GHG emission period ANOVAs

Zhang Zhenglin

Contents

Necessary libraries

```
library(knitr)
library(ggplot2)
theme_set(theme_bw())
library(emmeans)
library(multcomp)
library(PLS205)
library(lme4)
library(lmerTest)
library(multcompView)
library(car)
library(Rmisc)
library(dplyr) #https://r4ds.had.co.nz/ (Chapter 3, Chapter 5, look at filter and select)
# https://bookdown.org/ansellbr/WEHI_tidyR_course_book/
library(stringr)
library(data.table)
library(GGally)
library(formatR)
library(readxl)
library(openxlsx)
```

Data Organisation

Read from excel

```
#read directly from the directory where I generated the files from
master <- read_excel("D:/Academics/UC Davis/School Work/Linquist Lab/Data/R stats/GHG and MAOM POM/Seas
str(master)
```

```
## tibble [42 x 10] (S3: tbl_df/tbl/data.frame)
##  $ Plot                  : chr [1:42] "106" "107" "204" "209" ...
##  $ total_CH4_emissions   : num [1:42] 209255 386325 336023 447950 245630 ...
##  $ total_N2O_emissions   : num [1:42] 0 16.9 0 24.2 0 ...
##  $ Period_Year           : chr [1:42] "Summer_2021" "Summer_2021" "Summer_2021" "Summer_2021" ...
##  $ Period                : chr [1:42] "Summer" "Summer" "Summer" "Summer" ...
##  $ Treatment             : chr [1:42] "FR" "CR" "FR" "CR" ...
##  $ GWP                   : num [1:42] 5859128 10821585 9408655 12549014 6877636 ...
##  $ GWP_kg_CO2            : num [1:42] 5859 10822 9409 12549 6878 ...
##  $ total_CH4_emissions_kg: num [1:42] 209 386 336 448 246 ...
##  $ total_N2O_emissions_kg: num [1:42] 0 0.0169 0 0.0242 0 ...
```

Change variable type

```
#add in block
#first character in the plot number refers to blk
#master <- master %>% mutate(Blk = substr(Plot, 1, 1))
```

```r
master <- mutate_if(master, is.character, as.factor)

str(master)
```

```
## tibble [42 x 10] (S3: tbl_df/tbl/data.frame)
##  $ Plot                  : Factor w/ 19 levels "106","107","204",..: 1 2 3 4 5 6 7 8 9 10 ...
##  $ total_CH4_emissions   : num [1:42] 209255 386325 336023 447950 245630 ...
##  $ total_N2O_emissions   : num [1:42] 0 16.9 0 24.2 0 ...
##  $ Period_Year           : Factor w/ 5 levels "Summer_2021",..: 1 1 1 1 1 1 2 2 2 2 ...
##  $ Period                : Factor w/ 2 levels "Summer","Winter": 1 1 1 1 1 1 1 1 1 1 ...
##  $ Treatment             : Factor w/ 3 levels "CR","F","FR": 3 1 3 1 3 1 3 1 3 1 ...
##  $ GWP                   : num [1:42] 5859128 10821585 9408655 12549014 6877636 ...
##  $ GWP_kg_CO2            : num [1:42] 5859 10822 9409 12549 6878 ...
##  $ total_CH4_emissions_kg: num [1:42] 209 386 336 448 246 ...
##  $ total_N2O_emissions_kg: num [1:42] 0 0.0169 0 0.0242 0 ...
```

```r
table(master$Period)
```

```
##
## Summer Winter
##     24     18
```

Organise into summer and winter

```r
Summer <- master %>%
  filter (Period == "Summer")

Winter <- master %>%
  filter (Period == "Winter")

str(Summer)
```

```
## tibble [24 x 10] (S3: tbl_df/tbl/data.frame)
##  $ Plot                  : Factor w/ 19 levels "106","107","204",..: 1 2 3 4 5 6 7 8 9 10 ...
##  $ total_CH4_emissions   : num [1:24] 209255 386325 336023 447950 245630 ...
##  $ total_N2O_emissions   : num [1:24] 0 16.9 0 24.2 0 ...
##  $ Period_Year           : Factor w/ 5 levels "Summer_2021",..: 1 1 1 1 1 1 2 2 2 2 ...
##  $ Period                : Factor w/ 2 levels "Summer","Winter": 1 1 1 1 1 1 1 1 1 1 ...
##  $ Treatment             : Factor w/ 3 levels "CR","F","FR": 3 1 3 1 3 1 3 1 3 1 ...
##  $ GWP                   : num [1:24] 5859128 10821585 9408655 12549014 6877636 ...
##  $ GWP_kg_CO2            : num [1:24] 5859 10822 9409 12549 6878 ...
##  $ total_CH4_emissions_kg: num [1:24] 209 386 336 448 246 ...
##  $ total_N2O_emissions_kg: num [1:24] 0 0.0169 0 0.0242 0 ...
```

```r
str(Winter)
```

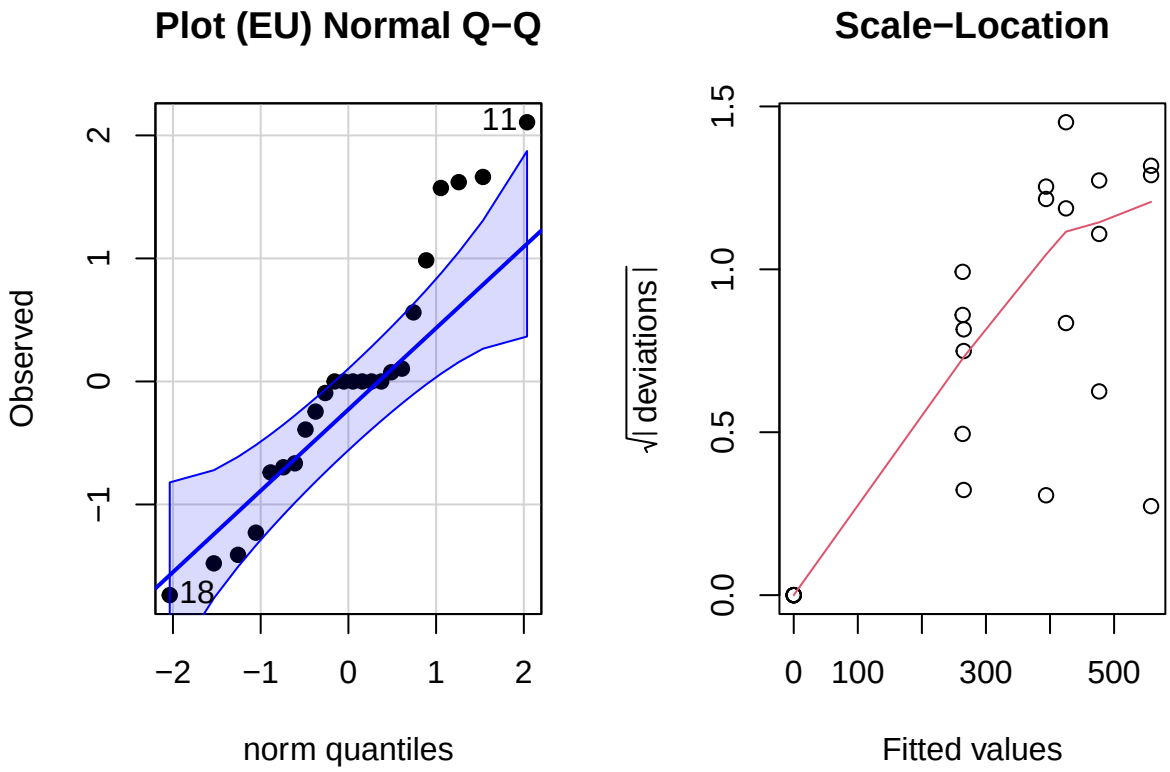
```
## tibble [18 x 10] (S3: tbl_df/tbl/data.frame)
##  $ Plot                  : Factor w/ 19 levels "106","107","204",..: 1 2 3 4 5 6 7 8 9 10 ...
```

```
##  $ total_CH4_emissions   : num [1:18] 3448 22050 11589.6 19900.6 -46.8 ...
##  $ total_N2O_emissions   : num [1:18] -456 0 746 0 327 ...
##  $ Period_Year           : Factor w/ 5 levels "Summer_2021",..: 4 4 4 4 4 4 5 5 5 5 ...
##  $ Period                : Factor w/ 2 levels "Summer","Winter": 2 2 2 2 2 2 2 2 2 2 ...
##  $ Treatment             : Factor w/ 3 levels "CR","F","FR": 3 1 3 1 3 1 3 1 3 1 ...
##  $ GWP                   : num [1:18] -24286 617401 522245 557217 85308 ...
##  $ GWP_kg_CO2            : num [1:18] -24.3 617.4 522.2 557.2 85.3 ...
##  $ total_CH4_emissions_kg: num [1:18] 3.448 22.05 11.5896 19.9006 -0.0468 ...
##  $ total_N2O_emissions_kg: num [1:18] -0.456 0 0.746 0 0.327 ...
```

