Preliminary Results on Soil Permeability and Physical Characteristics of Feedlot Pens

P.H. Southcott
B.E., M.E.S., MIEAust, CPEng
Cooperative Research Centre for the Cattle and Beef Industry (Meat Quality); Lecturer, Department of Resource Engineering, University of New England, Australia.
S.C. Lott
B.E.(Agr), MIEAust, CPEng
Cooperative Research Centre for the Cattle and Beef Industry (Meat Quality); Research Fellow, Department of Resource Engineering, University of New England, Australia.

Summary The beef cattle feedlot industry is a potential source of a number of environmental problems. These include odour, contamination of surface water and groundwater. To overcome these waste management problems in Australia, attention has been focussed on removing water from the pens by rapid drainage to holding ponds and leaving only a thin layer of manure on the surface. In the United States, the odour problem is not as severe due to a generally drier and cooler climate. Consequently, more manure is left on the pens which mixes with the underlying soil to form an impermeable 'interface layer'. A stable interface layer protects against groundwater pollution. In this study, the in situ permeability of feedlot pen surfaces is measured before and after stocking to assess the potential for salts and nutrients to leach through to the water table, under Australian feedlot waste management practices. Although the study is not yet complete, preliminary results show that the use of compaction can be used to protect groundwater in the short term. In the longer term, it is demonstrated that even a thin interface layer will produce a large reduction in permeability of the pen surface.

1. INTRODUCTION

The Australian beef cattle feedlot industry has experienced a rapid expansion in recent years due to increasing demand in the domestic and international markets. Concurrently, society has become 'greener' and in response regulatory authorities continue to tighten environmental compliance criteria. In comparison to the feedlot industry in the USA, Australia operates in a climate which is both hotter and wetter resulting in some difficult waste management problems.

Potential environmental problems of feedlots include odour nuisance, surface water and ground water pollution. These arise out of the wetting of the manure which accumulates on the pen surface. Wet manure decomposes anaerobically, producing offensive odours. Water leaving the pen surfaces is laden with organic matter (from the manure) and is capable of degrading surface water. Australian feedlots operate under a 'Total Containment Policy' to minimise this risk. Similarly, water leaching below the pen surface could contaminate ground water with salts and nutrients from the manure.

It has been shown that as the manure accumulates on a pen surface, a distinct profile is developed comprising a surface layer of loose manure, overlying compact manure, an 'interface layer' and the original pen surface material (Lott *et al*, 1994). Under very wet conditions the loose and compact manure layers can become homogenised into a slurry. The interface layer is a compact mixture of soil and manure (which is mostly organic matter). This layer forms a relatively impermeable barrier to water, nutrients and salts (Lott *et al*, 1994). Currently, the interface is considered to provide adequate protection against ground water contamination.

The Australian feedlot industry has adopted sophisticated waste management techniques to minimise the odour problems. The basis of these techniques is to minimise wetting and maximise drying. Techniques used include providing rapid drainage to holding ponds, frequent cleaning of the loose manure, sloped pen surfaces and good pen design (Lott *et al*, 1994). As a result, only a thin layer of manure is left on the pen surface. This may result in a thin interface layer that potentially offers little protection to the ground water. To counteract this phenomena, soil compaction could be used during construction to reduce permeability to an acceptable level.

In this paper, preliminary results of permeability and other soil testing of pens at the "Tullimba" Cattle Research Facility are presented. Tullimba is located approximately 50 km due West of Armidale in northern New South Wales. The geology of this area forms part of the New England Fold Belt.

Rocks in the area of the pens include regionally and contact metamorphosed mudstone and greywacke (Hill, 1993). Geotechnical investigations prior to the feedlot construction found residual soils which were highly variable in depth (0.2 to 2.0m), distribution and composition (classifications of CH, CL, SC and GC) (Southcott, 1993).

The feedlot was designed to incorporate a few different slopes (1.5% to 5%) to allow investigation of feedlot hydrology. Drains direct runoff from pairs of the pens used in this investigation to flumes, and finally to holding ponds. To achieve this required considerable cut and fill, resulting in large quantities of the underlying weathered rock being worked up to form the pen surfaces.

