Comparison of treatments - CH4, NH3, CO2 with select approaches only

Sasha D. Hafner and Frederik Dalby

15 februar, 2023

Purpose

Compare different slurry handling systems in terms of methane emission.

Prep

```
rm(list = ls())

source('../functions/rbindf.R')
source('../functions/dfcombos.R')
source('../functions/ggsave2x.R')

library('DescTools')
library('dplyr')
library('tidyr')
library('readxl')
library('multcomp')
library('ggplot2')
library('FSA')

sessionInfo()
```

```
## R version 4.2.2 (2022-10-31 ucrt)
## Platform: x86_64-w64-mingw32/x64 (64-bit)
## Running under: Windows 10 x64 (build 19044)
##
## Matrix products: default
##
## locale:
## [1] LC_COLLATE=Danish_Denmark.utf8  LC_CTYPE=Danish_Denmark.utf8    LC_MONETARY=Danish_Denmark.utf8
## [4] LC_NUMERIC=C                    LC_TIME=Danish_Denmark.utf8
##
## attached base packages:
## [1] stats     graphics  grDevices utils     datasets  methods   base
##
## other attached packages:
```

```
##  [1] ggplot2_3.4.0     multcomp_1.4-20   TH.data_1.1-1     MASS_7.3-58.1     survival_3.4-0    mvtnor
##  [7] readxl_1.4.1      tidyr_1.2.1       dplyr_1.0.10      DescTools_0.99.47 FSA_0.9.4         rmarkd
##
## loaded via a namespace (and not attached):
##  [1] tinytex_0.43      zoo_1.8-11        tidyselect_1.2.0  xfun_0.36         purrr_1.0.0       splin
##  [7] lattice_0.20-45   colorspace_2.0-3  vctrs_0.5.1       generics_0.1.3    expm_0.999-6      htmlt
## [13] yaml_2.3.6        utf8_1.2.2        rlang_1.0.6       e1071_1.7-12      pillar_1.8.1      withr
## [19] glue_1.6.2        DBI_1.1.3         rootSolve_1.8.2.3 lifecycle_1.0.3   stringr_1.5.0     munse
## [25] gtable_0.3.1      cellranger_1.1.0  codetools_0.2-18  evaluate_0.19     labeling_0.4.2    knitr
## [31] fastmap_1.1.0     lmom_2.9          class_7.3-20      fansi_1.0.3       highr_0.10        Rcpp_
## [37] scales_1.2.1      farver_2.1.1      gld_2.6.6         Exact_3.2         digest_0.6.31     strin
## [43] grid_4.2.2        cli_3.5.0         tools_4.2.2       sandwich_3.0-2    magrittr_2.0.3    proxy
## [49] tibble_3.1.8      pkgconfig_2.0.3   Matrix_1.5-1      data.table_1.14.6 assertthat_0.2.1  httr_
## [55] rstudioapi_0.14   R6_2.5.1          boot_1.3-28       compiler_4.2.2
```

Measurement data

Get stacked data with high-resolution measurements. Calculate mean emission rate by period.

```
dat <- read.csv('../data/dat_stacked.csv')

emis_dat <- summarise(group_by(dat, period, treatment),
                      mean_CH4_barn = mean(CH4_rate/pigs, na.rm = T),
                      mean_CH4_slurry = mean(CH4_emis_rate/pigs, na.rm = T),
                      mean_NH3_barn = mean(NH3_emis_rate/pigs, na.rm = T),
                      mean_CO2_barn = mean(CO2E, na.rm = T),
                      mean_CO2_slurry = mean(CO2_emis_rate, na.rm = T))
```

```
## `summarise()` has grouped output by 'period'. You can override using the `.groups` argument.
```

```
emis_dat$treatment <- factor(emis_dat$treatment)
```

Analysis

Loop through all variables, fit models, print results. Crude and a lot of pages. . .