Summer

CH4

```
#Summer_CH4_model <- lm(total_CH4_emissions_kg~Treatment*Period_Year, data = Summer)

Summer_CH4_model <- lm(total_CH4_emissions_kg~Treatment*Period_Year, data = Summer)

PLS205::pls205_diagnostics(Summer_CH4_model)
```




```
anova(Summer_CH4_model)
```

```
## Analysis of Variance Table
```

```
##
## Response: total_CH4_emissions_kg
##                        Df Sum Sq Mean Sq F value    Pr(>F)
## Treatment               2 821735  410868 50.6732 1.195e-07 ***
## Period_Year             2   4958    2479  0.3057   0.74081
## Treatment:Period_Year   3  86826   28942  3.5695   0.03779 *
## Residuals              16 129731    8108
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
#by year and treatment
Summer_CH4_means <- emmeans(Summer_CH4_model, spec ='Treatment', by = 'Period_Year')
Summer_CH4_effects <- contrast(Summer_CH4_means, method = 'pairwise', adjust = "tukey")
#summary(Summer_CH4_effects)
cld(Summer_CH4_means)
```

```
## Period_Year = Summer_2021:
##  Treatment emmean SE df lower.CL upper.CL .group
##  F              0 52 16     -110      110  1
##  FR           264 52 16      153      374   2
##  CR           477 52 16      366      587    3
##
## Period_Year = Summer_2022:
##  Treatment emmean SE df lower.CL upper.CL .group
##  F              0 52 16     -110      110  1
##  CR           394 52 16      284      504   2
##  FR           425 52 16      315      535   2
##
## Period_Year = Summer_2023:
##  Treatment emmean SE df lower.CL upper.CL .group
##  FR           265 52 16      155      375  1
##  CR           558 52 16      447      668   2
##  F         nonEst NA NA       NA       NA
##
## Confidence level used: 0.95
## P value adjustment: tukey method for varying family sizes
## significance level used: alpha = 0.05
## NOTE: If two or more means share the same grouping symbol,
##       then we cannot show them to be different.
##       But we also did not show them to be the same.
```

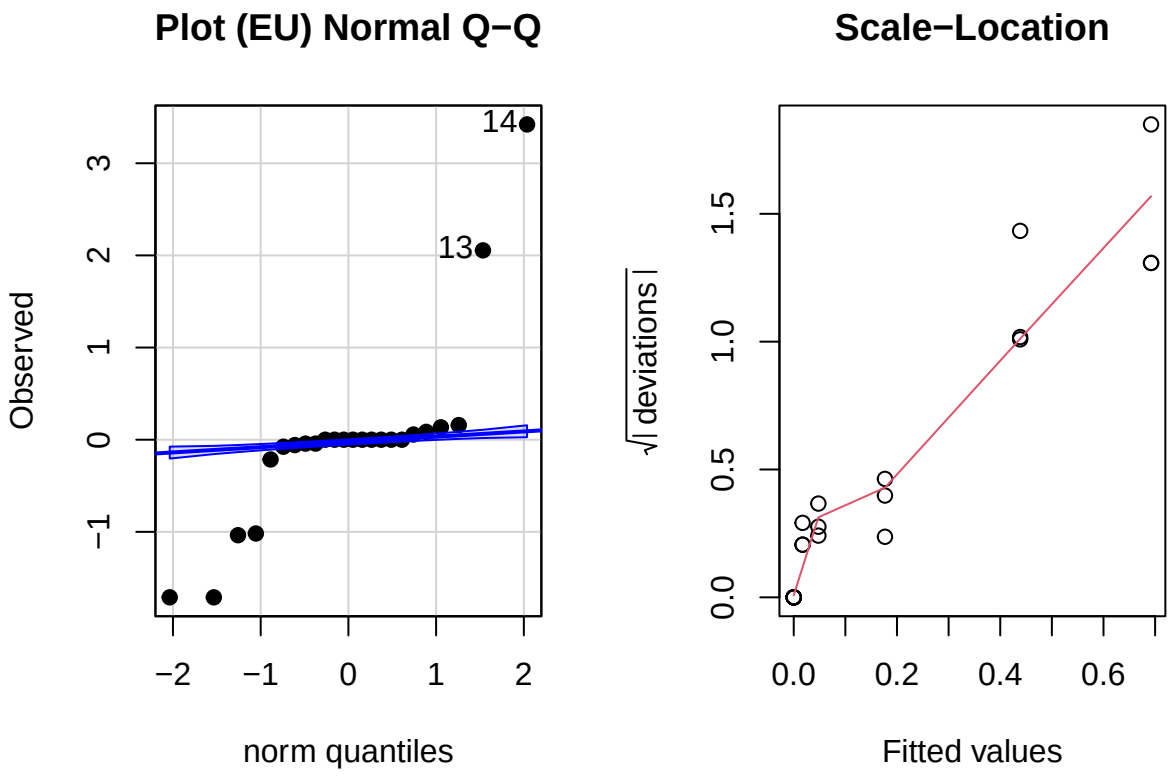
```
Summer_CH4_model_treatment_only <- lm(total_CH4_emissions_kg~Treatment, data = Summer)

#looking only at treatment together
Summer_CH4_means_all <- emmeans(Summer_CH4_model_treatment_only, spec ='Treatment')
Summer_CH4_effects_all <- contrast(Summer_CH4_means_all, method = 'pairwise', adjust = "tukey")
#summary(Summer_CH4_effects)
cld(Summer_CH4_means_all)
```

```
##  Treatment emmean   SE df lower.CL upper.CL .group
##  F              0 41.9 21    -87.2     87.2  1
##  FR           318 34.2 21    246.7    389.1   2
##  CR           476 34.2 21    404.9    547.3    3
```

```
##
## Confidence level used: 0.95
## P value adjustment: tukey method for comparing a family of 3 estimates
## significance level used: alpha = 0.05
## NOTE: If two or more means share the same grouping symbol,
##       then we cannot show them to be different.
##       But we also did not show them to be the same.
```

N2O

```
#Summer_N2O_model <- lm(total_N2O_emissions_kg~Treatment*Period_Year, data = Summer)
Summer_N2O_model <- lm(total_N2O_emissions_kg~Treatment*Period_Year, data = Summer)

PLS205::pls205_diagnostics(Summer_N2O_model)
```




```
anova(Summer_N2O_model)
```

```
## Analysis of Variance Table
##
## Response: total_N2O_emissions_kg
##                      Df Sum Sq Mean Sq F value Pr(>F)
## Treatment             2 0.1061 0.05303  0.2159 0.8081
## Period_Year           2 1.2169 0.60843  2.4775 0.1155
```

```
## Treatment:Period_Year  3 0.0865 0.02882  0.1173 0.9486
## Residuals             16 3.9293 0.24558
```

```
#by year and treatment
Summer_N2O_means <- emmeans(Summer_N2O_model, spec ='Treatment', by = 'Period_Year')
Summer_N2O_effects <- contrast(Summer_N2O_means, method = 'pairwise', adjust = "tukey")
#summary(Summer_N2O_effects)
cld(Summer_N2O_means)
```

