Potential odorous volatile organic compound emissions from feces and urine from cattle fed corn-based diets with wet distillers grains and solubles

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HIGHLIGHTS
- We collected manure from cattle fed 0–45% wet distillers grains with solubles.
- We measured VOC flux and odor activity value (OAV) from feces and urine.
- WDGS had little effect on OAV or VOC flux rates.
- VOC emission rates and OAV were higher from urine than feces.
- 4-methylphenol accounted for the majority of OAV in urine and feces.

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ABSTRACT
Odor and volatile organic compound (VOC) emissions are a concern at animal feeding operations (AFOs). The issue has become more prevalent as human residences move into areas once occupied only by agriculture. Odors near AFOs are generally caused by odorous VOCs emitted from manure, the mixture of feces and urine. Wet distillers grains with solubles (WDGS) are a by-product of the ethanol industry, and WDGS have become a staple in many beef cattle finishing diets. The objective of this research was to determine specific VOC emissions from frozen feces and urine of cattle fed steam-flaked corn (SFC)-based diets containing 0, 15, 30, or 45% WDGS. No differences in flux were detected across dietary treatments for phenol, indole, skatole, or 4-methylphenol (P > 0.23). Dimethyl disulfide and dimethyl trisulfide flux in feces were not different across treatments (P > 0.35) and the flux of volatile fatty acids (VFA) such as acetic, propionic, isobutyric, butyric, isovaleric, and valeric were not different across treatments (P > 0.35). There was a tendency for dimethyl disulfide flux from urine to be greater for cattle consuming an SFC-based diet with 15% WDGS than the other diets (P = 0.10). Furthermore, flux of acetic, propionic, isobutyric, butyric, isovaleric, and valeric acid from the urine were not different (P > 0.61) across dietary treatment. There were no significant differences in odor activity value (OAV) across treatments for feces, and only a tendency for dimethyl disulfide in the feces (P = 0.08). Thus, there was no obvious indication that feeding WDGS in conjunction with SFC affects flux of odor or odorous VOC from beef manure. The summed OAV was three times higher in the urine than feces, and a single odorous compound (4-methylphenol) accounted for 97.6% and 67.3% of the OAV in urine and feces, respectively. Therefore, engineering or dietary strategies to reduce odor from beef cattle manure should focus on controlling or reducing 4-methylphenol concentrations in the urine and feces.

1. Introduction

Odor emissions have been of great interest in recent decades and animal production has long been considered a source of odor. In fact, odor nuisance generates a significant fraction of the complaints in air pollution (Shusterman, 1992). Odor and volatile organic compound (VOC) emissions have been an issue at animal feeding operations (AFOs), and the issue has become more prevalent as human habitats encroach upon areas once occupied only by
agriculture (Chen et al., 1999). Odors immediately adjacent to AFOs have been found to be caused by odorous VOCs emitted from manure (i.e., the mixture of feces and urine) sources as well as feed and silage (Parker et al., 2007, in press). The presence of microbial populations in the manure leads to fermentation of undigested residues and endogenous losses, producing VOC (Mackie et al., 1998; Spiels and Varel, 2009). Volatile organic compounds found in livestock manure have been linked to human odor perception (Zahn et al., 2001). Phenols and indoles are produced from proteins (Spoelstra, 1980), and volatile fatty acids (VFAs) are produced from carbohydrates (Williams, 1984; Powers et al., 1999). Animal feeding operations have been identified as a source of over 200 VOCs (Cai et al., 2006; Trabue et al., 2011a,b; Wright et al., 2005).

However, there is evidence that only a small percentage of those compounds are actually responsible for odor downwind from AFOs (Wright et al., 2005; Trabue et al., 2011a; Parker et al., in press).

Dry and wet distillers grains and distillers solubles are by-products of grain fermentation used to produce fuel ethanol. The growing ethanol industry throughout the U.S. has increased the use of wet distillers grains with solubles (WDGS) in beef cattle finishing diets (DiLorenzo and Galyean, 2010). However, most cattle feeding studies with WDGS have used diets based on dry-rolled or high-moisture corn, and surprisingly few studies have fed steam-flaked corn (SFC) which is the most common method of corn processing in feedlot diets throughout the U.S. (Vasconcelos and Galyean, 2007).