```
for (y in c('mean_CH4_barn', 'mean_CH4_slurry', 'mean_NH3_barn', 'mean_CO2_barn', 'mean_CO2_slurry')) {
  cat('\n')
  cat('\n', rep(c(y, '\n'), 4), '\n')
  cat('\n')

  emis_dat$y <- emis_dat[, y, drop = TRUE]

  m2 <- aov(log10(y) ~ factor(period) + treatment, data = emis_dat)
  d2 <- glht(m2, linfct = mcp(treatment = "Dunnett"))

  cat('Transformed aov summary:\n')
  print(summary(m2))
  cat('\n', rep(c(y, '\n'), 4), '\n')
  cat('Transformed lm summary:\n')
```

```
  print(summary.lm(m2))
  cat('\n', rep(c(y, '\n'), 4), '\n')
  cat('Transformed Dunnetts test:\n')
  print(summary(d2))
  cat('\n', rep(c(y, '\n'), 4), '\n')
  cat('Transformed confidence intervals:\n')
  print(100 * (10^confint(m2) - 1))

  cat('\n', rep(c(y, '\n'), 4), '\n')
  cat('Transformed relative reduction (coef):\n')
  print(round(100 * (10^coef(m2)[-1:-2] - 1), 1))

  cat('\n\n')
  cat('\n', rep(paste('end', y), 3), '\n')
  cat('\n')

}
```

```
##
##
##  mean_CH4_barn
##  mean_CH4_barn
##  mean_CH4_barn
##  mean_CH4_barn
##
##
## Transformed aov summary:
##                Df Sum Sq Mean Sq F value   Pr(>F)
## factor(period)  3 0.0276 0.00919   1.649    0.246
## treatment       3 0.4397 0.14657  26.295 8.71e-05 ***
## Residuals       9 0.0502 0.00557
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
## 4 observations deleted due to missingness
##
##  mean_CH4_barn
##  mean_CH4_barn
##  mean_CH4_barn
##  mean_CH4_barn
##
## Transformed lm summary:
##
## Call:
## aov(formula = log10(y) ~ factor(period) + treatment, data = emis_dat)
##
## Residuals:
##       Min        1Q    Median        3Q       Max
## -0.102154 -0.039526 -0.002392  0.032105  0.091454
##
## Coefficients:
##                           Estimate Std. Error t value Pr(>|t|)
## (Intercept)                0.86010    0.04938  17.417 3.06e-08 ***
## factor(period)2            0.01949    0.05279   0.369  0.72057
```

```
## factor(period)3           -0.04276    0.05279  -0.810  0.43886
## factor(period)4           -0.08831    0.05279  -1.673  0.12869
## treatmentfrequentflushing -0.19613    0.05279  -3.715  0.00481 **
## treatmentslurryfunnels    -0.42879    0.05279  -8.122 1.96e-05 ***
## treatmentslurrytrays      -0.36226    0.05279  -6.862 7.37e-05 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 0.07466 on 9 degrees of freedom
##   (4 observations deleted due to missingness)
## Multiple R-squared:  0.9031, Adjusted R-squared:  0.8384
## F-statistic: 13.97 on 6 and 9 DF,  p-value: 0.0004169
##
##
##  mean_CH4_barn
##  mean_CH4_barn
##  mean_CH4_barn
##  mean_CH4_barn
##
## Transformed Dunnetts test:
##
##   Simultaneous Tests for General Linear Hypotheses
##
## Multiple Comparisons of Means: Dunnett Contrasts
##
##
## Fit: aov(formula = log10(y) ~ factor(period) + treatment, data = emis_dat)
##
## Linear Hypotheses:
##                                 Estimate Std. Error t value Pr(>|t|)
## frequentflushing - control == 0 -0.19613    0.05279  -3.715   0.0121 *
## slurryfunnels - control == 0    -0.42879    0.05279  -8.122   <0.001 ***
## slurrytrays - control == 0      -0.36226    0.05279  -6.862   <0.001 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
## (Adjusted p values reported -- single-step method)
##
##
##  mean_CH4_barn
##  mean_CH4_barn
##  mean_CH4_barn
##  mean_CH4_barn
##
## Transformed confidence intervals:
##                                2.5 %     97.5 %
## (Intercept)               460.25781 837.156194
## factor(period)2           -20.55591  37.693033
## factor(period)3           -31.16405  19.306934
## factor(period)4           -38.01840   7.426925
## treatmentfrequentflushing -51.64433 -16.189624
## treatmentslurryfunnels    -71.69999 -50.950230
## treatmentslurrytrays      -67.01512 -42.830377
##
##  mean_CH4_barn
```