The objectives of our study were to : to measure the permeability of the pen surfaces before stocking and after 6 months stocking; to measure the in situ density of the pen surface before stocking and after 6 months stocking; to observe the development of the manure and interface layers on the pen surface over a 6 month period; to sample the pen surface soils and manure for laboratory testing to determine engineering soil classification.

2. METHODOLOGY

This experiment was set up with the aim of best simulating the conditions that are present in a commercial feedlot operation. The test site, Tullimba, was a purpose built experimental facility, which has 40 small feedlot pens (12.5m x 36.8m) and 6 large feedlot pens (50m x 36.8m). The small pens were designed for feeding trials involving small numbers of cattle. However, the large pens were designed principally for commercial scale feedlotting and to investigate waste management systems. The range of pen slopes also offered the potential to investigate the influence of pen slope on permeability, although this will not be dealt with in this paper. Thus the 6 large pens (B9 to B14) were determined to be the most suitable.

Locations for testing were determined by dividing the entire area of the six large pens into lengthwise strips. One of the strips was randomly allocated to each pen and a random number used to determine the distance along the centreline of the strip to the sampling point. These positions were used for locating the permeability testing, determining the profile and in situ density, and taking of samples for laboratory testing. Testing at these locations was undertaken before stocking of the pens and again after 6 months of equivalent commercial stocking rates. Location of the test sites is shown in Figure 1.

Due to the drought, stocking in the pens was not continuous and the number of stock per pen also varied. A stocking rate of 1 beast per 25 m^2 was assumed. Thus, full time equivalent stocking for six months gives a total of 13432 beast days per pen. The actual stocking rates were calculated by summing the product of the number of beasts by the number of days they were present in the pens. The 'six month' testing was carried out when the actual number of beast days was greater than or equal to 13432 equivalent stocking rate (ie variable testing times).

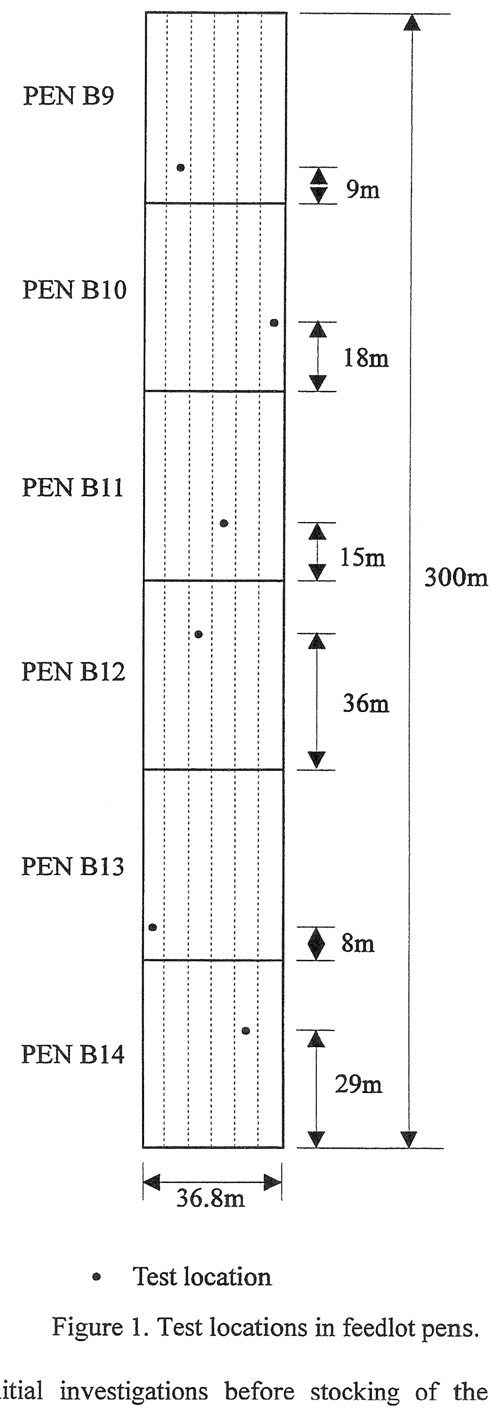

Figure 1. Test locations in feedlot pens.