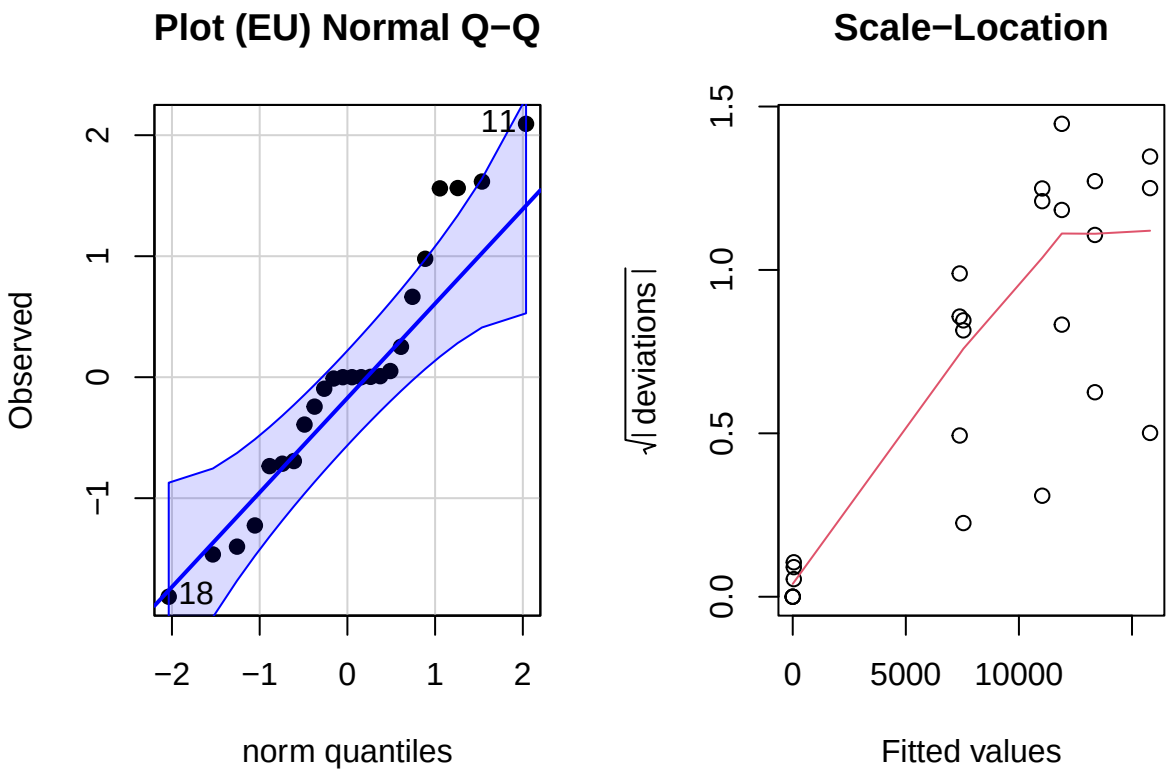
```
## Period_Year = Summer_2021:
##  Treatment emmean    SE df lower.CL upper.CL .group
##  F         0.0000 0.286 16  -0.6065    0.607  1
##  FR        0.0000 0.286 16  -0.6065    0.607  1
##  CR        0.0477 0.286 16  -0.5588    0.654  1
##
## Period_Year = Summer_2022:
##  Treatment emmean    SE df lower.CL upper.CL .group
##  FR        0.0000 0.286 16  -0.6065    0.607  1
##  CR        0.0172 0.286 16  -0.5894    0.624  1
##  F         0.1767 0.286 16  -0.4298    0.783  1
##
## Period_Year = Summer_2023:
##  Treatment emmean    SE df lower.CL upper.CL .group
##  FR        0.4386 0.286 16  -0.1680    1.045  1
##  CR        0.6921 0.286 16   0.0856    1.299  1
##  F         nonEst    NA NA       NA       NA
##
## Confidence level used: 0.95
## P value adjustment: tukey method for varying family sizes
## significance level used: alpha = 0.05
## NOTE: If two or more means share the same grouping symbol,
##       then we cannot show them to be different.
##       But we also did not show them to be the same.
```

```
Summer_N2O_model_treatment_only <- lm(total_N2O_emissions_kg~Treatment, data = Summer)

#looking only at treatment together
Summer_N2O_means_all <- emmeans(Summer_N2O_model_treatment_only, spec ='Treatment')
Summer_N2O_effects_all <- contrast(Summer_N2O_means_all, method = 'pairwise', adjust = "tukey")
#summary(Summer_N2O_effects)
cld(Summer_N2O_means_all)
```

```
##  Treatment emmean    SE df lower.CL upper.CL .group
##  F         0.0884 0.204 21  -0.3354    0.512  1
##  FR        0.1462 0.166 21  -0.1998    0.492  1
##  CR        0.2523 0.166 21  -0.0937    0.598  1
##
## Confidence level used: 0.95
## P value adjustment: tukey method for comparing a family of 3 estimates
## significance level used: alpha = 0.05
## NOTE: If two or more means share the same grouping symbol,
##       then we cannot show them to be different.
##       But we also did not show them to be the same.
```

GWP

```
#Summer_GWP_model <- lm(GWP_kg_CO2~Treatment*Period_Year, data = Summer)
Summer_GWP_model <- lm(GWP_kg_CO2~Treatment*Period_Year, data = Summer)

PLS205::pls205_diagnostics(Summer_GWP_model)
```




```
anova(Summer_GWP_model)
```

```
## Analysis of Variance Table
##
## Response: GWP_kg_CO2
##                        Df    Sum Sq   Mean Sq F value    Pr(>F)
## Treatment               2 648309188 324154594 50.3612 1.247e-07 ***
## Period_Year             2   4765170   2382585  0.3702   0.69638
## Treatment:Period_Year   3  68710302  22903434  3.5583   0.03814 *
## Residuals              16 102985464   6436592
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
#by year and treatment
Summer_GWP_means <- emmeans(Summer_GWP_model, spec ='Treatment', by = 'Period_Year')
Summer_GWP_effects <- contrast(Summer_GWP_means, method = 'pairwise', adjust = "tukey")
```

```
#summary(Summer_GWP_effects)
cld(Summer_GWP_means)
```

```
## Period_Year = Summer_2021:
##  Treatment  emmean   SE df lower.CL upper.CL .group
##  F             0.0 1465 16    -3105     3105  1
##  FR         7381.8 1465 16     4277    10487   2
##  CR        13360.1 1465 16    10255    16465    3
##
## Period_Year = Summer_2022:
##  Treatment  emmean   SE df lower.CL upper.CL .group
##  F             46.8 1465 16    -3058     3152  1
##  CR         11030.7 1465 16     7926    14136   2
##  FR         11897.3 1465 16     8792    15002   2
##
## Period_Year = Summer_2023:
##  Treatment  emmean   SE df lower.CL upper.CL .group
##  FR         7543.8 1465 16     4439    10649  1
##  CR        15798.5 1465 16    12693    18904   2
##  F          nonEst   NA NA       NA       NA
##
## Confidence level used: 0.95
## P value adjustment: tukey method for varying family sizes
## significance level used: alpha = 0.05
## NOTE: If two or more means share the same grouping symbol,
##       then we cannot show them to be different.
##       But we also did not show them to be the same.
```

```
Summer_GWP_model_treatment_only <- lm(GWP_kg_CO2~Treatment, data = Summer)

#looking only at treatment together
Summer_GWP_means_all <- emmeans(Summer_GWP_model_treatment_only, spec ='Treatment')
Summer_GWP_effects_all <- contrast(Summer_GWP_means_all, method = 'pairwise', adjust = "tukey")
#summary(Summer_GWP_effects)
cld(Summer_GWP_means_all)
```

```
##  Treatment  emmean   SE df lower.CL upper.CL .group
##  F             23.4 1183 21    -2438     2484  1
##  FR         8941.0  966 21     6932    10950   2
##  CR        13396.4  966 21    11387    15406    3
##
## Confidence level used: 0.95
## P value adjustment: tukey method for comparing a family of 3 estimates
## significance level used: alpha = 0.05
## NOTE: If two or more means share the same grouping symbol,
##       then we cannot show them to be different.
##       But we also did not show them to be the same.
```