Only 10–20% of the nutrients consumed by livestock are retained (NRC, 1996) and AFOs concentrate large quantities of manure in small areas. Therefore, developing feeding regimes to decrease excretion of nutrients that affect odor production from cattle feedlots could have profound environmental implications (Miller and Varel, 2001). Currently, there is little data on the emission of odors and VOCs from AFOs. However, the recently completed U.S. EPA National Air Emissions Monitoring Study (NAEMS) was instituted to quantify air quality emissions from AFOs (Heber et al., 2008). The NAEMS study mainly focused on quantifying air emissions from buildings and lagoons. Others have studied the emissions of odor and VOCs following land application of swine manure (Feilberg et al., 2010; Parker et al., in press).

This study was conducted to quantify potential VOC emissions from beef cattle feces and urine. The specific objectives of the study were to: 1) determine specific VOC emissions from feces and urine separately from cattle fed SFC-based diets with 0, 15, 30, or 45% WDGS, and 2) using OAV analyses, determine which compounds were most responsible for odor in feces and urine.

2. Materials and methods

2.1. Live animal procedures

All procedures involving live animals were approved by and conducted within the guidelines of the Cooperative Research, Education, and Extension Team animal care and use committee (Texas Agrilife Research, USDA-ARS, West Texas A&M University). Four Jersey steers were used in (initial body weight = 322 kg) and were housed at the USDA-ARS research laboratory near Bushland, TX. The experiment was conducted from early October of 2010 to mid February of 2011. Steers were housed in four fly ash-surfaced pens (1 steer/pen; 3.7 m wide × 3.7 m deep). Steers had ad libitum access to fresh water and were fed above their maintenance requirement at all times (Hales et al., in press). The four treatments were as follows: 1) SFC-based diet with 0% WDGS (SFC-0); 2) SFC-based diet with 15% WDGS (SFC-15); 3) SFC-based diet with 30% WDGS (SFC-30); and 4) SFC-based diet with 45% WDGS (SFC-45). The SFC-0 diet included added fat, yellow grease, and cottonseed meal to balance for ruminally degradable protein. All diets were formulated to contain approximately 8.0% ruminally degradable protein and 6.0% total ether extract (fat) and vitamins and minerals to meet or exceed animal requirements based on the NRC (1996) calculations. Each of the four periods in the Latin square consisted of an initial 16-d diet adaptation and 5 d of fecal and urine collections, resulting in a total of 84 d for the experiment.

During the collection periods, steers were housed in four chambers (1 steer per chamber) of external dimensions 210 cm H × 244 cm L × 115 cm W, resulting in an approximate internal volume of 6500 L. Each chamber was constructed with 5 cm pipe panels (W—W Livestock Systems, Weatherford, OK). The panel exterior was covered with clear Lexan, approximately 0.6 cm thick. The flooring inside each chamber was made up of plastic boards, with a high density polyethylene pan (66 cm L × 15 cm W × 15 cm H) for urine collection placed underneath a plastic coated metal grate in the center of each chamber. Outside air was pulled into each chamber through polyvinylchloride (PVC, 7.6 cm i.d.) pipe and outgoing air from each chamber was pulled through PVC pipe (5.1 cm i.d.) to the gas sampling system. An air-conditioning system (Fredrich Company, San Antonio, TX) was located inside each chamber to facilitate air circulation, remove humidity, and maintain the temperature (51 cm L × 15 cm W, resulting in an approximate internal volume of 2.36 L (Fig. 1). Further details on the wind tunnel construction can be found in Parker et al. (in press). Generally, the wind tunnel technique is a way to quantify emissions at a point in time; however, emission measurements over time are needed because odor and VOC flux from feces and urine are not static, and can have very active microbial populations which are always changing.

Sweep air was supplied from the laboratory compressed air system. The air was passed through an activated carbon filtration
system to remove VOCs. Relative humidity was maintained at 10% by mixing dry and humidified air in a 15 L tank equipped with a PC-recorded relative humidity and temperature sensor (Model RH-USB, Omega Engineering, Stamford, CT, USA). The conditioned air was passed through a final rotameter to control the sweep air flow rate of 1 L min⁻¹ into the wind tunnel.