Initial investigations before stocking of the pens were carried out between August and September 1994. At the time of writing, only pens B12 and B14 had received greater than 6 months equivalent stocking. Final investigations in these pens were carried out between September 1995 and January 1996.

2.1 In situ Density

Density in situ was measured using the sand replacement method (AS 1289.5.3.1, 1993) which disturbs the soil. For this reason, the initial density tests were located 1m north and 1m west of the permeability testing site. Subsequent tests were located 1m south and 1m east of the permeability testing site. At the six month equivalent stocking period, the density of the manure and interface layers was also determined by the same method.

It was found that under very wet conditions that the loose and compact manure became homogenised into a high moisture content slurry. Density of this slurry was determined in the laboratory by determining the mass to fill a 500 mL beaker. Samples of soil and manure were taken for oven drying moisture content determination (AS 1289.2.1.1, 1992).

2.2 Profile, Sampling and Laboratory tests

After the in situ density tests, the soil profile was determined by excavating to a depth of approximately 300 mm. Samples were taken for laboratory testing which included :

- particle size analysis - sieving (AS 1289.3.6.1, 1977);
- liquid and plastic limits (AS 1289.3.1.1, 1977; AS 1289.3.2.1, 1977);
- plasticity index (AS 1289.3.3.1, 1977);
- optimum moisture content and maximum dry density using Standard compaction (AS 1289.5.1.1, 1977).

Organic matter content of loose and compacted manure samples were determined by high temperature ignition method (ashing at 650°C for 1 hour).

2.3 Permeability

The in situ saturated coefficient of permeability was determined by using a disc permeameter (CSIRO, 1988). The disc permeameter was used because it would allow accurate in situ measurement of very low infiltration rates. This apparatus maintains a small constant head of ponded water within a confining ring. The ring is usually driven approximately 5 mm into the soil surface to prevent water escaping under the edge of the ring. However, on the engineered surface of the pens it was found that the surface was too hard to drive the rings in easily without significant disturbance of the surface. This disturbance may have been a significant influence on the permeability. To overcome this, the rings were placed directly on the soil and plasticine used to seal around the edge.

Testing after six months stocking required a slightly modified technique. All loose manure was removed from the site before driving the ring through the compacted manure and interface layers. This did not result in the disturbance of these layers inside the ring. The compacted manure and interface layers were removed from the outside of the ring and plasticine used to seal against the original soil surface. Set up of the instrument then proceeded as usual.

3. RESULTS AND DISCUSSION

3.1 Profile

Prior to stocking, investigation of the soil profile was limited to around 300 mm depth as it was considered that these soils would most influence the surface permeability (Table 1). It is quite possible that less permeable layers underlie this surface layer. However, once water has penetrated through the surface layer it may then move laterally or vertically downwards. It is unlikely to move upwards because of the absence of plants and the manure pack which will act as seal minimising surface evaporation. Thus, the surface layer will be of most importance in preventing groundwater contamination.

Table 1. Depth of the pen surface soil layer.

Pen	B9	B10	B11	B12	B13	B14
Depth (mm)	300	300	200	300	180	260

Table 2. Developed manure profile (dry conditions).

Pen	Depth of layer (mm)		
	loose	compact	interface
B12	20-30	35-40	1-5
B14	19-21	20-25	1-5

Development of the loose and compact manure layers, and the interface layer (mixture of manure and soil) in pens B12 and B14 (Table 2) is consistent with that observed by Lott *et al* (1994). However, at the time of the investigation, the interface layer was found to be of variable thickness, poorly defined and only 1 to 5 mm thick. This made measurement difficult and sampling impossible. In contrast, values of 25 to 75 mm were reported by Mielke *et al* (1974) from a United States feedlot.

During a period of exceptionally wet weather after stocking of the pens it was observed that the compact manure layer was not stable. At this time, the compact and loose layers of manure became thoroughly mixed into a slurry.