Yield

```r
# Add in yield
Yield <- read_excel("Yield.xlsx", sheet = 1)
Yield$Plot <- as.factor(Yield$Plot)

#remove fallow plots and then match yield by plots
Summer_Rice <- Summer %>%
  filter(Treatment != "F") %>%
  mutate(Yield_kgha = Yield$Yield_kgha[match(Plot, Yield$Plot)])

Summer_Rice_Yield_model <- lm(Yield_kgha~Treatment*Period_Year, data = Summer_Rice)

#by year
anova(Summer_Rice_Yield_model)
```

```
## Analysis of Variance Table
##
## Response: Yield_kgha
##                         Df   Sum Sq  Mean Sq F value    Pr(>F)
## Treatment                1  1423546  1423546  1.3038   0.27579
## Period_Year              2 86463143 43231572 39.5964 5.192e-06 ***
## Treatment:Period_Year    2  6272773  3136386  2.8727   0.09563 .
## Residuals               12 13101652  1091804
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```r
Summer_Rice_Yield_means <- emmeans(Summer_Rice_Yield_model, spec ='Treatment', by = 'Period_Year')
Summer_Rice_Yield_effects <- contrast(Summer_Rice_Yield_means, method = 'pairwise', adjust = "tukey")
#summary(Summer_Rice_Yield_effects)
cld(Summer_Rice_Yield_means)
```

```
## Period_Year = Summer_2021:
##  Treatment emmean  SE df lower.CL upper.CL .group
##  CR         13040 603 12    11725    14354  1
##  FR         13845 603 12    12531    15160  1
##
## Period_Year = Summer_2022:
##  Treatment emmean  SE df lower.CL upper.CL .group
##  FR         11893 603 12    10579    13208  1
##  CR         12311 603 12    10996    13625  1
##
## Period_Year = Summer_2023:
##  Treatment emmean  SE df lower.CL upper.CL .group
##  FR          7233 603 12     5918     8547  1
##  CR          9308 603 12     7994    10623   2
##
## Confidence level used: 0.95
## significance level used: alpha = 0.05
## NOTE: If two or more means share the same grouping symbol,
##       then we cannot show them to be different.
##       But we also did not show them to be the same.
```

```r
#all
Summer_Rice_Yield_means_all <- emmeans(Summer_Rice_Yield_model, spec ='Treatment')
```

```
## NOTE: Results may be misleading due to involvement in interactions
```

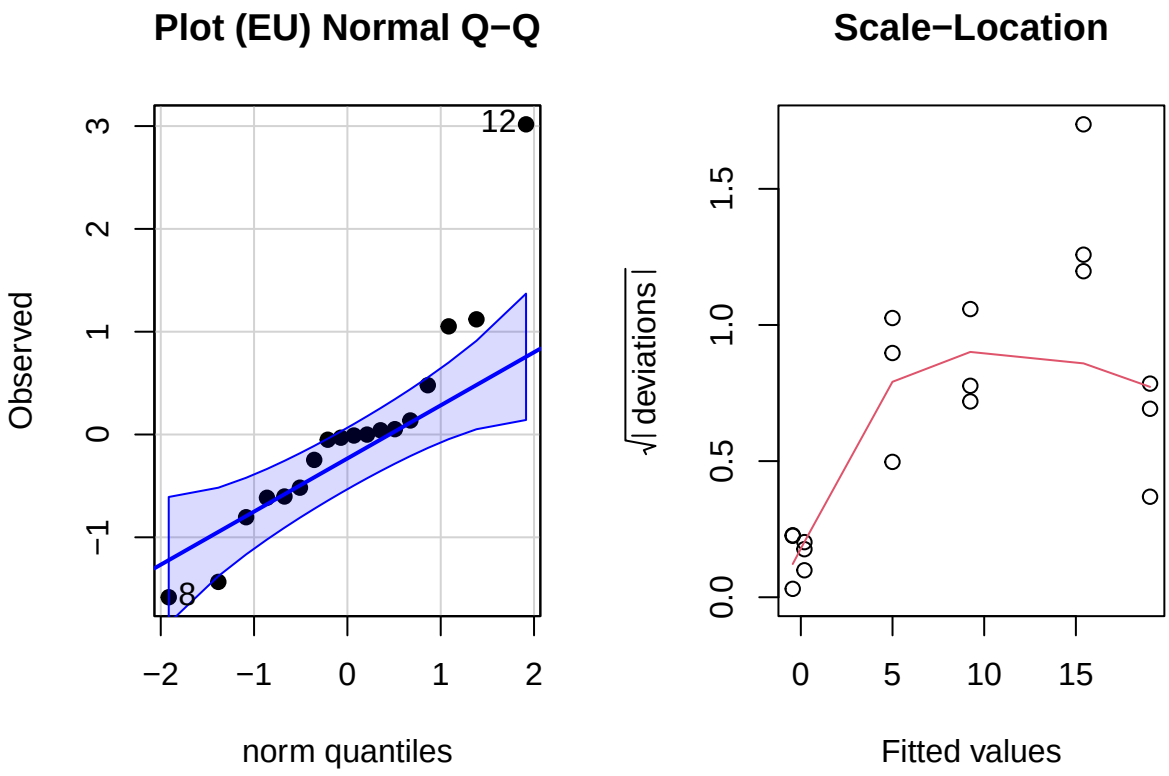
```r
Summer_Rice_Yield_effects_all <- contrast(Summer_Rice_Yield_means_all, method = 'pairwise', adjust = "t
#summary(Summer_Rice_Yield_effects)
cld(Summer_Rice_Yield_means_all)
```

```
##  Treatment emmean  SE df lower.CL upper.CL .group
##  FR         10990 348 12    10232    11749  1
##  CR         11553 348 12    10794    12312  1
##
## Results are averaged over the levels of: Period_Year
## Confidence level used: 0.95
## significance level used: alpha = 0.05
## NOTE: If two or more means share the same grouping symbol,
##       then we cannot show them to be different.
##       But we also did not show them to be the same.
```

Winter

CH4

```r
#Summer_CH4_model <- lm(total_CH4_emissions_kg~Treatment*Period_Year, data = Summer)
Winter_CH4_model <- lm(total_CH4_emissions_kg~Treatment*Period_Year, data = Winter)

PLS205::pls205_diagnostics(Winter_CH4_model)
```




```
anova(Winter_CH4_model)
```

```
## Analysis of Variance Table
##
## Response: total_CH4_emissions_kg
##                        Df Sum Sq Mean Sq F value   Pr(>F)
## Treatment               2 911.74  455.87  7.7363 0.006945 **
## Period_Year             1   0.79    0.79  0.0133 0.909991
## Treatment:Period_Year   2  46.65   23.32  0.3958 0.681612
## Residuals              12 707.11   58.93
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
#by year and treatment
Winter_CH4_means <- emmeans(Winter_CH4_model, spec ='Treatment', by = 'Period_Year')
Winter_CH4_effects <- contrast(Winter_CH4_means, method = 'pairwise', adjust = "tukey")
#summary(Winter_CH4_effects)
cld(Winter_CH4_means)
```

```
## Period_Year = Winter_2021_2022:
##  Treatment emmean   SE df lower.CL upper.CL .group
##  F         -0.442 4.43 12  -10.098     9.21  1
##  FR         4.997 4.43 12   -4.659    14.65  12
##  CR        19.046 4.43 12    9.390    28.70   2
##
```

```
## Period_Year = Winter_2022_2023:
##  Treatment emmean   SE df lower.CL upper.CL .group
##  F          0.195 4.43 12   -9.461     9.85  1
##  FR         9.244 4.43 12   -0.413    18.90  1
##  CR        15.416 4.43 12    5.759    25.07  1
##
## Confidence level used: 0.95
## P value adjustment: tukey method for comparing a family of 3 estimates
## significance level used: alpha = 0.05
## NOTE: If two or more means share the same grouping symbol,
##       then we cannot show them to be different.
##       But we also did not show them to be the same.
```

```
#looking only at treatment together
Winter_CH4_means_all <- emmeans(Winter_CH4_model, spec ='Treatment')
```