Following an equilibration time allowing three volumes of sweep air to pass through the wind tunnel, VOC samples were collected from the air exiting the wind tunnel. Air samples were collected in stainless steel sorbent tubes filled with Tenax TA© sorbent using the same procedures described in Parker et al. (in press). Flux density was calculated on a mass per unit area per unit time basis (µg m⁻² min⁻¹) as described in Parker et al. (in press).

2.3. Gas chromatography/mass spectrometry/statistical analyses

All sorbent tube samples were collected in duplicate and results were averaged. Sorbent tube samples were analyzed using the procedures outlined in Parker et al. (in press) using a thermal desorption-gas chromatography-mass spectrometry (TD-GC-MS) system. Samples were analyzed for eight volatile fatty acids (VFA: acetic, propionic, butyric, isobutyric, valeric, isovaleric, hexanoic, and heptanoic acid), four aromatic compounds (phenol, 4-methylphenol, indole, and skatole), and two sulfur-containing VOCs (dimethyl disulfide and dimethyl trisulfide). Calibration and method detection limit (MDL) calculations were conducted as previously described (Parker et al., in press), and are presented in Table 1.

All data were analyzed as a Latin square with using the Mixed procedure of SAS (SAS Institute, 2008). The fixed effects of treatment (diet) and the random effects of steer and period were included in the model. Treatment means were separated using the pdiff option in SAS. Treatment effects were considered significant at P-value of ≤0.05, with tendencies declared at P-values between 0.05 and 0.10.

2.4. Odor activity value analyses

The idea of summing the individual OAVs to assess overall odor potential was initially proposed by Guadagni et al. (1963) and later by Leffingwell and Leffingwell (1991). The OAV is defined as the ratio of the concentration of a single compound to the odor threshold for that single compound (Parker et al., 2010; Trabue et al., 2006). Conceptually, the larger the OAV, the more likely that compound will contribute to the overall odor of a complex odor mixture. To assess the relative importance of each individual compound on odor, the concentrations of individual compounds were converted to their respective odor activity values (OAV) as described by Parker et al. (in press).

3. Results and discussion

3.1. Volatile organic compound flux

Flux of VOC from feces samples from cattle fed SFC-based diets with WDGS is presented in Table 2. Few differences were found in VOC flux across dietary treatments for variables with low precision, and sample size and animal numbers associated with the 4 x 4 Latin square design may have been inadequate to find a statistical difference. No differences in flux were detected across dietary treatments for phenol, indole, and skatole (P > 0.23); however, the lack of differences could be caused by the additional protein and fat in the diets through WDGS inclusion. Phenol is a product of tyrosine fermentation, whereas indole is the product of tryptophan metabolism (Mackie et al., 1998). Hawe et al. (1992) reported an increase in fecal excretion of indole by swine fed dried distillers grains, which is an expected result since the tryptophan