3.2 Density

In situ density tests of the pen soil (Table 3) show that the contractor obtained good compaction of the material, with results ranging between 96% and 100% of maximum dry density (Standard compaction). One outlying result of 108%, may be the result of a site with an unusually high gravel content. Density of the layer does not appear to be related to the infiltration rates measured in situ.

Density of the compacted manure layer is of the order of 3 times as dense as the loose manure that lies on the surface of the pens under dry conditions (Table 4). These results are consistent with Mielke *et al* (1974) and Tucker *et al* (1991) for compacted manure. Density of the slurry during wet conditions is similar to that of the loose manure in the dry state.

Table 3. In situ dry density and maximum dry density (Standard compaction) of pen soils.

Pen	In situ dry density (t/m^3)	Maximum dry density (t/m^3)	Dry density ratio (R_d) (%)
B9	1.85	1.93	96
B10	2.02	1.87	108
B11	1.80	1.86	97
B12*	1.86	1.88	99
B13	1.86	1.85	100
B14*	1.81	1.85	98

* Mean of 2 tests

Table 4. In situ dry density of manure in loose and compacted layers and under very wet conditions.

Pen	Loose manure (t/m^3)	Compact manure (t/m^3)	Wet conditions (t/m^3)
B12	0.28	0.95	0.30
B14	0.31	0.87	0.37

3.3 Laboratory testing

Pen surface soils can be classified into two groups of the unified soil classification system based on laboratory testing. Pens B9 to B12 have a classification of GC (clayey gravels) while pens B13 and B14 are classified as SM (silty sands) (Table 5, Table 6). However, results in Table 5 show that the material is poorly graded and therefore a difficult material to compact to a level where low permeability is achieved. Furthermore, all samples of the surface layer have significant quantities of sharp angular gravel present from incorporation of the underlying weathered rock. This is undesirable from both the perspective of animal health (from injuries to the feet) and increased infiltration rates into the pen surfaces.

Based on the classifications (Table 6), pens B13 and B14 should be semi-pervious to impervious (consistent with table 9). However, although soils of pens B9 to B12 should be an ideal impervious material for the pen surface, results in Table 9 show clearly that this is not the case. Pen soils are poorly graded which will tend to increase the coefficient of permeability. This is demonstrated by pens B9 and B10 (less than 20% sand) having higher permeability than pens B11 and B12 (greater than 20% sand).

Table 5. Pen soil particle size distribution.

Pen	Grading (% pass)			
	75 mm	19 mm	2.36mm	0.075mm
B9	95	77	36	17
B10	100	80	41	24
B11	100	87	54	29
B12	100	86	45	22
B13	100	100	75	37
B14	100	97	78	39

Table 6. Pen soil properties

Pen	Initial moisture content (%)	Atterberg limits		Classification
		w_L (%)	I_p (%)	
B9	6.2	28	10	GC
B10	5.3	33	15	GC
B11	5.8	29	10	GC
B12	5.4	28	11	GC
B13	8.0	18	np	SM
B14	4.7	19	np	SM

np = non plastic

Table 7. Final moisture content (%) of soil, loose and compacted manure layers (dry conditions) and manure slurry for pens B12 and B14.

Material	Pen B12	Pen B14
loose	10.9	55.3
compact	9.4	8.6
soil	9.4	8.6
slurry	265	177

Moisture content of the soils in pens B12 and B14 had risen in both cases from the as constructed samples (Table 7). This confirms that the pen surfaces are not completely impermeable. Interestingly, in both pens after stocking, the compact manure and soil had identical moisture contents. Manure in a wet condition resembles a viscous slurry and is capable of holding large amounts of water.

Organic matter contents of both the loose and compact manure are very similar (Table 8). From this it can be concluded that the major difference between these layers is simply the density of the material.