```
##  mean_CH4_barn
##  mean_CH4_barn
##  mean_CH4_barn
##
## Transformed relative reduction (coef):
##           factor(period)3           factor(period)4 treatmentfrequentflushing    treatmentslurryfunne
##                      -9.4                     -18.4                     -36.3                      -61
##      treatmentslurrytrays
##                     -56.6
##
##
##
##  end mean_CH4_barn end mean_CH4_barn end mean_CH4_barn
##
##
##
##  mean_CH4_slurry
##  mean_CH4_slurry
##  mean_CH4_slurry
##  mean_CH4_slurry
##
##
## Transformed aov summary:
##                Df Sum Sq Mean Sq F value   Pr(>F)
## factor(period)  3 0.1753  0.0584   1.645 0.247169
## treatment       3 2.4274  0.8091  22.784 0.000154 ***
## Residuals       9 0.3196  0.0355
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
## 4 observations deleted due to missingness
##
##  mean_CH4_slurry
##  mean_CH4_slurry
##  mean_CH4_slurry
##  mean_CH4_slurry
##
## Transformed lm summary:
##
## Call:
## aov(formula = log10(y) ~ factor(period) + treatment, data = emis_dat)
##
## Residuals:
##       Min        1Q    Median        3Q       Max
## -0.286000 -0.112487  0.001559  0.122449  0.208276
##
## Coefficients:
##                            Estimate Std. Error t value Pr(>|t|)
## (Intercept)                  0.8369     0.1246   6.714 8.71e-05 ***
## factor(period)2             -0.1602     0.1333  -1.202 0.259872
## factor(period)3             -0.1996     0.1333  -1.498 0.168306
## factor(period)4             -0.2891     0.1333  -2.169 0.058165 .
## treatmentfrequentflushing   -0.3109     0.1333  -2.333 0.044532 *
## treatmentslurryfunnels      -1.0124     0.1333  -7.597 3.34e-05 ***
## treatmentslurrytrays        -0.7443     0.1333  -5.586 0.000341 ***
```

```
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 0.1885 on 9 degrees of freedom
##   (4 observations deleted due to missingness)
## Multiple R-squared:  0.8906, Adjusted R-squared:  0.8177
## F-statistic: 12.21 on 6 and 9 DF,  p-value: 0.0007015
##
##
##  mean_CH4_slurry
##  mean_CH4_slurry
##  mean_CH4_slurry
##  mean_CH4_slurry
##
## Transformed Dunnetts test:
##
##   Simultaneous Tests for General Linear Hypotheses
##
## Multiple Comparisons of Means: Dunnett Contrasts
##
##
## Fit: aov(formula = log10(y) ~ factor(period) + treatment, data = emis_dat)
##
## Linear Hypotheses:
##                                  Estimate Std. Error t value Pr(>|t|)
## frequentflushing - control == 0  -0.3109     0.1333  -2.333  0.10566
## slurryfunnels - control == 0     -1.0124     0.1333  -7.597  < 0.001 ***
## slurrytrays - control == 0       -0.7443     0.1333  -5.586  0.00112 **
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
## (Adjusted p values reported -- single-step method)
##
##
##  mean_CH4_slurry
##  mean_CH4_slurry
##  mean_CH4_slurry
##  mean_CH4_slurry
##
## Transformed confidence intervals:
##                                 2.5 %      97.5 %
## (Intercept)                258.87112 1214.877580
## factor(period)2            -65.45962   38.424082
## factor(period)3            -68.45616   26.415147
## factor(period)4            -74.32746    2.885281
## treatmentfrequentflushing -75.58357   -2.148700
## treatmentslurryfunnels    -95.14531  -80.544331
## treatmentslurrytrays      -90.99974  -63.930547
##
##  mean_CH4_slurry
##  mean_CH4_slurry
##  mean_CH4_slurry
##  mean_CH4_slurry
##
## Transformed relative reduction (coef):
```

