A promising and simple method to quantify soil/manure mixing on beef feedlot pens

Chris Pratt[A,B], *Matthew Redding*[A] *and Jaye Hill*[A]

[A]Department of Agriculture, Fisheries and Forestry, 203 Tor Street, Toowoomba, Qld 4350, Australia.
[B]Corresponding author. Email: christopher.pratt@daff.qld.gov.au

Abstract.   On beef cattle feed pen surfaces, fresh and decayed manure is mixed with base rock or soil (base). Quantifying this mixing has beneficial applications for aspects including nutrient and greenhouse gas budgeting. However, no practical methods exist to quantify mixing. We investigated if measuring element concentrations in: (A) fresh manure, (B) base material, and (C) pen manure offers a promising method to quantify manure/base mixing on pen surfaces. Using three operational beef feedlots as study sites, we targeted carbon (C), and silicon (Si), which are the two most abundant and easily measurable organic and inorganic elements. Our results revealed that C concentrations were strongly (>15 times) and significantly ($P < 0.05$) higher whereas Si concentrations strongly (>10 times) and significantly ($P < 0.01$) lower in fresh manure than base material at all three sites. These relative concentrations were not significantly impacted by manure decay, as determined by an 18-week incubation experiment. This suggested that both of these elements are suitable markers for quantifying base/manure mixing on pens. However, due to the chemical change of manure during decay, C was shown to be an imprecise marker of base/manure mixing. By contrast, using Si to estimate base/manure mixing was largely unaffected by manure decay. These findings were confirmed by measuring C and Si concentrations in stockpiled pen surface manure from one of the sites. Using Si concentrations is a promising approach to quantify base/manure mixing on feed pens given that this element is abundantly concentrated in soils and rocks.

Additional keywords: beef cattle, carbon, feedlots, manure, rock, silicon, soil.

Introduction

Beef feedlots are used for finishing cattle from pastures, particularly in the USA, Canada and Australia. In Australia it is estimated that 5% of the total beef cattle population (23 million) is on feedlots at any time (Australian-Govt 2012). In the USA, ~20 million cattle are raised on feedlots annually (Rogge *et al*. 2006). Feedlot pens directly overlay native soil or a base of imported crushed rock material, often in the absence of bedding material.

Although feed pen surfaces have been reported to be dominated by manure (Durso *et al*. 2011), they may contain significant quantities of base rock/soil (herein referred to as base material) (Larney *et al*. 2006; García *et al*. 2012). No practical methods exist for quantifying base material/manure mixing on pen surfaces. Uncertainty regarding the extent of base material mixing with manure causes mass balance problems in fields such as nutrient and carbon (C) budgeting (Dantzman *et al*. 1983; Eghball *et al*. 1997), and greenhouse gas emission measurement where emissions from pad manure are often reported on a manure weight basis without necessarily accounting for the amount of soil/rock mixed in with it (Hao *et al*. 2001; Pattey *et al*. 2005). Indeed, the need for quantifying base material mixing with manure on feedlots has arisen in studies examining *in situ* soil profiles in feedlot pens (Mielke *et al*. 1974; Dantzman *et al*. 1983;

Berry and Miller 2005; García *et al*. 2012) as well as investigations into characterising manure hauled from feedlot pens (Larney *et al*. 2000; Rogge *et al*. 2006).

Using a marker element displaying a strong concentration contrast in base material relative to manure, or vice versa, could provide a useful approach to quantify mixing and assist with resolving this problem. Carbon is the most abundant and easily measurable organic element. Carbon concentrations in beef cattle manures have been reported to range between 34% (Hao *et al*. 2001) and 46% dry weight (Helgason *et al*. 2005) whereas C concentrations in topsoils generally range from 1.5% (Cremers *et al*. 2001) to 8.5% (Tate *et al*. 2007) dry weight with an average concentration of 2.5% dry weight (Shacklette and Boerngen 1984).

The most abundant inorganic element is silicon (Si) whose global-scale soil/rock concentration has been reported to be 27% dry weight (Shacklette and Boerngen 1984; Faure 1998). Only one study was found reporting beef cattle manure Si concentrations [9.5% dry weight by Kobayashi *et al*. (2008)]. It is unclear whether this was fresh manure or pen manure.