Table 8. Volatile solids (%) of loose and compact manure layers (dry conditions)

Material	Pen B12	Pen B14
loose	53.5	55.4
compact	55.2	50.6

3.4 Permeability

As constructed permeability of the pen surfaces was found to be highly variable, with a range covering an order of magnitude (Table 9). The current results are consistent but lower than the permeability (6.4×10^{-6} m/s) of an Australian feedlot pen soil measured by Walker *et al* (1979). The values compare well with the range expected for fine sands and coarse silts of 10^{-5} m/s to 10^{-7} m/s (Smith, 1990).

Prior to construction of the pen surfaces, no in situ infiltration measurements were made in the vicinity. However, Burton (1993) carried out double ring infiltrometer tests on the effluent disposal area, which is of a similar soil type. Values in the disposal area for the topsoil were similar to the pen surfaces ranging between 3×10^{-7} m/s and 2×10^{-6} m/s. In situ tests by Burton (1993) of the effluent disposal area subsoils showed that the coefficient of permeability was lower being of the range 3×10^{-7} m/s and 6×10^{-7} m/s. It may be concluded that the infiltration rates into the pen surface are not significantly different to the soils present prior to construction. However, given the poor grading of the pen soils used in construction, permeability might reasonably be expected to be have been higher than the residual soils. That this is not the case may be attributed to the use of compaction to minimise the coefficient of permeability.

No clear reasons are apparent for the large range of infiltration rates measured. Perusal of the other parameters measured such as density and plasticity show no consistent pattern which could explain the differences. Part of the problem may be that only a small surface area is measured (ring diameter is 240 mm), while there is significant variation in the soil macro structure. At the time of the experimental design, a number of methods of infiltration rate measurement were considered, including the use of a rainfall simulator and tracers which would test a large area. The difficulty with the rainfall simulator is that it would be difficult to measure the very low infiltration rates because effects such as evaporation would be hard to quantify or avoid. Tracers would require destructive sampling and were also beyond the budget of the project.

Permeability testing of pens B12 and B14 after stocking show dramatic reductions in the infiltration rate of between one and two orders of magnitude (Table 9). This clearly demonstrates that even after only a short time of stocking that the development of the interface layer will lower the infiltration rates. Field measurements conducted in the United States by Mielke *et al* (1974) of a well established interface layer of several centimetres depth showed zero infiltration over a twenty day period. Mielke and Mazurak (1976) in a field investigation of a well established feedlot measured an infiltration rate of 1.4×10^{-8} m/s, which is comparable with the current study. No field studies have been conducted in Australia but Walker *et al* (1979) took cores from a feedlot after 6 months stocking and tested them in the laboratory. Results ranged from 1.2×10^{-9} to 1.4×10^{-8} m/s, again which are consistent with the current results.

Table 9. In situ saturated coefficient of permeability ($\times 10^{-6}$ m/s)

Pen	Initial	6 Months
B9	1.3	
B10	5.4	
B11	0.84	
B12	0.31	0.023
B13	0.52	
B14	2.5	0.014
Mean	1.8	0.019

These results after stocking are even more important because both pens were tested after an unusually wet period. Breakdown of the compact manure layer into a slurry had occurred and breaks in the interface layer (from the impact of hooves) were visually apparent. Furthermore, in pen B12 while trying to remove the slurry so that testing could commence, it is believed that some inadvertent damage to the interface layer may have resulted. It should be remembered that saturated conditions occur infrequently in the feedlot pen surfaces. Given that the measured saturated coefficient of permeability is typically significantly greater than unsaturated permeability, mean infiltration rates will be very low. Thus, values obtained for pens B12 and B14 could be considered a worst case scenario.

Variation in the infiltration rates between pens B12 and B14 after stocking are smaller than the as constructed results. Although it is difficult to draw conclusions before the full testing program is complete, it would appear that the interface layer will provide greater uniformity of infiltration rate. Furthermore, as modifications to the permeameter method were required, testing of the pens B12 and B14 were not carried out until 6.7 months and 8.6 months equivalent stocking respectively. Thus, part of the difference between the results may simply be a function of the length of equivalent stocking. This, if true, indicates that the pen surface will become even more impermeable over time.