```
##           factor(period)3           factor(period)4 treatmentfrequentflushing    treatmentslurryfunne
##                     -36.9                     -48.6                     -51.1                      -9
##     treatmentslurrytrays
##                     -82.0
##
##
##
##  end mean_CH4_slurry end mean_CH4_slurry end mean_CH4_slurry
##
##
##
##  mean_NH3_barn
##  mean_NH3_barn
##  mean_NH3_barn
##  mean_NH3_barn
##
##
## Transformed aov summary:
##                Df  Sum Sq Mean Sq F value  Pr(>F)
## factor(period)  3 0.16370 0.05457   9.378 0.00393 **
## treatment       3 0.20644 0.06881  11.826 0.00178 **
## Residuals       9 0.05237 0.00582
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
## 4 observations deleted due to missingness
##
##  mean_NH3_barn
##  mean_NH3_barn
##  mean_NH3_barn
##  mean_NH3_barn
##
## Transformed lm summary:
##
## Call:
## aov(formula = log10(y) ~ factor(period) + treatment, data = emis_dat)
##
## Residuals:
##       Min        1Q    Median        3Q       Max
## -0.102192 -0.047033  0.001905  0.026331  0.141972
##
## Coefficients:
##                           Estimate Std. Error t value Pr(>|t|)
## (Intercept)                0.82837    0.05045  16.418 5.14e-08 ***
## factor(period)2           -0.12362    0.05394  -2.292 0.047632 *
## factor(period)3           -0.26402    0.05394  -4.895 0.000854 ***
## factor(period)4           -0.21883    0.05394  -4.057 0.002855 **
## treatmentfrequentflushing  0.10859    0.05394   2.013 0.074939 .
## treatmentslurryfunnels    -0.15296    0.05394  -2.836 0.019534 *
## treatmentslurrytrays      -0.16569    0.05394  -3.072 0.013315 *
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 0.07628 on 9 degrees of freedom
##   (4 observations deleted due to missingness)
```

```
## Multiple R-squared:  0.8761, Adjusted R-squared:  0.7934
## F-statistic:  10.6 on 6 and 9 DF,  p-value: 0.0012
##
##
##  mean_NH3_barn
##  mean_NH3_barn
##  mean_NH3_barn
##  mean_NH3_barn
##
## Transformed Dunnetts test:
##
##   Simultaneous Tests for General Linear Hypotheses
##
## Multiple Comparisons of Means: Dunnett Contrasts
##
##
## Fit: aov(formula = log10(y) ~ factor(period) + treatment, data = emis_dat)
##
## Linear Hypotheses:
##                                  Estimate Std. Error t value Pr(>|t|)
## frequentflushing - control == 0  0.10859    0.05394   2.013   0.1725
## slurryfunnels - control == 0    -0.15296    0.05394  -2.836   0.0479 *
## slurrytrays - control == 0      -0.16569    0.05394  -3.072   0.0332 *
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
## (Adjusted p values reported -- single-step method)
##
##
##  mean_NH3_barn
##  mean_NH3_barn
##  mean_NH3_barn
##  mean_NH3_barn
##
## Transformed confidence intervals:
##                                  2.5 %      97.5 %
## (Intercept)                417.885107 775.9997438
## factor(period)2            -43.197430  -0.3678552
## factor(period)3            -58.888805 -27.8906482
## factor(period)4            -54.379605 -19.9814771
## treatmentfrequentflushing   -3.044583  70.0605452
## treatmentslurryfunnels     -46.908681  -6.8774180
## treatmentslurrytrays       -48.441838  -9.5665878
##
##  mean_NH3_barn
##  mean_NH3_barn
##  mean_NH3_barn
##  mean_NH3_barn
##
## Transformed relative reduction (coef):
##           factor(period)3           factor(period)4 treatmentfrequentflushing    treatmentslurryfunne
##                     -45.6                     -39.6                      28.4                      -29
##      treatmentslurrytrays
##                     -31.7
##
```