The large manure/soil concentration differences for C and Si, initially suggest that both these elements could offer a practical opportunity to quantify mixing on pen surfaces. To use this concentration contrast to evaluate mixing ratios, sampling and

analysis of three representative materials would be required at a given feedlot: (A) fresh manure, (B) underlying base material; and (C) pen surface material, (which contains fresh and degraded manure as well as base material). In this work we assess if measuring C and Si concentrations offers a promising approach to quantify base/manure mixing on beef feedlot pen surfaces.

Methods

Study sites, sample collection and preparation

The three feedlots are located on the Darling Downs, 150 km west of Brisbane, Australia. Site A's herd size is 17 000 with a stocking density of 15 m^2/head. Feed materials include barley and sorghum. The feedlot pens are constructed on soils native to the region (i.e. black Vertosol derived from weathering of mafic parent material). Manure from the pens is worked into a mound in the middle of the pen and removed every 4–6 months to a stockpiling site. Site B has an average herd size of 28 000 with a stocking density of 15 m^2/head. The cattle receive a mixed ration diet comprising ~65% grain with the remainder consisting of wet distiller's grain (ethanol byproduct), molasses, and cotton products. Site C's herd size is 26 000 with a stocking density of 9–12 m^2/head. Diet includes molasses, wheat, barley, sorghum, corn silage, cereal silage, cotton seed, cotton seed hulls, cotton seed meal, cereal hay, and sorghum. The pens at Site B and C overlie crushed rock from local quarries (alluvial weathered basalt at Site B and Ca-Mg rich conglomerate at Site C). Manure from the pens at these feedlots is scraped out every few weeks using a box scraper.

We were permitted access to one pen at each of the three sites. A 1-kg composite sample of fresh manure, observed to be deposited at the time of sampling, was collected from each site. These manure subsamples were taken from at least five deposits at each site. Care was taken to avoid scraping pen manure into the fresh samples. One-kilogram samples of the base material (i.e. soil for Site A and rock for Sites B and C) from each feedlot were obtained using material combined from six cores (to 20 cm depth) at each site. In addition to the fresh manure samples and soil/rock samples, a 1-kg composite manure sample was collected from a 250-m^3 stockpile of manure scraped from the pens at Site A. The composite sample was acquired from six cored subsamples at a depth of 1.5 m in the 1-day-old pile; with each core extracting ~150 g of manure. Each material was homogenised using a mechanical mixer. Batches of each material were collected and refrigerated for further experimentation and analysis.

Fresh manure decay experiment

Five-hundred grams (wet weight) of homogenised fresh manure from Sites A and B, and 250 g of manure from Site C (where less fresh manure was available), was split into 12 equal-weight batches. These batches were loosely packed into 50-mL open-topped plastic containers. These were placed inside a 35°C incubator in order to assess dry mass loss from manure under warm conditions: optimal for respiration rates in manures and soils (Sikora and Sowers 1985; Murwira *et al.* 1990; Keith *et al.* 1997). The containers were left in the incubator for 18 weeks (126 days), i.e. the average maximum clean-out period for manure

on pens in Queensland (Skerman 2004) and representative of typical clean-out periods for pens in the USA (Dantzman *et al.* 1983). The experiment represents a decay simulation for pen-deposited manure with the aim to estimate the impact of decay on manure C and Si concentrations.

Deionised (to avoid possible elemental contamination) water was used to adjust manure moisture contents between almost dry (<5% by dry weight) and starting levels, which would be expected under field conditions. Manure batches were removed from the incubator at regular intervals (see Fig. 1 for timing), as sacrificial replicates, and measured for their dry matter content by oven-drying the samples overnight at 105°C and recording weight loss. In addition to the above, sacrificial replicates of each manure were taken from the incubator and set aside for chemical analysis at various times (see Results and Discussion for timing).

Chemical analyses

Chemical analyses were performed on manure and soil/rock samples. Total (Dumas) C was analysed using a Leco analyser following the Dumas dry combustion principle where samples are combusted at 1050°C. This method has been well described in previous work (Buckee 1994). X-ray fluorescence spectroscopy was used to analyse for Si concentrations in the samples. Chemical analyses were performed in triplicate on the fresh manure, the stockpiled manure from Site A and soil/rock samples from each site.

Quality control

Lower detection limits for the elemental analyses conducted in this study are presented in Table 1. The table also shows recoveries of element concentrations for reference standard samples analysed by the laboratory.

