate (in volume and weight) in W30 than control, and in W60 than control and W30 at the end of the feeding period. The delay in pen cleaning did not change the VS content of the pad substrate after the end of the feeding period, and so the only adjustment made to substrate amount removed was the change in moisture content. The volume of substrate, and the particle size of the woodchips made cleaning very difficult and time-consuming in the W60 pens. The time required for cleaning was based on a small loader and so the values for cleaning time, labour, fuel and equipment should be adjusted downwards for large pens in a commercial operation that can be cleaned with a large front-end loader.

Purchasers of feedlot manure for composting that were interviewed for this project considered that contamination of the manure with bedding materials would likely be considered a negative in terms of value and desirability. These users prefer to have control over the blending of the final compost composition to ensure a consistent product, and use feedlot manure to provide N to mix with their other sources of C. The ideal ratio C:N for composting is in the range of 15 – 30 (Smith *et al.* 2010). This puts the cleaned manure from the control pens at the lower end of this range, and that from W30 at the upper end. W60 manure would contain too little N to be an effective compost. As a result, a lowered value of stockpiled manure contaminated with woodchip (25 % and 50 % discount for W30 and W60, respectively) was assumed in the benefit cost analysis in this project, although no market values could be obtained for woodchip contaminated manure. Most commercial manure composters only source from a single feedlot, and so may be able to account for some bedding contamination, as long as consistency of woodchip application rate and manure (days on feed for each bedding load) was maintained. Alternatively, on-farm composting of woodchip contaminated manure may produce a more valuable product, and the W30 substrate may be a simpler, more cost-effective product to compost on-farm than uncontaminated manure, since it is would not require other sources of C to be added. We recommend further research into the composting of woodchip contaminated manure from feedlot pens so as to better understand the commercial value and opportunities of this product.

Due to the small size of the experimental pens, the woodchip bedding was laid with a front-end loader, rather than directly from the truck. Each bucket load was dumped in individual piles, and was not spread evenly. When the cattle entered the pen, they quickly (within ~48 hours) distributed the woodchip relatively evenly over the pen surface. In a commercial setting, the pens would be large enough that delivery trucks could unload woodchip directly into the pens. As a result, it was considered that there would be no need for additional feedlot labour to spread the woodchip, and therefore, no cost of laying bedding has been included in the benefit-cost analysis of this project.

Net benefit analysis

Woodchip bedding increased carcase value by $74 in this experiment, from greater HSCW and higher grid price. The benefit cost analysis for this experiment used as assumptions the actual values encountered in this experiment, and net benefit was found to be highly sensitive to the input costs, which include not only the price of woodchip, but also application and cleaning costs, and the production margin. Our analysis shows that there is good potential for the value of the production benefits to exceed the additional costs of woodchip bedding strategies. However, the numerical values of the net benefit obtained in this project should not be expected to be reproduced at commercial scale. Further commercial-scale research is required to fully understand the economic Although woodchip purchased for the experiment was valued at $50/t delivered, equivalent to $24/m^3, Watts *et al.* (2015) reported that woodchip was available at $15 to $42.50/m^3 delivered. As woodchip costs are a significant factor in the net benefit of woodchip bedding, a sensitivity analysis to woodchip price was conducted, finding that W30 bedding strategy was advantageous until woodchip purchase costs reached > $40/head. It is important that the outlay cost of woodchip is considered in terms of the feeding period it will be used for, so that costs are amortised to $/head.day. Interviews with commercial yards currently using woodchip bedding indicated that it is currently preferred for use with medium-fed to long-fed cattle, with most yards preferring to replace the woodchip no more frequently than 6 monthly, reducing the cost per head-day of purchase, application and cleaning. Commercial yards using woodchip for long-fed cattle report benefits of such bedding in reducing mortality, especially from casting. The small pen design of this experiment limited our ability to observe differences in mortality. Further large pen research is required to quantify the effect of woodchip bedding on mortality and lameness (see further discussion in section 5.1.3) and the implications of these for the economic benefit of woodchip bedding strategies. The net benefit calculation in this project is based on a 109 day feeding (and cleaning) period. Increasing the lifespan of the woodchip to 180 days or more would significantly reduce the cost of woodchip on a head-day basis. However, the observed increase in pen scores and mixing of manure through the woodchip substrate by week 10 in the W30 treatment pens indicates that a higher application rate may be required for longer-fed cattle. It is not possible to extrapolate from this project whether the gains in feed efficiency and liveweight gain from woodchip bedding would be sustained beyond the tested feeding period.

5.2 Practical implications

When commercial feedlots are considering the implication of similar application of woodchip as provided in the outcomes of this experiment, including the BCA provided, there are certain factors that will need to be considered such as:

- Outlay costs for woodchip need to be calculated on a head-day basis, which will decrease as the feeding period lengthens. This experiment tested a 109 day feeding period, and it is possible that at the W30 level of woodchip application, the benefits of this strategy for cattle may have started to decrease beyond this, requiring a heavier woodchip application rate.
- The availability of woodchip, its dimensions, cost and transport cost will vary depending on location of feedlot.
- The ability to market and provide revenue from the sale of the used woodchip, is likely highly variable, especially if potential purchasers consider woodchip a contaminant.
- The cleaning cost will depend on machinery type used, the operator experience and methodology and location of composting piles from the pen.
- The marginal cost of production will differ from one feedlot to another depending on cattle and commodity availability and pricing, due to seasonal fluctuations and feed processing.