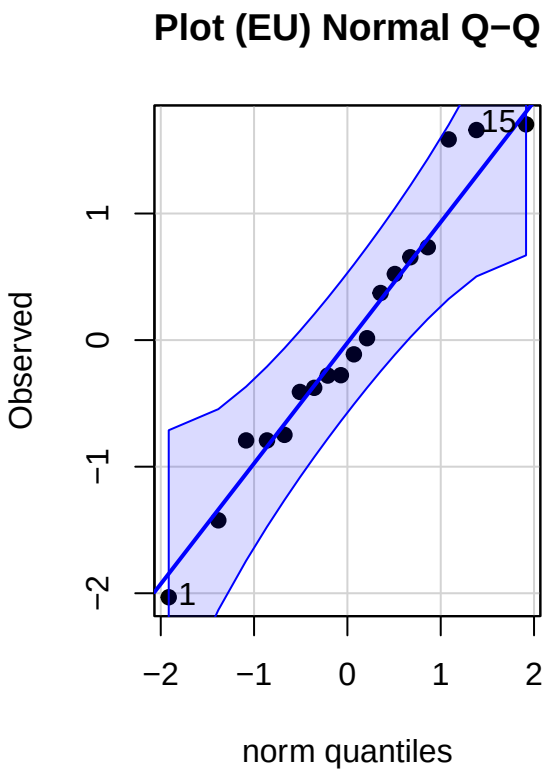
```
## NOTE: Results may be misleading due to involvement in interactions
```

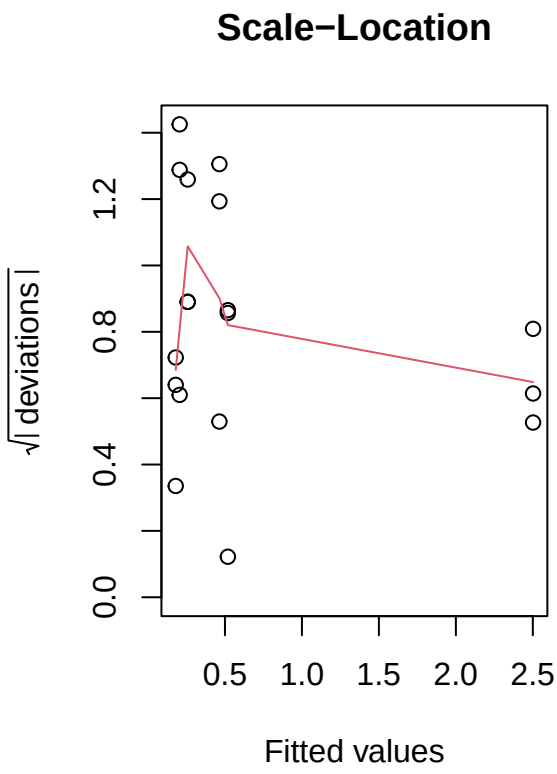
```
Winter_CH4_effects_all <- contrast(Winter_CH4_means_all, method = 'pairwise', adjust = "tukey")
#summary(Winter_CH4_effects)
cld(Winter_CH4_means_all)
```

```
##  Treatment emmean   SE df lower.CL upper.CL .group
##  F         -0.123 3.13 12   -6.951      6.7  1
##  FR         7.120 3.13 12    0.292     13.9  12
##  CR        17.231 3.13 12   10.403     24.1   2
##
## Results are averaged over the levels of: Period_Year
## Confidence level used: 0.95
## P value adjustment: tukey method for comparing a family of 3 estimates
## significance level used: alpha = 0.05
## NOTE: If two or more means share the same grouping symbol,
##       then we cannot show them to be different.
##       But we also did not show them to be the same.
```

N2O

```
#Summer_CH4_model <- lm(total_CH4_emissions_kg~Treatment*Period_Year, data = Summer)
Winter_N2O_model <- lm(total_N2O_emissions_kg~Treatment*Period_Year, data = Winter)

PLS205::pls205_diagnostics(Winter_N2O_model)
```






```
anova(Winter_N2O_model)
```

```
## Analysis of Variance Table
##
## Response: total_N2O_emissions_kg
##                       Df Sum Sq Mean Sq F value    Pr(>F)
## Treatment              2 5.7440 2.87202  18.049 0.0002412 ***
## Period_Year            1 2.5835 2.58351  16.236 0.0016711 **
## Treatment:Period_Year  2 3.8016 1.90078  11.945 0.0013971 **
## Residuals             12 1.9095 0.15913
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
#by year and treatment
Winter_N2O_means <- emmeans(Winter_N2O_model, spec ='Treatment', by = 'Period_Year')
Winter_N2O_effects <- contrast(Winter_N2O_means, method = 'pairwise', adjust = "tukey")
#summary(Winter_N2O_effects)
cld(Winter_N2O_means)
```

```
## Period_Year = Winter_2021_2022:
##  Treatment emmean   SE df lower.CL upper.CL .group
##  FR         0.206 0.23 12  -0.2961    0.707  1
##  CR         0.258 0.23 12  -0.2436    0.760  1
##  F          0.464 0.23 12  -0.0380    0.966  1
##
```

```
## Period_Year = Winter_2022_2023:
##  Treatment emmean   SE df lower.CL upper.CL .group
##  CR         0.180 0.23 12  -0.3215    0.682  1
##  FR         0.519 0.23 12   0.0172    1.021  1
##  F          2.502 0.23 12   1.9998    3.003   2
##
## Confidence level used: 0.95
## P value adjustment: tukey method for comparing a family of 3 estimates
## significance level used: alpha = 0.05
## NOTE: If two or more means share the same grouping symbol,
##       then we cannot show them to be different.
##       But we also did not show them to be the same.
```

```
#looking only at treatment together
Winter_N2O_means_all <- emmeans(Winter_N2O_model, spec ='Treatment')
```