Statistical analyses

Expanded regression (GENSTAT) was used to determine means of the manure C and Si concentrations at time 0, half way
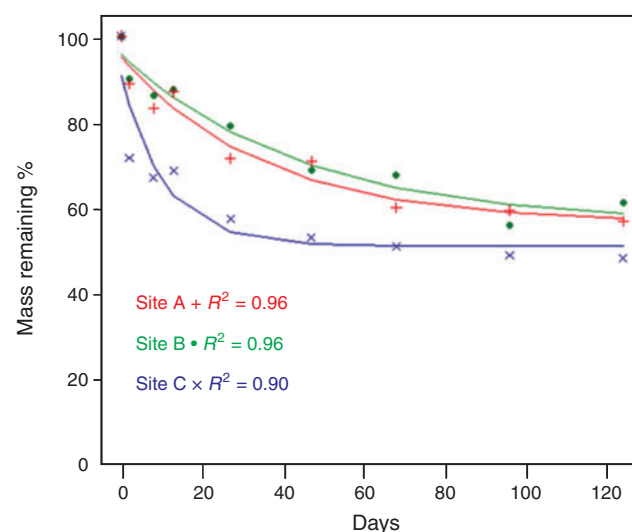

Fig. 1. Mass loss due to biological decay for fresh manures. Points are sacrificial replicates; decay curves fitted using classic decay equation. R^2 values show correlation of empirical data to equation.

through the decay experiment (63 days) and at the end (126 days). ANOVA was then applied to the data to determine the statistical significance of the differences in relative concentrations of elements between the manure and the soil/rock across all three sites. A *P*-value of <0.05 was considered significant. Confidence intervals (CI) to describe the variability in element concentrations during decay were determined using Excel, employing the equation:

$$\text{CI upper, lower} = \pm 1.96 \times (\text{s.d.}/\sqrt{n}) \qquad (1)$$

Where, s.d. = standard deviation, n = sample number, and 1.96 is the critical value for the 95% CI.

Results and discussion

Dry mass losses for each of the manures during the incubation are plotted in Fig. 1. Manures from all three feedlots lost ~40–50% of their dry mass (Fig. 1).

Mass loss for each manure type was well described by the classic exponential decay model. Most mass loss (>two-thirds) occurred in the first month, demonstrating that the composition of manure deposited on feedpads can change rapidly. In order to assess how biological decay affected the manures' composition, we recorded C and Si concentrations at various times during the decay experiment. The data is presented in Table 1. Changes in C concentrations during decay were significant (*P* < 0.05).

Carbon values tended to increase initially and then fall back to initial levels (Table 2). This trend might seem surprising as substantial C losses from manure have been reported during decay and composting processes (Kirchmann and Witter 1992; Larney *et al*. 2005). Yet, in this study the manure's starting C concentrations were greater than typical carbohydrate C concentrations (40%). Thus, it makes sense that as carbohydrates in manure are initially consumed for respiration the overall manure C concentration would go up. This would be exacerbated by the loss of other volatiles with even lower C contents, such as urea, ammonia, and fermentation products all of which have been reported in cattle manure (Miller and Varel 2002; Cole *et al*. 2005; Pratt *et al*. 2014). Later during decay, as more complex C compounds are consumed in biological processes and the ash content increases relative to the volatile content, manure C concentrations would drop, which was observed in our work.

Silicon concentrations tended to increase during decay (Table 2), which was expected given that it is a non-volatile element; although Si concentration changes were not significant (*P* > 0.05). Using the elemental concentrations of the base material given in Table 3 and the manure data in Table 2, we calculated differences in relative concentrations of elements between the manure and the soil/rock across all three sites (Table 4). The relative concentration ratios are expressed as enrichments in base material relative to manure for Si

Table 1.   Quality control data for element analyses

Element	Lower detection limit%	Reference sample 1 – % deviation from target concentration	Reference sample 2 – % deviation from target concentration	Reference sample 3 – % deviation from target concentration
Carbon	0.01	5.3	5.0	0.3
Silicon	0.01	3.9	4.0	3.8

Table 2.   Concentrations of carbon and silicon in the studied manures, as affected by biological decay (reported on a dry weight basis) for sacrificial replicate samples
Laboratory error given in parentheses. IS, insufficient sample for analyses

	Site	Days 0	12	26	67	126	Significance of change
Carbon %	A	41.5 (1.47)	53.3 (1.88)	47.9 (1.69)	41.2 (1.46)	41.2 (1.46)	–
	B	44.2 (1.56)	44.9 (1.59)	49.7 (1.76)	41.7 (1.47)	42.2 (1.49)	*P* < 0.05
	C	41.5 (1.47)	68.4 (2.42)	48.5 (1.71)	43.4 (1.53)	43.6 (1.54)	–
Silicon %	A	1.84 (0.07)	1.91 (0.07)	2.02 (0.08)	IS	2.53 (0.10)	–
	B	0.54 (0.02)	0.97 (0.04)	1.29 (0.05)	IS	1.15 (0.04)	None
	C	1.02 (0.04)	0.92 (0.04)	1.05 (0.04)	IS	1.42 (0.06)	–