```
##
##
##  end mean_NH3_barn end mean_NH3_barn end mean_NH3_barn
##
##
##
##  mean_CO2_barn
##  mean_CO2_barn
##  mean_CO2_barn
##  mean_CO2_barn
##
##
## Transformed aov summary:
##                Df   Sum Sq  Mean Sq F value Pr(>F)
## factor(period)  3 0.005206 0.001736   1.563  0.265
## treatment       3 0.005640 0.001880   1.693  0.237
## Residuals       9 0.009993 0.001110
## 4 observations deleted due to missingness
##
##  mean_CO2_barn
##  mean_CO2_barn
##  mean_CO2_barn
##  mean_CO2_barn
##
## Transformed lm summary:
##
## Call:
## aov(formula = log10(y) ~ factor(period) + treatment, data = emis_dat)
##
## Residuals:
##       Min        1Q    Median        3Q       Max
## -0.043025 -0.014750  0.000852  0.013497  0.043762
##
## Coefficients:
##                            Estimate Std. Error t value Pr(>|t|)
## (Intercept)                 3.28390    0.02204 148.994   <2e-16 ***
## factor(period)2            -0.03678    0.02356  -1.561   0.1530
## factor(period)3            -0.04633    0.02356  -1.966   0.0808 .
## factor(period)4            -0.01587    0.02356  -0.674   0.5174
## treatmentfrequentflushing   0.03308    0.02356   1.404   0.1939
## treatmentslurryfunnels     -0.01475    0.02356  -0.626   0.5468
## treatmentslurrytrays       -0.01062    0.02356  -0.451   0.6628
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 0.03332 on 9 degrees of freedom
##   (4 observations deleted due to missingness)
## Multiple R-squared:  0.5205, Adjusted R-squared:  0.2008
## F-statistic: 1.628 on 6 and 9 DF,  p-value: 0.2451
##
##
##  mean_CO2_barn
##  mean_CO2_barn
##  mean_CO2_barn
```

```
##  mean_CO2_barn
##
## Transformed Dunnetts test:
##
##   Simultaneous Tests for General Linear Hypotheses
##
## Multiple Comparisons of Means: Dunnett Contrasts
##
##
## Fit: aov(formula = log10(y) ~ factor(period) + treatment, data = emis_dat)
##
## Linear Hypotheses:
##                                 Estimate Std. Error t value Pr(>|t|)
## frequentflushing - control == 0  0.03308    0.02356   1.404    0.405
## slurryfunnels - control == 0    -0.01475    0.02356  -0.626    0.866
## slurrytrays - control == 0      -0.01062    0.02356  -0.451    0.941
## (Adjusted p values reported -- single-step method)
##
##
##  mean_CO2_barn
##  mean_CO2_barn
##  mean_CO2_barn
##  mean_CO2_barn
##
## Transformed confidence intervals:
##                                   2.5 %       97.5 %
## (Intercept)               171310.927768 2.155536e+05
## factor(period)2              -18.732086 3.877700e+00
## factor(period)3              -20.499137 1.619034e+00
## factor(period)4              -14.724380 9.000402e+00
## treatmentfrequentflushing     -4.549047 2.200665e+01
## treatmentslurryfunnels       -14.504227 9.281805e+00
## treatmentslurrytrays         -13.687076 1.032630e+01
##
##  mean_CO2_barn
##  mean_CO2_barn
##  mean_CO2_barn
##  mean_CO2_barn
##
## Transformed relative reduction (coef):
##           factor(period)3           factor(period)4 treatmentfrequentflushing    treatmentslurryfunne
##                     -10.1                     -3.6                       7.9                       -3
##     treatmentslurrytrays
##                      -2.4
##
##
##
##  end mean_CO2_barn end mean_CO2_barn end mean_CO2_barn
##
##
##
##  mean_CO2_slurry
##  mean_CO2_slurry
##  mean_CO2_slurry
```