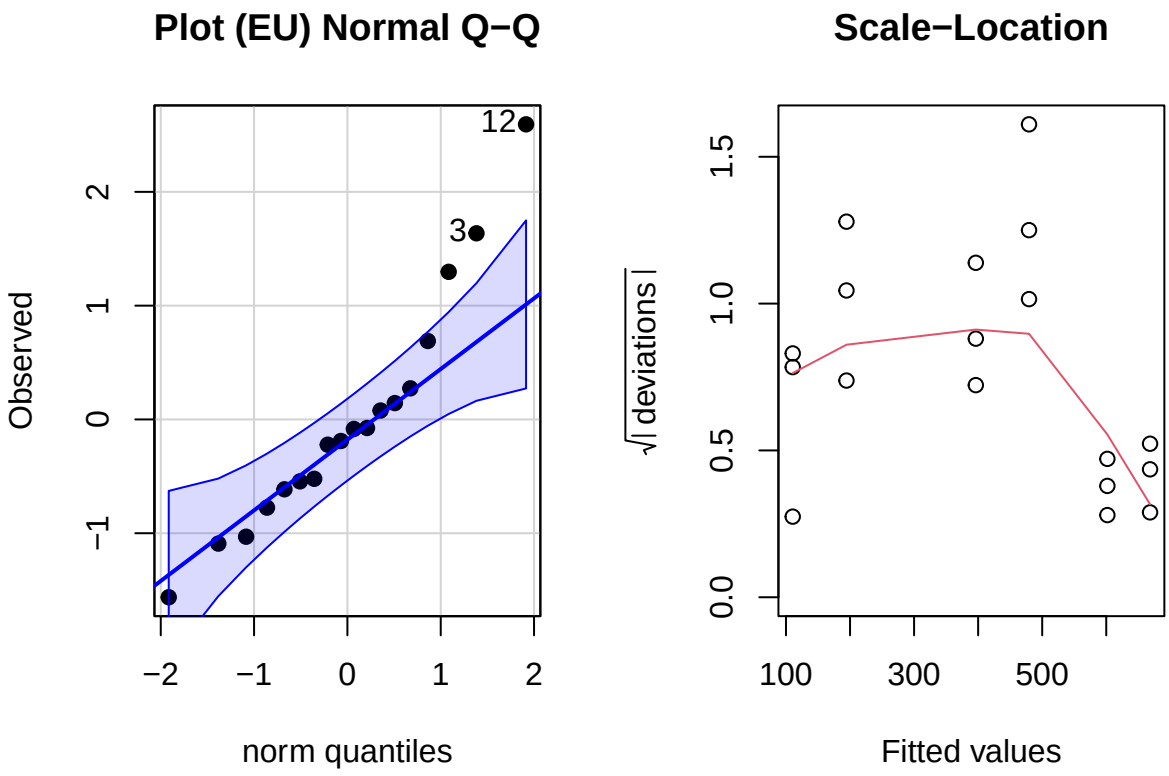
```
## NOTE: Results may be misleading due to involvement in interactions
```

```
Winter_N2O_effects_all <- contrast(Winter_N2O_means_all, method = 'pairwise', adjust = "tukey")
#summary(Winter_N2O_effects)
cld(Winter_N2O_means_all)
```

```
##  Treatment emmean    SE df lower.CL upper.CL .group
##  CR         0.219 0.163 12 -0.13561    0.574  1
##  FR         0.362 0.163 12  0.00751    0.717  1
##  F          1.483 0.163 12  1.12786    1.838   2
##
## Results are averaged over the levels of: Period_Year
## Confidence level used: 0.95
## P value adjustment: tukey method for comparing a family of 3 estimates
## significance level used: alpha = 0.05
## NOTE: If two or more means share the same grouping symbol,
##       then we cannot show them to be different.
##       But we also did not show them to be the same.
```

GWP

```
Winter_GWP_model <- lm(GWP_kg_CO2~Treatment*Period_Year, data = Winter)

PLS205::pls205_diagnostics(Winter_GWP_model)
```




```
anova(Winter_GWP_model)
```

```
## Analysis of Variance Table
##
## Response: GWP_kg_CO2
##                        Df Sum Sq Mean Sq F value  Pr(>F)
## Treatment               2 183586   91793  1.5236 0.25726
## Period_Year             1 203184  203184  3.3724 0.09118 .
## Treatment:Period_Year   2 347211  173606  2.8815 0.09506 .
## Residuals              12 722983   60249
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
#by year and treatment
Winter_GWP_means <- emmeans(Winter_GWP_model, spec ='Treatment', by = 'Period_Year')
Winter_GWP_effects <- contrast(Winter_GWP_means, method = 'pairwise', adjust = "tukey")
#summary(Winter_GWP_effects)
cld(Winter_GWP_means)
```

```
## Period_Year = Winter_2021_2022:
##  Treatment emmean  SE df lower.CL upper.CL .group
##  F            111 142 12   -198.2      419  1
##  FR           194 142 12   -114.3      503  1
##  CR           602 142 12    292.9      910  1
##
```

```
## Period_Year = Winter_2022_2023:
##  Treatment emmean  SE df lower.CL upper.CL .group
##  FR           396 142 12     87.6      705  1
##  CR           479 142 12    170.6      788  1
##  F            668 142 12    359.6      977  1
##
## Confidence level used: 0.95
## P value adjustment: tukey method for comparing a family of 3 estimates
## significance level used: alpha = 0.05
## NOTE: If two or more means share the same grouping symbol,
##       then we cannot show them to be different.
##       But we also did not show them to be the same.
```

```
#looking only at treatment together
Winter_GWP_means_all <- emmeans(Winter_GWP_model, spec ='Treatment')
```

```
## NOTE: Results may be misleading due to involvement in interactions
```

```
Winter_GWP_effects_all <- contrast(Winter_GWP_means_all, method = 'pairwise', adjust = "tukey")
#summary(Winter_GWP_effects)
cld(Winter_GWP_means_all)
```

```
##  Treatment emmean  SE df lower.CL upper.CL .group
##  FR           295 100 12     77.1      514  1
##  F            389 100 12    171.1      608  1
##  CR           541 100 12    322.2      759  1
##
## Results are averaged over the levels of: Period_Year
## Confidence level used: 0.95
## P value adjustment: tukey method for comparing a family of 3 estimates
## significance level used: alpha = 0.05
## NOTE: If two or more means share the same grouping symbol,
##       then we cannot show them to be different.
##       But we also did not show them to be the same.
```

Annual emissions for 2021/22 and 2022/23

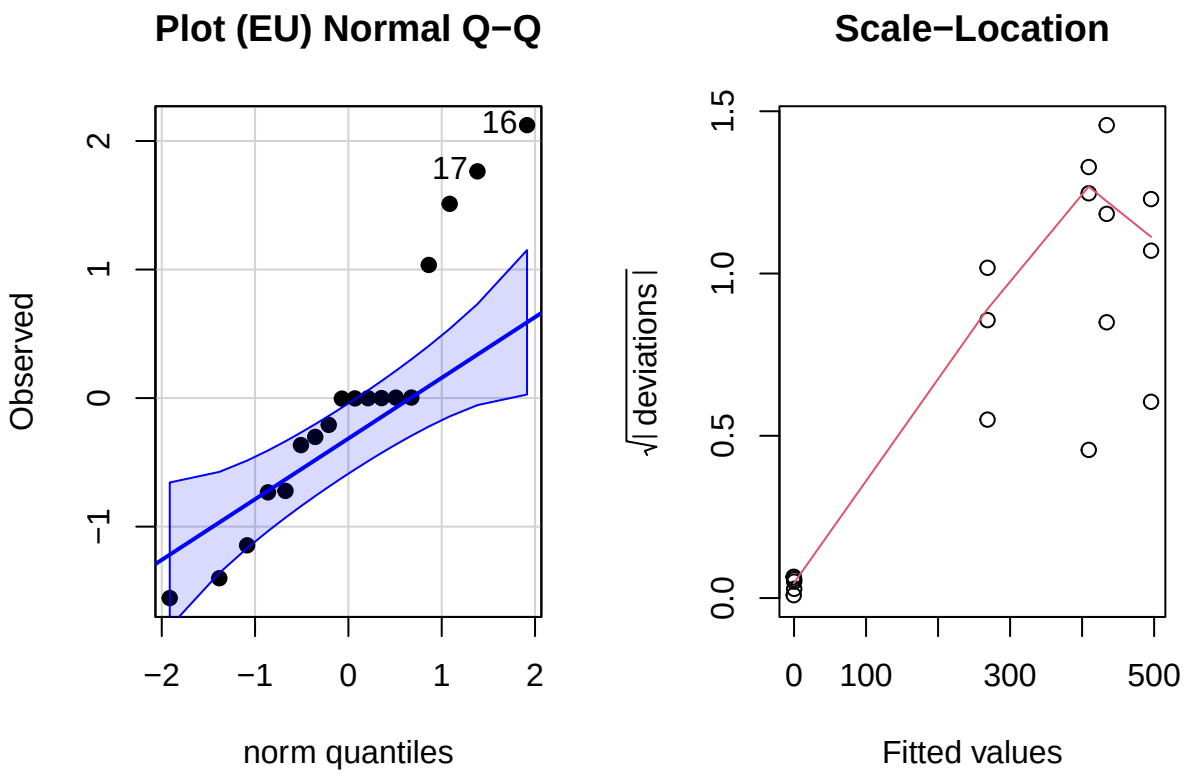
Sum the values

```
remove_2023 <- master %>%
  filter(Period_Year != "Summer_2023")

annual_emissions <- remove_2023 %>% group_by(Plot, Treatment) %>%
  summarize(total_CH4_emissions_kg = sum(total_CH4_emissions_kg,  na.rm = TRUE),
            total_N2O_emissions_kg = sum(total_N2O_emissions_kg,  na.rm = TRUE),
            GWP_kg_CO2 = sum(GWP_kg_CO2,  na.rm = TRUE)) %>%
  mutate(Treatment_Plot = paste(Plot, Treatment, sep ="_")) %>%
  mutate(Year = case_when(
         Treatment_Plot %in% c("106_FR","107_CR","204_FR","209_CR","302_FR","307_CR", "402_F", "505_F",
         Treatment_Plot %in% c("402_FR","409_CR","505_FR","512_CR", "209_F", "307_F","601_FR", "608_CR"
  ))
```