Table 3.   Composition of base material at the studied sites
Average values of triplicate analyses. Laboratory error given in parentheses for means

	Site A Mean	Relative standard deviation% of mean	Site B Mean	Relative standard deviation % of mean	Site C Mean	Relative standard deviation % of mean
Carbon %	2.39 (0.08)	2	0.08 (<0.01)	26	1.15 (0.04)	1
Silicon %	34.4 (1.34)	2	38.0 (1.48)	4	20.3 (0.79)	1

(i.e. base material element concentration/manure element concentration) and vice versa for C (i.e. manure element concentration/base material element concentration).

Based on data in Table 4 it appears that the strong relative concentration differences in C and Si between manure and base

materials are not impacted by manure decay and, thus, both of these elements could be effectively used to estimate mixing on feedlot pen surfaces. However, it is important not only to consider how manure decay affects relative concentrations but also how it affects the application of these contrasts to quantify

Table 4.   Concentration ratios for silicon and carbon between base material and manure across sites over time
Calculated from the rock/soil means in Table 3 and the fitted means of manure concentrations in Table 2 determined using expanded regression (GENSTAT)

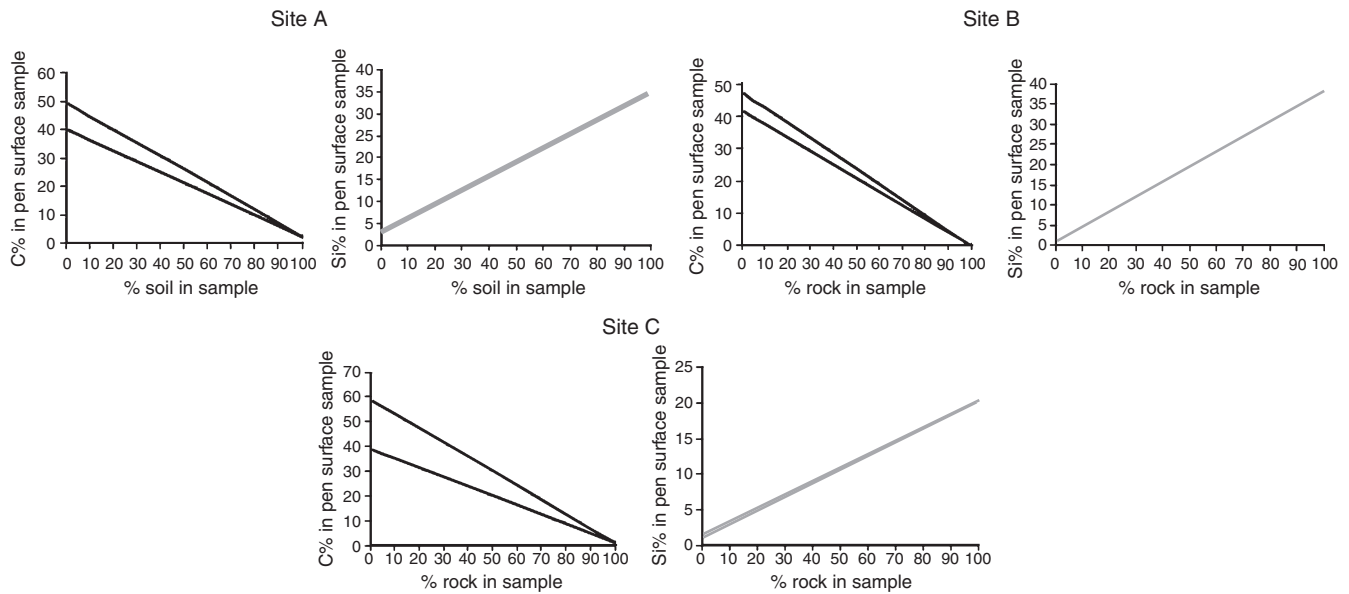| Element	Site	Concentration ratio			Significance of contrast	Average concentration ratio across site and days
		Day 0	Day 63	Day 126		
Carbon	A	19.8	18.9	17.0	$P < 0.01$	200
	B	576	549	495	$P < 0.05$	
	C	44.4	42.5	38.7	$P < 0.01$	
Silicon	A	19.0	14.5	14.3	$P < 0.01$	19.6
	B	52.7	29.6	28.9	$P < 0.01$	
	C	24.3	14.5	14.2	$P < 0.01$	