Table 1

<table>
<thead>
<tr>
<th>Compound</th>
<th>MW</th>
<th>Retention time (min)</th>
<th>Min (ng)</th>
<th>Max (ng)</th>
<th>MDL (ng)</th>
<th>MDLb (µg m⁻² min⁻¹)</th>
<th>RSDb</th>
<th>$r^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phenol</td>
<td>94.1</td>
<td>20.2</td>
<td>5.5</td>
<td>1105</td>
<td>6.0</td>
<td>0.44</td>
<td>0.14</td>
<td>0.99</td>
</tr>
<tr>
<td>4-methylphenol</td>
<td>108.1</td>
<td>21.1</td>
<td>5.2</td>
<td>1045</td>
<td>4.0</td>
<td>0.29</td>
<td>0.11</td>
<td>0.99</td>
</tr>
<tr>
<td>Indole</td>
<td>117.1</td>
<td>25.2</td>
<td>6.3</td>
<td>1283</td>
<td>3.5</td>
<td>0.25</td>
<td>0.09</td>
<td>0.99</td>
</tr>
<tr>
<td>Skatole</td>
<td>131.2</td>
<td>25.6</td>
<td>7.1</td>
<td>1444</td>
<td>4.8</td>
<td>0.35</td>
<td>0.12</td>
<td>0.94</td>
</tr>
<tr>
<td>Dimethyl disulfide</td>
<td>94.2</td>
<td>5.2</td>
<td>5.3</td>
<td>2742</td>
<td>1.0</td>
<td>0.07</td>
<td>0.04</td>
<td>0.99</td>
</tr>
<tr>
<td>Dimethyl trisulfide</td>
<td>126.2</td>
<td>11.0</td>
<td>5.9</td>
<td>3084</td>
<td>2.1</td>
<td>0.16</td>
<td>0.14</td>
<td>0.99</td>
</tr>
<tr>
<td>Acetic acid</td>
<td>60.0</td>
<td>12.4</td>
<td>8.0</td>
<td>2210</td>
<td>16.3</td>
<td>1.18</td>
<td>0.38</td>
<td>0.99</td>
</tr>
<tr>
<td>Proionic acid</td>
<td>74.1</td>
<td>13.8</td>
<td>7.5</td>
<td>2083</td>
<td>7.5</td>
<td>0.54</td>
<td>0.89</td>
<td>0.99</td>
</tr>
<tr>
<td>Isobutyric acid</td>
<td>88.1</td>
<td>14.2</td>
<td>7.3</td>
<td>2020</td>
<td>6.8</td>
<td>0.49</td>
<td>0.82</td>
<td>0.99</td>
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<tr>
<td>Butyric acid</td>
<td>88.1</td>
<td>15.1</td>
<td>7.3</td>
<td>2020</td>
<td>4.1</td>
<td>0.29</td>
<td>0.87</td>
<td>0.99</td>
</tr>
<tr>
<td>Isovaleric acid</td>
<td>102.1</td>
<td>15.7</td>
<td>7.1</td>
<td>1957</td>
<td>2.8</td>
<td>0.20</td>
<td>0.80</td>
<td>0.99</td>
</tr>
<tr>
<td>Valeric acid</td>
<td>102.1</td>
<td>16.7</td>
<td>7.1</td>
<td>1957</td>
<td>1.2</td>
<td>0.09</td>
<td>0.62</td>
<td>0.99</td>
</tr>
<tr>
<td>Hexanoic acid</td>
<td>116.2</td>
<td>18.1</td>
<td>7.0</td>
<td>1936</td>
<td>0.54</td>
<td>0.04</td>
<td>0.50</td>
<td>0.99</td>
</tr>
<tr>
<td>Heptanoic acid</td>
<td>130.2</td>
<td>19.5</td>
<td>7.0</td>
<td>1936</td>
<td>0.77</td>
<td>0.06</td>
<td>0.25</td>
<td>0.98</td>
</tr>
</tbody>
</table>

* Method detection limit (MDL) for flux based on 4 min sampling time with wind tunnel flow rate of 1 L min⁻¹.

b Relative standard deviation (RSD) of the mean from 7 replications at minimum mass analyzed.
concentration of dried distillers grains is approximately three times greater than corn grain. There were no differences in 4-methylphenol flux (P = 0.91) from feces of cattle fed increasing concentrations of WDGS. The majority of 4-methylphenol is typically excreted in the urine rather than the feces of livestock (Mackie et al., 1998). Dimethyl disulfide and dimethyl trisulfide flux in feces were not different across treatment (P > 0.35; Table 2), which is somewhat surprising since the sulfur concentration of WDGS is elevated as a result of sulfuric acid use in the ethanol process to clean and maintain pH (Klopfenstein et al., 2008). The flux of VFA such as acetic, propionic, isobutyric, butyric, isovaleric, and valeric were not different across treatment (P > 0.25). Volatile fatty acids generally comprise a large portion of the total VOC present in cattle manure; however acetic, propionic, and butyric have been reported to have a lower potential for odor than branched-chain and long-chain VFA (Spiehs and Varel, 2009; Hales et al., in press). Miller and Varel (2001) reported that isobutyrate was present after four days of incubation in aged manure slurries, but no branched-chain VFA were detected in fresh manure slurries. Although not significant (P = 0.55) isobutyric acid was present in aged feces, which is plausible because isobutyrate is decarboxylated after the deamination of valine (Mackie et al., 1998). Odors of isobutyrate and isovalerate are typically considered less offensive than other VFA (Miller and Varel, 2001). Spiehs and Varel (2009) and Varel et al. (2010) reported that total VFA concentration in the feces corresponded with a decrease in WDGS in the diet. The results of the current experiment would suggest that there is no increase in the flux of odorous compounds when increasing concentrations of WDGS are fed, and the likely reason is the difference in corn processing methods used in each study. In the current study, the corn was steam-flaked in which the starch is more ruminable digestible and in the case of Varel et al. (2010) the corn was either dry-rolled or preserved as high-moisture corn, which leads to a higher starch concentration in the feces and a greater fermentation potential (Hales et al., in press). In the present experiment, differences in flux of hexanoic and heptanoic acid were not detected (P > 0.25). This is not surprising since the concentrations of these VOC are often reported to be very low in cattle feces irrespective of the type of diet fed (Hales et al., in press).