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

CH4

```
Annual_CH4_model <- lm(total_CH4_emissions_kg~Treatment*Year, data = annual_emissions)

PLS205::pls205_diagnostics(Annual_CH4_model)
```




```
anova(Annual_CH4_model)
```

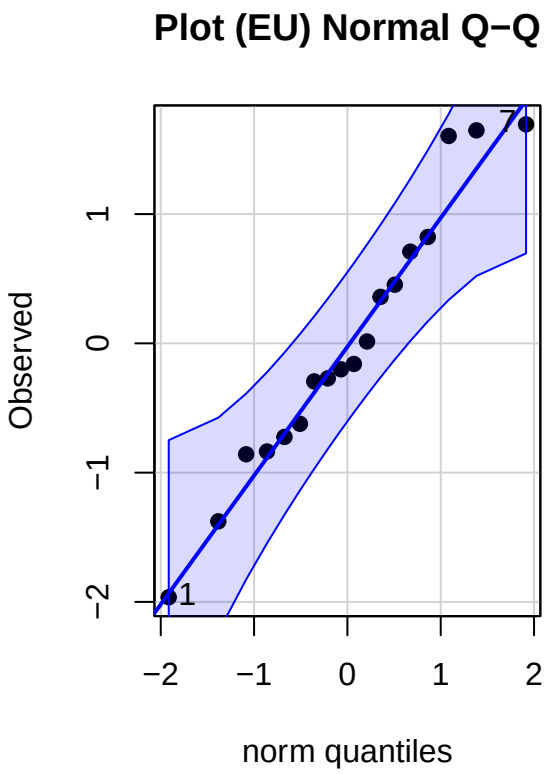
```
## Analysis of Variance Table
##
## Response: total_CH4_emissions_kg
##                Df Sum Sq Mean Sq F value   Pr(>F)
## Treatment       2 677248  338624 38.8140 5.76e-06 ***
## Year            1   3169    3169  0.3633   0.5579
## Treatment:Year  2  49156   24578  2.8172   0.0993 .
## Residuals      12 104691    8724
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

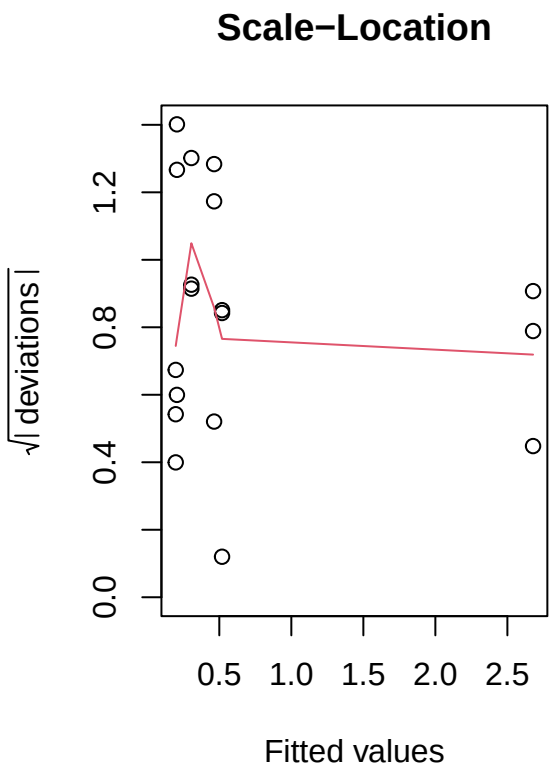
```r
#by year and treatment
Annual_CH4_means <- emmeans(Annual_CH4_model, spec ='Treatment', by = 'Year')
Annual_CH4_effects <- contrast(Annual_CH4_means, method = 'pairwise', adjust = "tukey")
#summary(Annual_CH4_effects)
cld(Annual_CH4_means)
```

```
## Year = 2021/22:
##  Treatment  emmean   SE df lower.CL upper.CL .group
##  F          -0.442 53.9 12     -118      117  1
##  FR        268.633 53.9 12      151      386   2
##  CR        495.741 53.9 12      378      613    3
##
## Year = 2021/23:
##  Treatment  emmean   SE df lower.CL upper.CL .group
##  F           0.195 53.9 12     -117      118  1
##  CR        409.207 53.9 12      292      527   2
##  FR        434.147 53.9 12      317      552   2
##
## Confidence level used: 0.95
## P value adjustment: tukey method for comparing a family of 3 estimates
## significance level used: alpha = 0.05
## NOTE: If two or more means share the same grouping symbol,
##       then we cannot show them to be different.
##       But we also did not show them to be the same.
```

N2O

```r
Annual_N2O_model <- lm(total_N2O_emissions_kg~Treatment*Year, data = annual_emissions)

PLS205::pls205_diagnostics(Annual_N2O_model)
```






```
anova(Annual_N2O_model)
```

```
## Analysis of Variance Table
##
## Response: total_N2O_emissions_kg
##                Df Sum Sq Mean Sq F value    Pr(>F)
## Treatment       2 6.4280  3.2140  18.878 0.0001968 ***
## Year            1 2.9264  2.9264  17.189 0.0013564 **
## Treatment:Year  2 4.5944  2.2972  13.493 0.0008505 ***
## Residuals      12 2.0430  0.1703
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