As this was an experimental setting with smaller sized pens and animal cohorts there are other factors that should be considered:

- The effect of weighing the cattle during the feeding period may have reduced overall live weight gain and feed intake for all treatments in this experiment. It was noted that feed intake reduced after these events and therefore daily gain dipped at these experimental events. Therefore, under commercial conditions where cattle are weighed on arrival and then towards the end of the feeding period only, this will need to be taken into account in terms of the BCA.

- The experimental pens were not similar in size to commercial feedlot pens. Due to the dimensional restrictions, the area of the cement aprons surrounding both the water trough and the feed bunk relative to the area of the rest of the pen may affect animal use of space and other results of this experiment.
- The application and cleaning of the woodchip of pens was not a replicate of a commercial enterprise. A small front end loader was used due to the small area of space and the woodchip was not applied in a pile, as recommended in the final report of Watts *et al.* (2015). Although the woodchip soon spread throughout the area of pen it may not necessarily have the same effect in a larger area.
- The time taken to clean did not account for the time taken to travel to piles as the truck that was being used was significantly smaller than a commercial feedlot tipper and therefore a significantly greater number of trips was required. The only time that was considered was the time in the pen of the loader to clean.

5.3 Additional research recommended

The additional research which is recommended by the research team are broken into themes of animal factors and woodchip use and the final product.

Animal factors

- Commercial-scale research should be the next step in advancing this research. This project was small pen design with large statistical power, and has provided confidence in the reproducibility of the effects of woodchip on feedlot performance. However, there are significant limitations to this experimental design, especially in calculating a value for the economic costs and benefits of woodchip bedding. While the significant differences in net benefit between treatments are valid, the numerical size of the net benefit is likely to be larger in commercial operations where feed costs are lower, and pen cleaning costs may be cheaper, due to scale.
- Commercial-scale research will also provide better data on the effects of woodchip bedding on morbidity and mortality.
- This project tested the benefits of woodchip bedding of a short-fed feeding period (109 days). The deterioration of the woodchip pad in W30 by week 10 suggests that this application rate may not be suitable for medium and long-fed cattle, and so further research is required to make recommendations on suitable bedding strategies for these cattle. Some commercial feedlots in Australia are already using woodchip for long-fed cattle.
- The finding of this project, and review of literature, with respect to the effect of mud on intake suggest that estimates in the current NRC model of nutrient requirements should be reviewed subject to further research quantifying these effects.
- A comprehensive scoring of lameness in individual cattle, over time may show significant effects on the welfare of cattle. In this experiment, lameness was only recorded if this was severe enough for an animal to be pulled from the pen to the hospital. The small size of the pens, and therefore restricted total pen space, as well as the depth of mud in the pens, limited opportunities to quantify lameness effectively in this experiment. An experiment designed to test lameness would require that cattle be removed from their pens to individually walk a

short course, free of mud, with qualitative scoring and potentially more quantitative video analysis of lameness.

- Bedding was cleaned out after one batch of cattle. It may have been economically beneficial to have two batches of short-fed cattle for a single application of chip, but as this is contrary to current feedlot standards potential health, disease and welfare risks would need to be quantified.
- Cattle in this experiment went to the abattoir in mid-September, so their coats may not have been as long as in winter. A study could quantify wash times during the winter period when their coats are at their greatest length and compare lairage washing and soaking times at various facilities to determine quickest and most efficient washing method.

Woodchip and final product

- This project was conducted on the East coast of Australia where eucalypt woodchip is available, but other regions may use different tree species such pine. It is recommended that other wood be tested other than the wood chip in this study as the moisture absorption rate, and thus what the cattle are exposed to, would differ.
- Cattle were on feed for 109 days in the current project, but the feasibility of utilising woodchip of lower rates for shorter fed cattle and higher rates for long fed cattle would be a worthwhile addition to the cost-benefit analysis, and would improve the applicability of this research to other production systems, and would reflect current commercial usage of woodchip for long-fed cattle.
- The current study quantified C:N, VS and bulk density; further research could investigate the chemical and physical properties of the product at clean out to more clearly determine end uses as a soil ameliorate, for composting or for use as solid fuel.
- A survey of feedlots for current use or sale of feedlot solid waste and potential for value adding via composting would be informative.
- A comparative composting trial could determine the feasibility of composting the control, W30 and W60 and determine if a valuable product can be produced.
- The composted product made from W30 and W60 could be screened to recover wood chips, but before reuse, research on potential health, disease and welfare risks would be required.
- Similarly, the potential for the bedding material to be reused for more than one batch of cattle would improve the net benefit of woodchip bedding, but consideration of the health, disease and welfare risks is required.
- Current trial was in small pens which did not allow for pen riders, quantification of horses slipping on woodchips needs to be quantified within a commercial operation.
- The current project was on clay on rock base, but suitability on other pen surfaces should be investigated.
- Researchers in the current project noticed fungi growing in some woodchip, thus further research on potential impact of spores on cattle may be required.
- Researchers anecdotally observed a reduction in odour in the first month of the trial in the pens with woodchip, a study investigating the mechanism of odour and ammonia emission reduction may be beneficial for the industry.