Flux from urine samples from cattle fed diets including WDGS are presented in Table 3. There were no differences in flux of phenol, indole, skatole, dimethyl trisulfide, acetic, propionic, isobutyric, butyric, isovaleric, valeric, hexanoic or heptanoic (P > 0.24). However, there were no differences in the flux of 4-methylphenol (P = 0.63). A majority of the phenols excreted by livestock species are present in the urine as 4-methylphenol (Mackie et al., 1998;
Hales et al., in press). Generally, as the protein concentration of the diet increases, urinary 4-methylphenol excretion also increases as a result of amino acid fermentation in the lower gut (Mackie et al., 1998; Hales et al., in press). Therefore, a greater urinary 4-methylphenol flux in cattle fed 30 and 45% WDGS was expected because of the greater protein concentration in these diets compared to the 0 and 15% WDGS diets. There was a tendency for dimethyl disulfide flux to be greater for cattle consuming the SFC-based diet with 15% WDGS than the other diets \( (P = 0.10) \). The reason for this is not clear, especially because this tendency was observed in a diet with a lower concentration of WDGS. Other researchers have reported a 4-methylphenol increase in diets based on SFC with 0 or 15% WDGS from days 0 to 4 of an incubation (Hales et al., in press); however, feces and urine were mixed together in a slurry unlike the current experiment where they were analyzed for flux separately. To our knowledge, changes in VOC and VFA flux as a result of feeding WDGS in an SFC-based diet to finishing cattle has not been previously reported in the literature, therefore comparison with other data is limited.

### 3.2. Odor activity value

Odor activity values for feces and urine are presented in Tables 4 and 5, respectively. For feces, there were no differences in OAV across dietary treatments \( (P > 0.20; \text{Table 4.}) \). For urine, dimethyl disulfide was the only compound with a tendency for differences in OAV across dietary treatments \( (P = 0.09) \). Interestingly, the SFC-15 diet had the greatest OAV, although this diet had a lower concentration of sulfur (data not presented) than the SFC-30 or SFC-45. The sulfur concentration in WDGS is increased in the diet from 0 to 45%, the sulfur concentration is also increased beyond the animal requirement (NRC, 1996). The elevated OAV in the SFC-15 diet also corresponds to an elevated flux presented in Table 3. All other compounds evaluated had no differences \( (P > 0.20; \text{Table 5}) \) in OAV.

The summed OAV in the feces for all treatments was 220.0. The compounds with the highest OAV in feces were 4-methylphenol and butyric acid, with mean OAVs of 148.0 and 26.2 (Table 4). These two compounds accounted for 67.3 and 11.9% of the summed OAV, respectively. Pungent odor associated with butyric acid is sometimes reported from silage that has experienced a secondary fermentation in which clostridia ferments lactic acid to butyric acid (Bolsen, 1995). The two sulfide compounds accounted for 6.8% of the summed OAV in the feces. Collectively, the eight VFAs accounted for 18.9% of the summed OAV in the feces.

The summed OAV in the urine was 659.5, of which 4-methylphenol accounted for 97.6\% (Table 5). The two sulfide compounds and the eight VFAs accounted for 1.1% and 0.9% of the summed OAV, respectively.

Phenol and 4-methylphenol had higher OAV in the urine than feces. Despite 10 of the 12 compounds having higher OAV in the feces, the summed OAV was three times higher in the urine than feces (Fig. 2). This was due to the fact that the mean OAV for 4-methylphenol in urine was 643.6, compared to 148.0 in feces. The compound 4-methylphenol alone accounted for 97.6% of the summed OAV in the urine, and 67.3% of the summed OAV in the feces.

Others have reported that 4-methylphenol was the dominant odorant in animal manure. For example, Parker et al. (in press) reported that 4–methylphenol accounted for 79.5% of the summed OAV in land applied swine manure slurry. Using multidimensional gas chromatography-olfactometry-mass spectrometry and solid-phase microextraction, Wright et al. (2005) determined...