4. CONCLUSIONS

At the Tullimba cattle research facility, investigations into the permeability of the pen surface have been carried out both prior to and after six months of equivalent stocking. Whilst investigations are not yet complete, preliminary results show some important and favourable results. Firstly, the poor quality soil material used to construct the compacted pen has provided a mantle of low permeability which will minimise infiltration of water. Thus, during the initial build up of manure on the pen surface, groundwater is afforded some protection from contamination.

An interface layer usually develops on the pen surface of cattle feedlots. Concerns have been expressed that Australian waste management techniques may result in an interface layer that does not prevent groundwater contamination. However, from the results to date it is clear that large reductions in the infiltration rate have occurred due to the presence of only a very thin interface layer. In the longer term, the interface will develop further to form an essentially impermeable barrier. While some water will infiltrate below the interface layer under saturated conditions, this will occur infrequently. Consequently, the long term accession to the groundwater will be very small. Groundwater will thus be well protected from pollution by even thin interface layers in the pens.

5. REFERENCES

Australian Standard, 1995, *AS1289.3.1.1 Determination of the liquid limit of a soil -Four point Casagrande method*, Standards Australia, Sydney, pp. 1-6.

Australian Standard, 1995, *AS1289.3.2.1 Determination of the plastic limit of a soil - Standard method*,Standards Australia,Sydney,pp.1-3

Australian Standard, 1995, *AS1289.3.3.1 Calculation of the plasticity index of a soil (standard method)*, Standards Australia, Sydney, pp. 1.

Australian Standard, 1993, *AS1289.5.1.1 Determination of the dry density/ moisture content relation of a soil using standard compactive effort*, Standards Australia, Sydney, pp. 1-8.

Australian Standard, 1993, *AS1289.5.3.1 Determination of the field dry density of a soil - Sand replacement method using a sand-cone pouring apparatus*, Standards Australia, Sydney, pp. 1-8.

Australian Standard, 1992, *AS1289.2.1.1 Determination of the soil moisture content of a soil - Oven drying method (standard method)*, Standards Australia, Sydney, pp. 1-2.

Australian Standard, 1977, *AS1289.3.6.1 Determination of the particle size distribution of a soil - Standard method of analysis by sieving*, Standards Australia, Sydney, pp. 1-4.

Burton, J.R., 1993, *Engineering properties of 'Tullimba' soils,* Appendix 4, Cattle Research Facility 'Tullimba' EIS.

CSIRO, 1988, *CSIRO Disc permeameter - Instruction manual*, CSIRO, Canberra, pp. 1-26.

Hill, R., 1993, *Report on the Geology and Geohydrology of the property 'Tullimba',* Appendix 2, Cattle Research Facility 'Tullimba' EIS.

Lott, S.C., Powell, E. & Sweeten, 1994, 'Manure Collection, Storage and Spreading' in *Designing Better Feedlots*, eds Watts, P.J. & Tucker, Queensland DPI, Toowoomba, pp. 6.5-6.19.

Mielke, L.N., Norris, P.S. & McCalla, T.M., 1974, 'Soil Profile Conditions of Cattle Feedlots', *J. Environ. Quality,* Vol. 3, No.1, pp. 14-17.

Mielke, L.N. & Mazurak, A.P., 1976, 'Infiltration of Water on a Cattle Feedlot', *Transactions of the ASAE,* pp. 341-344

Smith, G.N., 1990, *Elements of Soil Mechanics*, 6th Ed., BSP Professional Books, Great Britain, pp. 47.

Southcott, P.H., 1993, *Cattle Research Facility 'Tullimba' - Pens, buildings and access roads - Report on geotechnical investigations,* University of New England.

Tucker, R.W., Watts, P.J., Lott, S.C. & Jukes, P., 1991, *Lot Feeding in Australia,* Queensland DPI, Feedlot Services Group, pp. 103-143.

Walker, L.W., Turner, A.K. & Vaneslow, D.V., 1979, 'Inflow to Groundwater from a large Cattle Feedlot in Victoria', *Proceedings of Australian Water Resources Council Conference on Groundwater Pollution,* pp. 215-225.