Fig. 2.   Models depicting percentage of rock/soil material mixed with manure on pen surfaces as a function of carbon and silicon in hypothetical pen manure samples at the three studied sites. The two lines in each graph represent upper and lower variability (95% confidence level) in manure concentrations as affected by decay.
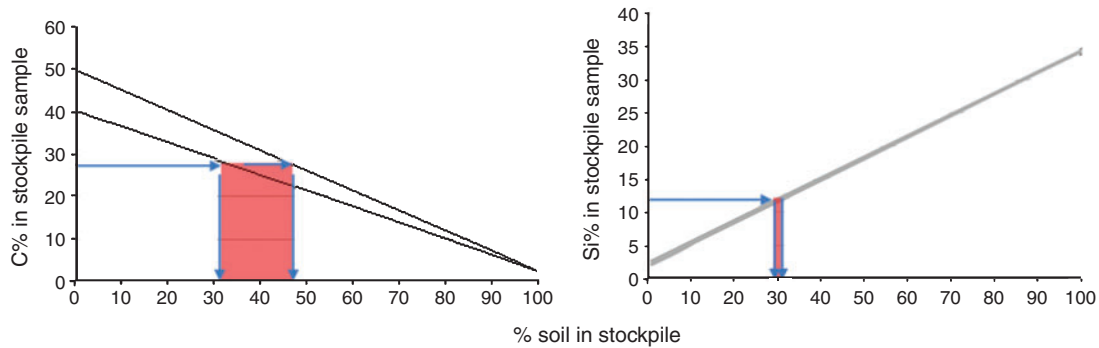

Fig. 3.   Applying the mixing model for Site A to estimate the proportion of soil mixed into a stockpile of pen manure from that site.

manure/base material mixing. To investigate this, we developed simple mixing models using our data (Fig. 2). The ratio of fresh to fully decayed manure in a given feed pen surface sample will likely be a continuum between the two extremes. In our models we represent this uncertainty by plotting upper and lower estimates of manure/base material mixing relationships using the width of the two-tail CI (95%) in element concentrations observed in the decay trial using Eqn 1.

It is evident that the precision of quantifying base material/manure mixing using C concentrations is poor, due to the effect of manure decay on C concentrations (Fig. 2). By contrast, Si yields a more precise estimate of base material/manure mixing on pen surfaces at each site (Fig. 2). To check our model approach, we applied C and Si concentrations measured in stockpiled manure from the pen surfaces at Site A to the mixing model generated for that site (Fig. 3). The average C and Si concentrations in the triplicate stockpile samples were 27% (RSD = 2%) and 10.5% (RSD = 10%) on a dry weight basis. It can be seen that using both elements yielded good agreement regarding the amount of soil (~30%) mixed in with the pen manure (Fig. 3). However, the precision using C concentrations was much poorer than that given by using Si concentrations (Fig. 3). The high proportion of base soil in the pen manure highlights the importance of quantifying manure/base mixing.

Although the current demonstration is based on limited data (three sites) we suggest that the use of Si concentrations quantify manure/base material mixing has widespread potential given the global concentration of Si in rocks and soils. Aluminium would be another potentially strong marker element given the literature shows vastly greater soil/rock Al contents on a global scale (Shacklette and Boerngen 1984; Faure 1998) compared with beef manure (Eghball and Power 1993; Chen *et al.* 2003; Ajiboye *et al.* 2004; Miller *et al.* 2013). In some locations, notably limestone landscapes, which are dominated by Ca, Mg and C, Si and Al would not be useful markers for estimating base/manure mixing on feedlots. In these cases background research could point to the use of other suitable element markers (e.g. Ca, Mg) to estimate base/manure mixing.

Conclusions

Our study showed that measuring Si concentrations offers a promising and simple method for quantifying manure/base material on beef feedlot pen surfaces. Based on our findings, as well as literature data, we suggest that this method has widespread potential due to the abundant global concentration of Si in soils and rocks. By contrast, using carbon and organic compounds to estimate mixing is not recommended because they are affected too much by manure decay. Accurate quantification of base material mixing with manure on pen surfaces will assist in fields such as greenhouse gas and nutrient budgeting within beef feedlots.

Acknowledgements

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