Table 4

<table>
<thead>
<tr>
<th>Item</th>
<th>Treatment ( ^a )</th>
<th>P-value ( ^b )</th>
<th>SE ( ^c )</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>SFC-0</td>
<td>SFC-15</td>
<td>SFC-30</td>
</tr>
<tr>
<td>Phenol</td>
<td>0.17</td>
<td>0.16</td>
<td>0.18</td>
</tr>
<tr>
<td>4-methylphenol</td>
<td>146.63</td>
<td>122.87</td>
<td>174.11</td>
</tr>
<tr>
<td>Indole</td>
<td>3.92</td>
<td>3.90</td>
<td>3.91</td>
</tr>
<tr>
<td>Skatole</td>
<td>6.99</td>
<td>8.21</td>
<td>27.62</td>
</tr>
<tr>
<td>Dimethyl disulfide</td>
<td>7.51</td>
<td>10.09</td>
<td>3.32</td>
</tr>
<tr>
<td>Dimethyl trisulfide</td>
<td>8.07</td>
<td>14.29</td>
<td>4.63</td>
</tr>
<tr>
<td>Acetic acid</td>
<td>0.94</td>
<td>0.94</td>
<td>0.62</td>
</tr>
<tr>
<td>Propionic acid</td>
<td>4.43</td>
<td>3.78</td>
<td>1.58</td>
</tr>
<tr>
<td>Isobutyric acid</td>
<td>1.21</td>
<td>1.27</td>
<td>0.65</td>
</tr>
<tr>
<td>Butyric acid</td>
<td>35.34</td>
<td>30.88</td>
<td>11.93</td>
</tr>
<tr>
<td>Isovaleric acid</td>
<td>9.35</td>
<td>7.71</td>
<td>4.66</td>
</tr>
<tr>
<td>Valeric acid</td>
<td>3.08</td>
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<td>1.37</td>
</tr>
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<td>Hexanoic acid</td>
<td>0.10</td>
<td>0.07</td>
<td>0.06</td>
</tr>
<tr>
<td>Heptanoic acid</td>
<td>0.07</td>
<td>0.05</td>
<td>0.06</td>
</tr>
</tbody>
</table>

\( ^a \) Corn grain was processed by steam flaking with a wet distillers grains and solubles concentration of 0, 15, 30, or 45% of dietary dry matter.

\( ^b \) Observed significance level for dietary treatment.

\( ^c \) Pooled standard error of main-effect means (\( n = 4 \)).
that 4-methylphenol was the only dominant odorant at a distance 2000 m downwind of a commercial beef cattle feedlot in Texas. In contrast, Trabue et al. (2008) reported that butyric acid accounted for the most OAV (35.2%) in the exhaust from a swine finishing building with a pull-plug waste management system, followed closely by indole (22.9%) and 4-methylphenol (22.2%).

It should be noted that one of the arguments against the use of the summed OAVs, and OAV in general, is that it does not account for possible synergistic or other complex interactive effects. Other researchers have acknowledged the importance of synergistic and antagonistic effects on individual odorous chemicals (DiSpirito et al., 1994; Zahn et al., 2001).

4. Conclusions

There were no differences in VOC emissions from feces or urine of cattle fed SFC-based diets with 0, 15, 30, or 45% WDGS ($P > 0.20$). With the exception of dimethyl disulfide, there were no differences in VOC emissions from urine of cattle fed these same diets ($P > 0.20$). Emissions of dimethyl disulfide were highest from the urine of cattle fed 15% WDGS ($P = 0.08$).

Based on the OAV analyses, a single compound (4-methylphenol) was most responsible for odor from cattle urine, accounting for 97.6% of summed OAV. Both 4-methylphenol and butyric acid contributed to odor from cattle feces. The summed OAV was three times higher from urine than feces.

This research has implications for the treatment of manure for odor reduction. Feeding strategies that focus on the reduction of the single odorant 4-methylphenol might have promise for odor reduction from both urine and feces. Based on this research, with the exception of dimethyl sulfide, there was little indication that feeding of WDGS affects the flux of VOC or other odorous compounds, with the exception of 4-methylphenol, from beef cattle feedlots.

References