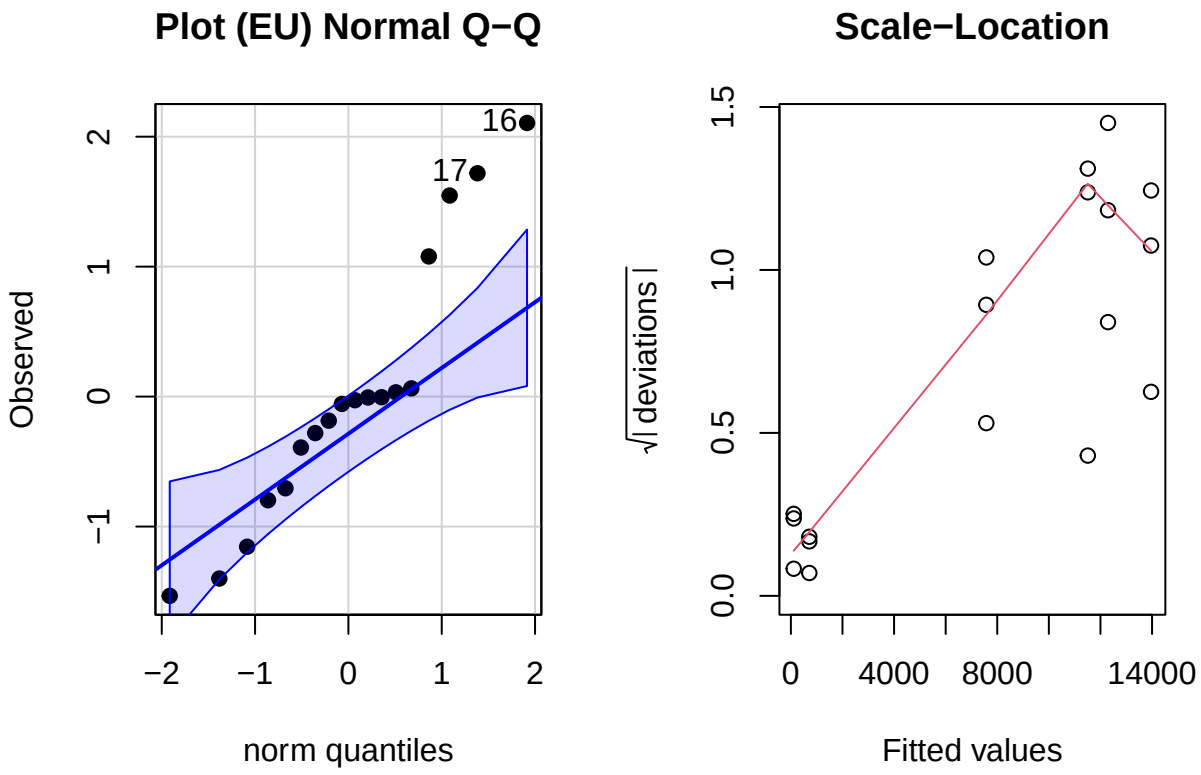
```
#by year and treatment
Annual_N2O_means <- emmeans(Annual_N2O_model, spec ='Treatment', by = 'Year')
Annual_N2O_effects <- contrast(Annual_N2O_means, method = 'pairwise', adjust = "tukey")
#summary(Annual_N2O_effects)
cld(Annual_N2O_means)
```

```
## Year = 2021/22:
##  Treatment emmean    SE df  lower.CL upper.CL .group
##  FR         0.206 0.238 12 -3.13e-01    0.725  1
##  CR         0.306 0.238 12 -2.13e-01    0.825  1
##  F          0.464 0.238 12 -5.52e-02    0.983  1
##
```

```
## Year = 2021/23:
##  Treatment emmean    SE df  lower.CL upper.CL .group
##  CR         0.197 0.238 12 -3.22e-01    0.716  1
##  FR         0.519 0.238 12 -8.01e-05    1.038  1
##  F          2.678 0.238 12  2.16e+00    3.197   2
##
## Confidence level used: 0.95
## P value adjustment: tukey method for comparing a family of 3 estimates
## significance level used: alpha = 0.05
## NOTE: If two or more means share the same grouping symbol,
##       then we cannot show them to be different.
##       But we also did not show them to be the same.
```

GWP

```
Annual_GWP_model <- lm(GWP_kg_CO2~Treatment*Year, data = annual_emissions)

PLS205::pls205_diagnostics(Annual_GWP_model)
```




```
anova(Annual_GWP_model)
```

```
## Analysis of Variance Table
##
```

```
## Response: GWP_kg_CO2
##                 Df    Sum Sq   Mean Sq F value    Pr(>F)
## Treatment        2 500748300 250374150 35.0110 9.806e-06 ***
## Year             1   4119579   4119579  0.5761    0.4625
## Treatment:Year   2  38826102  19413051  2.7146    0.1065
## Residuals       12  85815631   7151303
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
#by year and treatment
Annual_GWP_means <- emmeans(Annual_GWP_model, spec ='Treatment', by = 'Year')
Annual_GWP_effects <- contrast(Annual_GWP_means, method = 'pairwise', adjust = "tukey")
#summary(Annual_GWP_effects)
cld(Annual_GWP_means)
```

```
## Year = 2021/22:
##  Treatment emmean   SE df lower.CL upper.CL .group
##  F            111 1544 12    -3253     3474  1
##  FR          7576 1544 12     4212    10940   2
##  CR         13962 1544 12    10598    17326    3
##
## Year = 2021/23:
##  Treatment emmean   SE df lower.CL upper.CL .group
##  F            715 1544 12    -2649     4079  1
##  CR         11510 1544 12     8146    14874   2
##  FR         12294 1544 12     8930    15658   2
##
## Confidence level used: 0.95
## P value adjustment: tukey method for comparing a family of 3 estimates
## significance level used: alpha = 0.05
## NOTE: If two or more means share the same grouping symbol,
##       then we cannot show them to be different.
##       But we also did not show them to be the same.
```

Average annual emissions

Fallow

```
#filter out only fallow plots
#get the annual emission of each plot with the first summarize
#get mean values using the second summarize function

fallow_average_annual_emissions <- master %>%
  filter(Treatment == "F") %>%
  group_by(Plot) %>%
  summarize(total_CH4_emissions_kg = sum(total_CH4_emissions_kg,  na.rm = TRUE),
            total_N2O_emissions_kg = sum(total_N2O_emissions_kg,  na.rm = TRUE),
            GWP_kg_CO2 = sum(GWP_kg_CO2,  na.rm = TRUE)) %>%
  ungroup()%>%
  summarize(total_CH4_emissions_kg = mean(total_CH4_emissions_kg,  na.rm = TRUE),
         total_N2O_emissions_kg = mean(total_N2O_emissions_kg,  na.rm = TRUE),
```

```
        GWP_kg_CO2 = mean(GWP_kg_CO2,  na.rm = TRUE)
        )

fallow_average_annual_emissions
```

```
## # A tibble: 1 x 3
##   total_CH4_emissions_kg total_N2O_emissions_kg GWP_kg_CO2
##                    <dbl>                  <dbl>      <dbl>
## 1                 -0.123                   1.57       413.
```

CR and RF

```
#filter out CR, FR plots
#get the annual emission of each plot with the first summarize
#group dataframe by treatment
#get mean values using the second summarize function

CR_FR_avg_annual_emissions <- master %>%
  filter(Treatment != "F")%>%
    group_by(Treatment, Period) %>%
    summarize(total_CH4_emissions_kg = mean(total_CH4_emissions_kg,  na.rm = TRUE),
        total_N2O_emissions_kg = mean(total_N2O_emissions_kg,  na.rm = TRUE),
        GWP_kg_CO2 = mean(GWP_kg_CO2,  na.rm = TRUE)
        ) %>%
  ungroup()%>%
  group_by(Treatment) %>%
  summarize(total_CH4_emissions_kg = sum(total_CH4_emissions_kg,  na.rm = TRUE),
            total_N2O_emissions_kg = sum(total_N2O_emissions_kg,  na.rm = TRUE),
            GWP_kg_CO2 = sum(GWP_kg_CO2,  na.rm = TRUE))
```

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

```
CR_FR_avg_annual_emissions
```

```
## # A tibble: 2 x 4
##   Treatment total_CH4_emissions_kg total_N2O_emissions_kg GWP_kg_CO2
##   <fct>                      <dbl>                  <dbl>      <dbl>
## 1 CR                          493.                  0.472     13937.
## 2 FR                          325.                  0.509      9236.
```

Arm doors and cross-check

```
emissions_bytreatment <-master %>%
  group_by(Treatment, Period_Year) %>%
  summarize(total_CH4_emissions_kg = mean(total_CH4_emissions_kg,  na.rm = TRUE),
            total_N2O_emissions_kg = mean(total_N2O_emissions_kg,  na.rm = TRUE),
            GWP_kg_CO2 = mean(GWP_kg_CO2,  na.rm = TRUE))
```

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

```
master %>%
  group_by(Treatment, Period) %>%
  summarize(total_CH4_emissions_kg = mean(total_CH4_emissions_kg,  na.rm = TRUE),
            total_N2O_emissions_kg = mean(total_N2O_emissions_kg,  na.rm = TRUE),
            GWP_kg_CO2 = mean(GWP_kg_CO2,  na.rm = TRUE))
```

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

```
## # A tibble: 6 x 5
## # Groups:   Treatment [3]
##   Treatment Period total_CH4_emissions_kg total_N2O_emissions_kg GWP_kg_CO2
##   <fct>     <fct>                   <dbl>                  <dbl>      <dbl>
## 1 CR        Summer                476.                    0.252     13396.
## 2 CR        Winter                 17.2                   0.219       541.
## 3 F         Summer                  0                     0.0884       23.4
## 4 F         Winter                 -0.123                 1.48        389.
## 5 FR        Summer                318.                    0.146      8941.
## 6 FR        Winter                  7.12                  0.362       295.
```