Cost benefit analysis

- The development of a cost benefit calculator would help feedlots to estimate the benefit of this project for their enterprises.

5.4 Lessons from implementation of this project

The lessons learnt from the implementation of this project include both research and industry relevant outcomes. Firstly, in terms of research, the use of drones to collect animal behaviour was successful and allowed the collection of data without human/vehicle interference with the animals. In addition, it displayed clear images of pen surface prior to, during and after the trial. Images were analysed manually but it would be beneficial to develop machine learning algorithms for cattle identification and behaviour variables. The use of the drone was initiated due to the original observation tower at the feedlot being outdated and unsafe. This lead to a vast collection of superb images and footage that could be used for behavioural analysis. The drone used was equipped with low decibel propellers that provided a quiet mission and therefore no disturbance to cattle. The flight application used allowed a set waypoint path that could be automatically run for each data collection day, and eliminated any human operational error/ indifference between flights.

Weekly moisture was important so as to quantify the characteristics of the surface the cattle were interacting with, but the weekly in situ BD was not necessary, but important at the end to determine volume of manure removed from each pen. Separating surface and deep layers in the W30 and W60 treatments was important and at the end of the experiment it showed the mixing of the surface and deep layers for W30, whereas W60 still had a clear differentiation of layers.

For industry, the installation of the irrigation system to simulate rainfall, which could also be used to cool cattle during hot conditions, was problematic. The electrical supply was not adequate to power the pump, so a generator needed to be run in conjunction with the pump. The cattle manipulated the sprinkler heads with their muzzle and these needed to be replaced on numerous occasions.

6 Conclusions/recommendations

Previous studies suggested woodchips should help manage the problem of muddy pens and keeping cattle clean. In this trial, simulating a wet southern Australian winter, the addition of woodchip had a moderate weight and feed efficiency benefit, and lead to a $74 increase in carcase value. Feed intake was not affected by woodchip bedding, but average daily gain was increased by provision of bedding at 54 kg/m^3 (W30). Thus, the greatest impact of woodchip bedding is on improvement in feed efficiency, by reducing the maintenance energy requirement. There was no further performance advantage gained by providing woodchip bedding at twice this rate (W60). In the 109 day feeding period the benefit was obtained with woodchip treatment W30, and woodchips provided at twice this rate (W60) showed no further performance advantage, but for longer fed cattle this strategy may become more viable. There was a numerical net economic benefit of applying the W30 woodchip treatment, but this was highly variable, and subject to input costs. The extra cost of additional bedding in W60, combined with no further production benefit, caused the net benefit of that treatment to be less advantageous than the control treatment. Future research at commercial scale is required to understand the scale of economic benefits of woodchip bedding strategies. Animal behaviour data showed that even with unbedded mud (control), cattle in small pens are able to maintain their activity budgets for lying and eating. However, adrenal gland weights suggest that woodchip bedding reduces chronic stress in cattle in wet and muddy conditions. Cattle with woodchip bedding did not sink as low into the mud and at W60, and even at the end of the trial, they stood on a relatively clean surface. For medium and long-fed cattle a greater quantity of woodchip may be required than was provided by W30, as by 10 weeks on feed, the surface and deep layers were mixed and pad scores were increasing. The W60 pens were still in good order at the end of the trial and cattle could have been fed longer while maintaining good pen condition. It is possible that the benefits of woodchip bedding may be even greater for long-fed cattle, by amortising the woodchip input costs over a longer feeding period, and potentially improving the production, welfare and hoof health of more susceptible heavy cattle, however, this was untested in the current project. The researchers recommend that commercial-scale research is conducted to further test the economic benefits of woodchip bedding strategies for a range of production systems, and that commercial feedlots adapt the cost benefit analysis developed in this trial for their own input costs to determine the viability for their enterprise.

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8 Appendix 1: Analysed finisher ration composition

Table 19. Mean (± s.d.) nutrient composition of finisher ration, from daily samples bulked and analysed by wet chemistry weekly.

Nutrient	Mean ± s.d.
Dry matter, %	86.1 ± 3.06
Neutral detergent fibre, %	23.9 ± 1.90
Acid detergent fibre, %	12.9 ± 1.45
Crude protein, %	14.3 ± 0.49
Dry matter digestibility, %	79.3 ± 2.33
Organic matter digestibility, %	78.4 ± 2.23
Ash, %	5.3 ± 0.66
Organic matter, %	94.8 ± 0.66
Metabolisable energy, MJ ME/kg	13.1 ± 0.35
Fat, %	5.3 ± 0.69
Urea, %	0.03 ± 0.00
Starch, %	40.4 ± 2.60