```
##  mean_CO2_slurry
##

## Warning in eval(predvars, data, env): NaNs produced

## Transformed aov summary:
##                Df Sum Sq Mean Sq F value Pr(>F)
## factor(period)  3 0.1472 0.04908   2.132  0.174
## treatment       3 0.1642 0.05473   2.377  0.146
## Residuals       8 0.1842 0.02302
## 5 observations deleted due to missingness
##
##  mean_CO2_slurry
##  mean_CO2_slurry
##  mean_CO2_slurry
##  mean_CO2_slurry
##
## Transformed lm summary:
##
## Call:
## aov(formula = log10(y) ~ factor(period) + treatment, data = emis_dat)
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -0.18531 -0.09133 -0.02469  0.10005  0.18567
##
## Coefficients:
##                            Estimate Std. Error t value Pr(>|t|)
## (Intercept)                 2.56610    0.10115  25.370 6.24e-09 ***
## factor(period)2            -0.25049    0.10728  -2.335   0.0478 *
## factor(period)3            -0.22894    0.11861  -1.930   0.0897 .
## factor(period)4            -0.15958    0.10728  -1.487   0.1752
## treatmentfrequentflushing   0.18967    0.10728   1.768   0.1151
## treatmentslurryfunnels     -0.09050    0.10728  -0.844   0.4234
## treatmentslurrytrays        0.01625    0.11861   0.137   0.8944
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 0.1517 on 8 degrees of freedom
##   (5 observations deleted due to missingness)
## Multiple R-squared:  0.6284, Adjusted R-squared:  0.3497
## F-statistic: 2.255 on 6 and 8 DF,  p-value: 0.1423
##
##
##  mean_CO2_slurry
##  mean_CO2_slurry
##  mean_CO2_slurry
##  mean_CO2_slurry
##
## Transformed Dunnetts test:
##
##   Simultaneous Tests for General Linear Hypotheses
##
## Multiple Comparisons of Means: Dunnett Contrasts
```

```
##
##
## Fit: aov(formula = log10(y) ~ factor(period) + treatment, data = emis_dat)
##
## Linear Hypotheses:
##                                  Estimate Std. Error t value Pr(>|t|)
## frequentflushing - control == 0  0.18967    0.10728   1.768    0.257
## slurryfunnels - control == 0    -0.09050    0.10728  -0.844    0.747
## slurrytrays - control == 0       0.01625    0.11861   0.137    0.998
## (Adjusted p values reported -- single-step method)
##
##
##  mean_CO2_slurry
##  mean_CO2_slurry
##  mean_CO2_slurry
##  mean_CO2_slurry
##
## Transformed confidence intervals:
##                                 2.5 %        97.5 %
## (Intercept)               21420.44490 62901.3733373
## factor(period)2             -68.22298    -0.7090115
## factor(period)3             -68.55520    10.8069761
## factor(period)4             -60.82376    22.4107039
## treatmentfrequentflushing   -12.44678   173.5701917
## treatmentslurryfunnels      -54.06948    43.5152359
## treatmentslurrytrays        -44.69744    94.8783290
##
##  mean_CO2_slurry
##  mean_CO2_slurry
##  mean_CO2_slurry
##  mean_CO2_slurry
##
## Transformed relative reduction (coef):
##           factor(period)3           factor(period)4 treatmentfrequentflushing    treatmentslurryfunne
##                     -41.0                     -30.7                      54.8                      -18
##      treatmentslurrytrays
##                       3.8
##
##
##
##  end mean_CO2_slurry end mean_CO2_slurry end mean_CO2_slurry
```